



Insects Affecting Reforestation: Biology and Damage

Proceedings of a meeting of the
IUFRO working group on Insects Affecting Reforestation (S2.07-03)
held under the auspices of the XVIII International Congress of Entomology,
Vancouver, British Columbia, Canada, July 3-9, 1988

Edited by
René I. Alfaro and S.G. Glover

Foreword

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Forestry Canada
Pacific and Yukon Region
Pacific Forestry Centre
Victoria, British Columbia
Canada

1989

© Supply and Services Canada, 1989
DSS Catalog No. Fo 18-11/1988E
ISBN 0-662-16822-4
Printed in Canada

Additional copies of this publication
are available free of charge from:

Forestry Canada,
Pacific and Yukon Region
Pacific Forestry Centre
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Victoria, British Columbia
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Foreword

The increasing demand for forest products from a shrinking world resource is posing new challenges to the forestry profession. The only avenue open to meet these challenges is to increase the level of forest management. Insects that affect reforestation reduce forest productivity by causing tree mortality, reducing growth rates and lowering timber quality. Controlling these pests and their damage, therefore, represents an opportunity for productivity increases and cost reductions. Management of reforestation insects requires an accumulation of scientific knowledge, both basic and applied. It is the objective of IUFRO working party S2.07-03 to serve as a networking medium for scientists working in this field. Within this framework, information is exchanged and new ideas are generated. It is my hope that this symposium, by enabling active discussions, and this volume, which contains a fine sample of papers on the topic, will contribute to the improved management of these pests.

I wish to thank the organizers of the XVIII International Congress of Entomology, in particular Drs. G.G.E. Scudder and John McLean, for including this symposium in the congress program. I also express my gratitude to Bo Långström, the co-chairman of the working group, for his work in organizing this symposium.

The manuscripts in this publication were typed by Heather Matson and Sandra Flarrow of the Pacific Forestry Centre. I thank especially Emil Wegwitz for his invaluable technical assistance, and John Wiens and Poo Chee Graham of the Pacific Forestry Centre for preparing the manuscript for publication.

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Victoria, British Columbia, Canada
March 1989

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Insects affecting immature forests - why we study them and what they can do to us

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Abstract

The long-term economic and social benefits of the forest industry are dependent on continuing production of desirable, merchantable tree species. Insects can affect this production in various ways throughout a rotation and can cause extensive disruptions to both short- and long-term timber yields. Insects affecting plantation establishment and growth to free growing status must be considered during the initial site prescription and during the early growth stages. Losses and damage by these pests affect the accomplishment of short-term objectives and may, ultimately, have an impact on timber availability at maturity.

Résumé

À long terme, les avantages sociaux et économiques apportés par l'industrie forestière dépendent d'une production continue de bois marchand des espèces voulues. Les insectes peuvent affecter de diverses façons cette production pendant la durée d'une révolution et peuvent modifier considérablement la récolte tant à court qu'à long terme. Les insectes influant sur l'implantation des peuplements et la croissance des plants jusqu'à ce qu'ils se soient dégagés de la concurrence doivent être pris en considération au moment de l'aménagement initial du terrain et durant les premiers stades de croissance. Les pertes et dommages qu'ils causent nuisent à la réalisation des objectifs à court terme et peuvent ultimement avoir une incidence sur la disponibilité du bois à maturité.

Introduction

Forestry is a major worldwide industry. Management of forests is practiced in many countries for a variety of objectives including aesthetics, fuel production, pulp and paper production, and production of dimension lumber and panelling. In many areas, forests represent a major factor in the economic and social health of a population.

In British Columbia, the forest resource is the largest contributor to the provincial economy. The forest industry directly employs approximately 10% of the work force and supports about double this in secondary and indirect employment. Forest products including wood, paper, and allied products represented almost 45% of the total of manufacturing shipments by industry in the province in 1985 and had an aggregate value of \$8.5 billion (Can.). This was based on a harvest rate of approximately 70 million m³ per year.

The industry is supported by management programs implemented by both government and private business. For example, in 1985/86, 116.6 million seedlings were planted on almost 107 000 ha. A further 19 500 ha were treated in preparation for natural restocking. This level of forest regeneration is expected to continue and increase in the future. In addition to this planting and regeneration, over 31 000 ha of young forests were spaced, fertilized, or otherwise treated to enhance production. All of these activities are intended to assist in maintaining current production levels over the long term.

Management of young stands will become increasingly important as high-volume old-growth stands are replaced by lower volume second growth. Maintenance and protection of these stands will be a crucial factor in maintaining the forest resource; as each tree becomes more valuable in terms of investment in establishment and in terms of its contribution to future volume, losses to insects through mortality, growth reduction, and deformity will be less acceptable. Efforts must be increased to understand and deal with these pests.

Insects affecting young stands

Damage to the younger age classes has potentially serious impact to both the short and long term. In the short term, losses to regeneration and younger stands negate initial investments and require further effort to return the site to production. In the long term, unresolved losses during early growth stages may have an eventual impact on harvest volumes at maturity. In other types of stands, managed under shelterwood systems, the understory represents future crops and must be maintained in a healthy state. Stand types such as the dry-belt Douglas-fir (*Pseudotsuga menziesii*) forests in the interior of British Columbia must be managed in this fashion due to extreme difficulty of regeneration after clear-cutting. Loss of immature understory through pest damage can totally disrupt management of these sites for long periods of time.

Orders of insects affecting young stands include Lepidopterans such as the black army cutworm (*Actebia fennica*), western spruce budworm (*Choristoneura occidentalis*), and the Douglas-fir tussock moth (*Orgyia pseudotsugata*). Coleopteran pests include Scolytids such as *Ips* sp and Curculionids such as terminal weevils (*Pissodes* spp.) and root collar weevils like *Hylobius warreni* and *Steremnius carinatus*. Adelgids may also affect young stands and may influence seed production and require management effort. These examples represent only a small fraction of the insect species of real or potential concern.

These pest groups affect trees and stands in several ways: through outright mortality, caused either quickly or over a period of years; radial or height growth reduction which reduces eventual yield; and deformity which may reduce the value of trees or render them noncommercial. A few examples illustrate these potentials:

1) *Black army cutworm*

Prior to about 1960, this insect was considered an agricultural pest. However, with the increase in reforestation efforts and associated prescribed burning, this insect has been noted more and more as a possible serious problem in forest plantations. It feeds primarily on herbaceous growth on sites recently burnt; however, when insect populations are high and such growth is inadequate for their needs, these insects will consume foliage on newly planted coniferous seedlings causing growth loss, top kill, and mortality. Planting schedules have been disrupted to avoid planting during insect infestations and some areas have been replanted following damage. *But*, questions remain unanswered: How do large populations of this insect arise? what are realistic damage thresholds? How can this pest be monitored or predicted? What does the damage mean in terms of the need for treatment or eventual impacts on timber supply?

2) *Terminal weevils on spruce and pine*

Terminal weevils on spruce and pine attack and kill the terminal shoot of younger trees. The resultant damage takes the form of crooks and multiple tops and, in extreme cases of repeated attack, can lead to suppression of crop trees and render a stand noncommercial. In some areas of the Province, spruce is no longer planted, even though it would be the preferred species, because of the potential of the weevil. We do not have acceptable treatments for this pest, nor are we confident about their long-term effect on timber supply. What are realistic economic damage thresholds? Are we confident in our knowledge of these species biology, population dynamics, and relationship to their hosts?

3) *Western spruce budworm*

The western spruce budworm is a frequent defoliator of Douglas-fir forests on dryer sites. Although the biology of this insect is quite well understood, there is great concern regarding its impact on immature age classes in stands managed under selective cutting regimes. Damage to these trees includes top kill leading to multiple leaders and mortality. What population densities cause unacceptable loss? What is the long-term impact on timber supply? What treatments are possible in the short-term and how can management regimes be modified to reduce impacts over one or several rotations?

These pests and many others affect young stands. Roots, stems, foliage, and terminal shoots of most coniferous species of importance are affected by these insects and all such pests must be at least considered in forestry. Although many may prove to be innocuous or prove to have little impact on timber supply, many of these pests require study and assessment.

Insects, with their unique life cycles and quirks, cause a wide variety of damage. Population dynamics differ, ruled by differing environmental and biological factors. All of these aspects need to be studied, not for interest and scientific curiosity alone, but because understanding of the way pest populations function in relation to their host will allow us to quantify and predict damage, estimate its impact on management objectives, and develop effective treatments or management modifications, if necessary.

Considerations for management

Effective pest management is based on three activities: detection; impact assessment; and application of treatment where and when required. Evaluation of the treatments is also necessary in terms of impact on insect populations, host responses, and costs. These factors can then be integrated into management systems.

Treatments include application of direct control methods to reduce short-term damage and long-term silvicultural manipulations to avoid damage or limit damage over the long term. All of these activities require understanding of the biology and population dynamics of particular insects and insect complexes. Relationships between insects and diseases and their interaction with host trees must also be understood.

Detection

Detection and monitoring of potential insect pests is necessary to locate and delineate problem areas so that possible losses can be quantified and treatment applied. Adequate insect population monitoring can detect pest buildups prior to outbreak, thereby allowing early treatment and minimization of damage.

Study of potential problem insect species is required to allow effective monitoring. Life cycles must be detailed so that detection systems are carried out at the proper time of year to find conspicuous stages. Pheromone communication systems must be determined, identified, and quantified. Use of such chemicals greatly facilitates population monitoring and, sometimes, control. However, the chemical ecology of a species must be well understood before it can be used. Population factors must be determined that indicate rising and declining levels. As well, mechanisms of natural control such as climate, parasite/predator complexes, viral agents, and others must be understood so that survey data can be properly interpreted. Management decisions are based upon the quality of short and long-term predictions on insect abundance and impact.

Impact assessment

Impact assessment is, perhaps, the most vital component in forest pest management. Insects are only pests when they cause unacceptable damage in terms of management objectives. Many insects feed on or affect parts of trees; but what is the actual impact? Is the loss of a few seedlings or centimetres of growth important enough to warrant the application of rather expensive treatments for short-term alleviation of damage? Even changes to cultural management methods to avoid certain losses over the long term incur some costs that may not be warranted if the problem turns out to be trivial.

In British Columbia, one of the objectives of forest management is to ensure a steady supply of timber for lumber and pulp and paper production. The annual allowable cut (AAC) is determined after consideration of existing mature inventory, regeneration potential of harvested areas, associated growth and yield projections, and industrial requirements. Impacts on continued yield caused by insect pests of young stands lie in the area of decreasing future harvest as predicted from growth and yield models, or in the underestimation of the growth potential of a particular site or tree species.

Impact assessment is the vital link that connects initial detection of an insect to the selection of the most appropriate course of action. Impact assessment must flow from an initial appreciation of the objectives of the forest manager. The objectives of the production forest manager, amenity forest manager, and private land owner are each different and their willingness to pay for a control treatment is the best indication of their current intuitive evaluation. But, intuitive evaluation is insufficient to resource managers who are concerned with allocation of often scarce resources to a wide spectrum of potential courses of action. Adequate information on impact is required for consistent, rational decision making.

Damage, as reflected by lost timber production, must be evaluated from two aspects. The sustainability of long-term timber supplies over many decades and the impact on short-term timber supplies of a few to twenty years in duration.

In evaluating timber supply impacts over several rotations, an appraisal should not dwell on the fine points of an individual insect's life cycle, but on broader questions. How many outbreaks of a particular pest can be expected over the planning time frame? How long will it be before the next infestation of a particular pest? When the infestation returns, how severe will it be and of what duration? What level of loss or damage can be expected? These questions dominate the determination of long-term timber supplies and the selection of appropriate management strategies.

The development of short-term, 20-year impact assessment tools is no less important. These tools must reflect the projected population growth of the infestation under varying treatment scenarios, as well as a projection of impacted volumes.

As Reed and Errico (1987) demonstrated, the impact of mountain pine beetle (*Dendroctonus ponderosae*) was not significant over the long run, but did affect short-term capabilities. One must take note of such statements, especially when

talking to mill operators whose 5- or 10-year timber supply has just disappeared in a frenzy of feeding. Short-term protection action will be taken based on short-term damage projections.

The key point in damage assessment is that it must be conducted within a framework of management objectives. As entomologists, one of our tasks is to understand the management context of specific insects, and ensure that the necessary data is gathered during the initial research to address the assessment issues.

The assessment and evaluation of damage is key to determining the status of an insect as a pest and to determining the type of treatment required; the amount of damage sustained must always be compared to forestry objectives and the costs of available or potential treatments.

Treatment

Treatment of pests to alleviate damage has long been the main area of interest for forest entomologists. The history of operational pest management is strewn with examples of applications of pesticides or other treatments to combat apparently significant occurrences of insect pests. In the past, applications of treatments were somewhat haphazard and resulted in varying levels of success. Now, both direct and indirect (i.e., host manipulation and management) treatments are much more consistent in obtaining positive results. Why? Because there is a greater understanding of the pest and host biologies and interactions.

Development and application of treatments that will be effective in reducing damage to acceptable levels requires detailed information on the habits and phenology of pest insects and their hosts. Life cycles of insect species must be known so that stages amenable to some form of management can be identified and so that treatment windows or opportunities can be defined. Factors such as climate, temperature regimes and needs, and photoperiod requirements that affect the rate of development of both the insect and the host must be thoroughly understood so that management can be imposed in such a way as to avoid or limit damage while still allowing the achievement of management objectives. Dispersal mechanisms and patterns of target insects must also be well understood as these will affect efficacy and timing of treatments. Identifying, synthesizing, and using pheromone systems will allow much more effective monitoring and treatment programs. The objective in limiting damage is to treat the smallest area possible at the earliest stage possible.

Direct control of an insect population requires detailed knowledge of the insect and some knowledge of the host. Indirect control of insect pests requires extensive information on the entire ecological system in question.

Over the long term of one to several rotations, achievement of timber production goals will only be possible if insect problems are considered prior to establishment of plantations and during subsequent growth. Effective silvicultural management regimes that reduce or avoid pest-caused losses are possible only after the biology and population dynamics of potential pests and their hosts are studied and understood. What stand characteristics encourage insect activity? How can

these characteristics be manipulated within the constraints imposed by site and climate factors? The detailed relationships between an insect pest species and its hosts must be defined before effective management is possible. This will require the close collaboration of entomologists, silviculturists, and those in other forest management disciplines.

Future roles

Timber production, or other forest resource objectives, will continue to be a major contributor to many economies over the next few decades. Projections indicate that demand for the spectrum of forest products will increase over present levels. Yet, a variety of biological and social factors seem to show that the capacity to meet these greater demands will decline.

Population increases and resultant urban spread will reduce the area available for forest production. Alienation of forest land due to wilderness, agriculture, range, and other demands will also reduce the total productivity. In some areas, conversion of old-growth stands to second-growth forests, which produce lower mature volume per unit area, will further reduce our ability to maintain or increase production. Shorter rotations, increased tending, and decreased resident pest influence may counterbalance this somewhat. At the same time, the value and costs associated with establishing managed forests will climb. These managed forests and the individual trees within them represent an investment requiring greater tending and protection.

Forest entomology, and pest management in general, will be needed more and more to ensure that our management objectives are met. As entomologists, we must identify those pests which have the potential of disrupting management goals. The damage inflicted by these insects must be identified and quantified; it is just as important to label an insect as a trivial problem as it is to identify *bona fide* management issues. We must be able to concentrate effort where the returns are greatest.

Once pest issues are identified, management regimes to reduce the losses have to be developed and put in place, preferably through application of silvicultural techniques. Direct control options must also be developed and maintained for those situations where they are needed. The overall aim is to develop and implement integrated forest management practices which contribute to achieving forestry objectives in a cost-effective manner.

Insects affecting immature forests will be receiving greater and greater emphasis as forest management efforts increase. Our challenge is to provide the solutions to the problems posed by these insects. These solutions must be based on concrete information rather than speculation and the solutions must be compatible with standard forestry practices. The challenge is real: pest management holds one of the keys to maintaining, or enhancing, the role of forestry in the economy.

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Use of truncated life tables to assess importance of factors affecting reforestation

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Abstract

A record of seedling injury and mortality in a life table format, based on 2-3 examinations a year, provides a comprehensive data base for analyses of the direct and interactive effects of insects, diseases, and other factors on survival of planted trees. Cohort life tables logically begin with time of planting, and may extend for 3 or more years depending on the age span of interest. Current, or time-specific, ledgers are constructed by including a range of plantation age classes at the start. Both real and apparent mortality percentages should be used for analysis. The critical time intervals can be determined in terms of seasons or years. The relative importance of recorded mortality-causing agents or factors (including unknown) operating within critical intervals can be assessed by multiple regression using appropriate models for real and apparent mortality. Patterns of injury and mortality can be compared among ownerships and site types. Correlations of mortality with seedling source and age, site features, site preparation, and other factors can also be assessed. Two examples are described: (1) a study of Douglas-fir seedling mortality in northwestern California, covering the first 3 years following planting; and (2) a study of mortality of white pine in South Korea, encompassing five age classes of plantations.

Résumé

Un relevé des blessures infligées aux semis et de leur mortalité présenté sous la forme d'une table de survie établie à partir de deux à trois examens par année constitue une base de données globales à partir de laquelle il est possible d'analyser les effets directs et réciproques des insectes, des maladies et autres facteurs sur la

survie des arbres plantés. Les tables de survie des cohortes commencent logiquement avec le moment du plantage et peuvent porter sur trois années ou plus, selon la période d'étude souhaitée. L'inclusion d'une gamme de classes d'âge de plantation dès le départ permet de bâtir des registres de l'année en cours ou propres à une période particulière. Les pourcentages de mortalité réelle et apparente doivent être utilisés lors des analyses. Le ou les intervalle(s) critique(s) peut ou peuvent être déterminé(s) en fonction des saisons ou des années. L'importance relative des agents ou facteurs (y compris ceux d'origine inconnue) observés et causant la mort, agissant pendant des intervalles critiques, peut être évaluée par une régression multiple à l'aide de modèles appropriés sur la mortalité réelle et apparente. La nature des blessures infligées et le régime de mortalité peuvent être comparés d'un type de tenure et de station à l'autre. Les corrélations entre, d'une part, la mortalité et, d'autre part, l'origine et l'âge des semis, les caractéristiques de la station, la préparation du terrain et d'autres facteurs peuvent également être évaluées. Les auteurs décrivent deux exemples: (1) une étude de la mortalité de semis de douglas taxifolié dans le nord-ouest de la Californie pendant les trois premières années après leur mise en place et (2) une étude de la mortalité de pins blancs de la Corée du Sud formant des plantations de cinq classes d'âge.

Introduction

The occurrence of injuries and mortality in forest plantations is easily observed and recorded. However, identification of the causal agents or factors is not always easy due to their disappearance, time lags in effects, or other reasons. Moreover, mortality may be due to a combination of agents or factors operating together or in a sequence. For these reasons, if the factors affecting growth and survival in reforestation areas are to be fully understood and assessed, we need to have a basic record of seedling injury and mortality by all apparent causes over a meaningful span of time — beginning logically with the time of planting. Appropriate methods of data analysis then must be used to reliably evaluate, insofar as possible, the direct and joint effects of the factors involved, including insects. Effective protection and management of reforestation areas would seem to require a holistic approach.

This sort of comprehensive data base constitutes a truncated life table. Many forest entomologists are familiar with insect life tables (e.g., Morris and Miller 1954; Stark 1958; Campbell 1967; Southwood 1978; Mason and Torgersen 1987). These are perhaps the most complicated life tables to compile because of problems in sampling the successive stages, overlapping stages and generations, insect mobility, the need to estimate the proportion of females and fecundity, and other difficulties. Tree life tables, and truncated life tables of plantation trees in particular, are much simpler (Waters 1969; Silvertown 1987). The objects of interest are large and stay in place; sex of individuals is not a factor; time, age, or size intervals used for given cohorts are discrete and non-overlapping; and sampling error in succes-

sive examinations is eliminated by using a fixed number of seedlings at the start and examining each surviving individual thereafter.

Let us briefly summarize the major features and procedures of the life table approach applied to forest plantations.

Plantation and plot selection

For real insight into the range of effects and relative importance of the agents or factors affecting growth and survival, a basic requisite is that the number and distribution of selected plantations must be sufficient to adequately represent the universe of interest, however it is defined. It is tempting to confine detailed observations, as called for by a life table study, to a very few locations. But the findings from these data will be correspondingly limited and of questionable applicability elsewhere. With a broader based study, purposeful stratification by ownership (or other management units) or by habitat type (or other ecological units) will permit useful comparisons of trends in cumulative mortality and of the incidence of causal agents or factors over time among these strata.

The rationale for plot selection is different from that of a conventional pest survey, where the number of plots required is based on a desired precision of estimate for each plantation. For a life table study, each plot is considered a separate entity, and the data from each is compiled as a single life table. It is not a sampling unit for the plantation *per se*. Therefore, only a minimum number of randomly selected plots (2-3, in most cases) is needed to reflect the conditions in each plantation.

Plot size can be specified in terms of area or number of trees. If tree density is to be investigated as a factor of importance, an area basis should be used. Otherwise, a fixed number of trees is more advantageous. In the two studies that we will describe later, the individual plot size was 100 seedlings at the start of the study.

Frequency of examinations

At least two examinations should be made each year: the first at or just prior to bud break to cover overwintering and early spring conditions, the second in the fall to cover conditions through the growing season. An additional midsummer examination provides a finer-tuned record of injuries and mortality and a better opportunity to see some insects and other agents in action.

Record of injuries and adverse symptoms

A continuing record of injuries and adverse symptoms by part of seedling and probable cause provides information on (1) nonlethal effects (such as browsing damage) causing reduced seedling growth and quality, and (2) specific precursors to mortality. Multiple injuries frequently occur and this record is helpful in judging cause of death.

The mortality ledger

The basic data are simply a count of the number of seedlings live and dead, with probable cause of the latter noted, in each plot at each examination time. These plot counts are converted to real and apparent mortality values for analysis. Real mortality is the number of seedlings found dead at each examination time as a percentage of the number alive at the start of the study (i.e., time of planting or other starting time). It is the best measure for evaluating the relative importance of factors operating within the same generation (Southwood 1978) and their effects on crop yield (Harcourt 1970). It is also used for plotting and analyzing cumulative mortalities over time. Thus, it is the mortality figure of most interest to forest managers. Apparent mortality is the number of seedlings found dead at each examination time as a percentage of the number alive at the beginning of that time interval (i.e., the number recorded as live at the time of the previous examination). It better reflects the regulating influence of different factors on survival over multiple generations, which is why it is used for the analysis of insect life tables. However, it also is useful for comparing the effects of different factors operating in a given time interval, or the effects of the same factor in different locations (Southwood 1978).

The basic mortality data can be subjected to a variety of statistical analyses to: (1) compare mortality among time intervals (including seasons and years); (2) compare mortality among geographic locations, ownerships, habitat types, or other strata; (3) compare mortality among seedling sources, stock types (e.g., bare-root and containerized), or other seedling categories; (4) assess correlations between mortality and competing vegetation, site preparation, and other site factors; and (5) probe systematically into the actions and interactions of the mortality-causing agents or factors recorded. We will focus on this latter aspect here.

Direct assessment of the relative importance of different mortality-causing agents or factors operating on seedling populations is difficult, if not impossible, for the following reasons: (1) their effects, individually and jointly, vary greatly from place to place and over time, usually in an inconsistent manner; (2) insects, disease, weather, and other agents or factors interact in a variety of ways so that the real effect of any one cannot be discerned and evaluated from a record of its occurrence alone; and (3) there are time lags in the sequence of mortality effects, i.e., mortality occurring in any given time interval may be due to the direct and joint effects of agents or factors operating in one or more prior intervals. For these reasons, simple correlation and regression methods may produce spurious or misleading information.

In order to cope with these difficulties, we recommend the hierarchical modeling approach suggested by Watt (1961) and the analysis of determination procedure described by Mott (1966), used successfully in the analysis of some insect life tables (e.g., Campbell 1967), and by Morse and Kulman (1984) in a study of factors affecting plantation white spruce mortality in Minnesota. This involves using multiple regression to discern in turn: (1) the time interval(s) in which the most

critical mortality occurred; and (2) the most important agents or factors responsible for the mortality in these intervals.

The specific models used for these analyses are as follows:

Analysis of time intervals.—Different models are required for real mortality and apparent mortality.

$$\text{Real Mortality Model: } N_T = N_0 \left[1 - \left(\frac{M_1}{N_0} + \frac{M_2}{N_0} + \dots + \frac{M_n}{N_0} \right) \right]$$

$$= N_0 - M_1 - M_2 - \dots - M_n$$

where

N_T = number of seedlings alive at end of time interval n (end of study);

N_0 = number of seedlings alive at start of time interval 1 (e.g., time of planting);

$M_{1,2,\dots,n}$ = number of seedlings dying in intervals 1 to n .

Apparent Mortality Model: $N_T = N_0 \times S_1 \times S_2 \dots \times S_n$

Converted to logarithms to make it additive, this becomes

$$\log N_T = \log N_0 + \log S_1 + \log S_2 + \dots + \log S_n$$

where N_T and N_0 are the numbers of seedlings alive at the end of time interval n and start of time interval 1, respectively,

and $S_{1,2,\dots,n}$ = number of seedlings surviving at end of each time interval as a percentage of the number alive at the start of the interval

Each survival value = $100 - \text{apparent mortality } \%$

The relative importance of real mortality occurring in the successive time intervals can be evaluated in two ways: (1) direct assessment of the real mortality values — by definition, the interval with the highest mortality is the most important, other intervals with significantly large values may be judged critical; (2) variance-covariance analysis, where a variance-covariance matrix is calculated, and the variance-covariance components are expressed as percentages of total variation in the dependent variable N_T — these percentages, or partial r^2 's, signify the relative importance of the direct and joint effects of the respective "independent" variables in determining variation in seedling survival through the period of the study. If both procedures are used, the results can be compared and interpretations of importance stated accordingly.

The relative importance of the successive intervals in terms of apparent mortality occurring in each can be assessed only by variance-covariance analysis. Direct comparison of mean apparent mortalities is distorted by the change in base numbers from which they are calculated. The variance-covariance matrix is calculated from the apparent mortality model, and the variance-covariance components are evaluated in the same manner as those for real mortality.

Analysis of agents and factors operating within time intervals.—We recommend that this phase of analysis first be directed at causal categories, e.g., insects, diseases, or weather, rather than specific agents or factors. The record is more complete and reliable, and it is reasonable, we think, to determine if a particular category is really important before probing into it further. Also, when there appears to be more than one cause of mortality, it should be so recorded rather than attempting to arbitrarily assign a single cause. This means that a listing must be developed from the individual seedling record and summarized for plots of the complete array of single and combined causal categories. For the study of Douglas-fir seedling mortality described below, we developed a list of 35 categories including insects, diseases, animals, mechanical, planting, weather, and unknown as single categories, plus the double combinations thereof (e.g., insect-disease), plus a category of each with "other" (e.g., insect-other) which took care of the few cases where three or more causal categories were recorded. We also had a category of "lost or missing."

The basic data on mortality due to these causal categories can be converted to both real and apparent percentages, and analyzed as such. For the Douglas-fir study, we used only real mortality because it more clearly expressed for the forest manager the degree to which the different categories of causal agents and factors affected seedling survival.

Two measures of importance can be applied to the real mortality data at this level also: (1) direct assessment of the real mortalities associated with the different causal categories; and (2) variance-covariance analysis, using the partial r^2 values for the variance-covariance components as the criterion for evaluation.

For direct assessment, the data should first be summarized for all causal categories recorded in the critical intervals. These are mutually exclusive as categories, but not so for the agents or factors involved. For example, insect effects will be included in the insect category and in all of the other categories that include insect damage. When summarizing the data for specific time intervals, it is likely that one, or a very few, of the primary categories will appear in combination with many of the others. The full influence of any primary category, therefore, is revealed more clearly if the data are regrouped to show its total occurrence. To fully assess insect-related effects, for example, the real mortalities for the insect category alone and all other categories that include insect damage are added together. The same is done for each primary category, and a definite pattern emerges.

The general model for the variance-covariance analysis of causal categories is

$$M_T = M_1 + M_2 + \dots + M_n$$

where M_T = Total real mortality for a specified time interval;

$M_{1,2,\dots,n}$ = real mortality due to or associated with categories 1, 2, ..., n in the specified interval.

A variance-covariance analysis at this level presents a seemingly complex picture. Because the causal categories include many combinations of the primary categories of agents and factors, and are duplicative in that sense, significantly large covariances appear commonly in the matrix. However, these covariances also provide clues to real interactions among the primary agents and factors that may have ecological and management implications. Additional studies are needed to investigate these in proper detail, but at least some priorities are suggested.

Variance-covariance analysis of apparent mortalities associated with causal categories within time intervals is even more difficult to interpret and is not recommended.

Case study 1: Douglas-fir seedling survival in northwestern California

A 3-year study was conducted of factors affecting survival of Douglas-fir seedlings planted in recently harvested areas in Humboldt and Del Norte Counties, California. A total of 44 plantations were selected from a listing of 196 planted in 1984 in proportion to the numbers available by county and ownership. Seven ownerships, or management units, were included — four private companies and three ranger districts of the Six Rivers National Forest. Each plantation had two plots with an initial number of 100 seedlings each. Three examinations were made each year, which provided data on injuries and adverse symptoms and mortality occurring in nine time intervals following planting. Extensive analyses were made of these data (Waters et al. 1988).

Total real mortality in individual plots varied from 0 to 99.0%. Mean total mortality for the different ownerships ranged from 14.0 to 70.7%. The trends in cumulative mortality differed significantly (Figure 1). Calculated as polynomial curvilinear regressions, the linear components were significantly different; the curvilinear components did not differ significantly. The analyses of data in the life table format for time intervals produced similar results with both real and apparent mortalities, and for the real mortality, using both direct assessment and variance-covariance analysis. Seedling mortality occurring in intervals 2 and 3 (from late spring to fall of the first year) was most important overall; mortality in intervals 1, 4, 7, and 9 also was critical in some ownerships. Within intervals 2 and 3, both direct assessment and variance-covariance analysis showed that planting and weather-related effects were most important, with insect, animal, and unknown factors causing noticeable mortality also. In subsequent intervals, the effects of poor

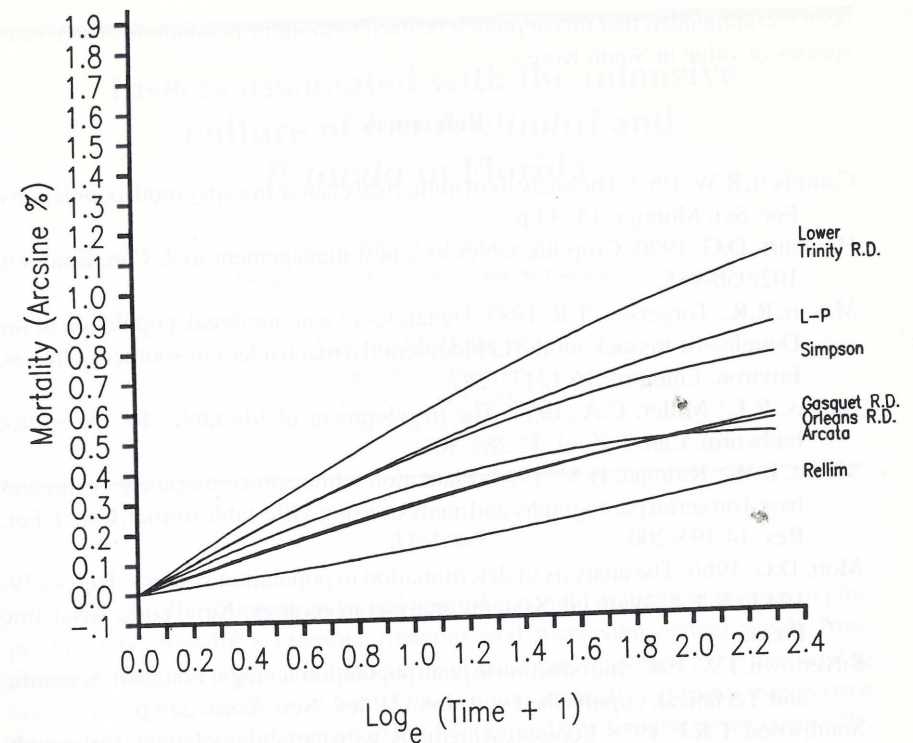


Figure 1. Curvilinear regressions of cumulative real mortality of Douglas-fir seedlings in four private ownerships and three Ranger Districts of the Six Rivers National Forest, California, in the first 3 years following planting.

planting and adverse weather were much reduced and mortality due to unknown factors, disease, and insects was more important.

Case study 2: Factors affecting survival of white pine in reforestation areas in South Korea

This study was initiated in 1987. It is intended to be carried on for a period of at least 3 years. It includes 30 plantations located in the northern provinces of Kyonggi-do and Kang-won-do, where Korean white pine has been planted most extensively. The plantations are stratified by elevation zone, with five plantations in each of two counties in each of three zones. In each set of five plantations per county, there is one plantation in each of five age classes differing by 3 years. The planting years chosen were 1987, 1984, 1981, 1978, and 1975. The plot setup and data recorded are similar to the Douglas-fir study, except that just two examinations are made each year. Given a 3-year record of injuries and mortality, we will be able to construct a broader based life table analogous to the current type of ledger. It has

been recommended that this approach be used to monitor plantations of other tree species of value in South Korea.

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Insects associated with the intensive culture of *Pinus elliotii* and *P. taeda* in Florida

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Abstract

Intensive fertilization and weed control can yield dramatic increases in pine productivity, thereby shortening rotations and increasing annual yields from managed forests. Large-scale application of these practices, however, may lead to serious insect and disease problems. Observations of small-scale pilot studies (two pine species and four combinations of fertilization and weed control) near Gainesville, Florida, U.S.A., showed tip moths, *Rhyacionia* spp., were more abundant on *Pinus taeda* than on *P. elliotii* and that incidence and severity decreased with increasing intensity of fertilization and weed control. Pitch moth, *Dioryctria amatella*, occurred about twice as often on *P. elliotii* as on *P. taeda*, and was most abundant on plots receiving the maximum fertilizer and weed control treatment. Pine webworm, *Tetralopha robustella*, showed no consistent relationship with cultural treatment while needle midges, *Contarinia* spp., were most abundant on untreated control plots. None of the insects alone caused a significant amount of injury, but interactions with disease organisms resulted in sufficient dead and deformed trees to suggest potentially severe pest problems if intensive fertilization and weed control are applied to large areas.

Résumé

Une fertilisation et un désherbage intensifs peuvent entraîner des augmentations spectaculaires de la productivité des pins, abaissant ainsi leur âge d'exploitabilité et augmentant le rendement annuel des forêts aménagées. L'utilisation à grande échelle de ces deux méthodes peut toutefois provoquer l'apparition de graves problèmes d'insectes et de maladies. Des observations effectuées dans de petites parcelles d'étude (2 essences de pin et 4 combinaisons de fertilisation et

désherbage) près de Gainesville (Floride), aux États-Unis, ont montré que les tordeuses des pousses (*Rhyacionia* spp.) étaient plus abondantes sur *Pinus taeda* que sur *P. elliotii* et que leur incidence et leur gravité diminuaient proportionnellement à l'augmentation de l'intensité de la fertilisation et du désherbage. La mineuse résineuse (*Dioryctria amatella*) était deux fois plus fréquente sur *P. elliotii* que sur *P. taeda* et était la plus abondante dans les parcelles qui avaient reçu les plus fortes doses de fertilisant et d'herbicide. Il n'y avait aucune relation logique entre les populations de la chenille tisseuse du pin (*Tetralopha robustella*) et le traitement cultural, tandis que les cécidomyies des aiguilles (*Contarinia* spp.) étaient les plus abondantes dans les parcelles-témoins qui n'avaient reçu ni fertilisation ni désherbage. Aucun des insectes ne causait à lui seul une quantité importante de dégâts, mais l'interaction de ces insectes et d'organismes pathogènes a entraîné la mort et provoqué la déformation d'un nombre suffisant d'arbres pour permettre de supposer que l'application de traitements fertilisants et désherbants intensifs sur de grandes superficies pourrait entraîner l'apparition de graves problèmes d'insectes et de maladies.

Introduction

Forestry is a major industry in the southern United States. In Florida there are over 6.3 million ha of commercial forests with nearly 50% being pine forests. Each year about one-fortieth of this pine area is harvested and replanted, primarily with slash, *Pinus elliotii* Engelm. var. *elliotii*, and loblolly, *P. taeda* L., pines. The pulpwood, sawlogs, and veneer logs harvested from these lands support nine pulpmills, 137 sawmills, and 13 veneer mills employing some 57 000 persons (Turner 1983). Much of the forest land is distant from the mills and transportation is a major expense in securing the desired quantities of raw materials. Many industrial foresters therefore are interested in increasing fiber production on nearby, high-quality land, thereby reducing transportation costs and decreasing the overall cost of wood procurement. Observations in the southern hemisphere show that pines have the potential to grow more rapidly than typically observed in their natural range. For these reasons, a small-scale study was initiated in 1983 to determine the biological growth potential of loblolly and slash pines, the two species most frequently planted on the coastal plain of the southern United States. The objective of this paper is to report on the occurrence of forest insects through year 4 of the study.

The maximum growth study was initiated by the Intensive Management Practices Assessment Center (IMPAC), a federal, state, and industry cooperative located in Gainesville, Florida. Detailed descriptions of the study site, experimental design, and methods are contained in Comerford et al. (1985). Briefly, the site is typical of many slash pine sites in northern Florida, the topography being nearly level and the surface soil being sandy and somewhat poorly drained. The 2 x 2 x 2 factorial experiment consists of two pine species, two levels of fertilization, and two levels

of competition control (Table 1). Three replicates follow a natural moisture gradient which, when augmented with supplemental irrigation, permit some inferences about moisture effects. One-year-old pine seedlings were hand planted during January 1983 at 1.83-m intervals in previously prepared beds. Treatment plots were 12 trees long and nine beds wide; measurement plots of 40 trees were eight trees long in the central five beds.

Tree survival and growth through year 4 are reported in Swindel et al. (1988). Figure 1 illustrates how continuous elimination of either nutrient deficiencies or interspecific competition increased the height growth of both species and how combining the treatments yielded even greater height gains. Average DBH values (diameter at breast height) followed the same pattern for the four cultural treatments. Diameter and height differences among the three replicates were small and not significant. Measurements of diameter and height over a 1-year period indicated that the fertilization and competition control treatments increased annual growth by increasing the growth rates and by extending the growing season. Tree survival through year 4 averaged 93% and was not influenced by any treatment.

Table 1. Treatment symbols and descriptions. IMPAC research plots, Gainesville, Florida, 1983-1986

Symbol	Description
Fertilization	
F ₀	No supplemental fertilization
F ₁	Trees individually fertilized four times during each of the first two growing seasons and three times in years 3 and 4
Competition control	
H ₀	No competition control after initial site preparation
H ₁	Herbaceous competition controlled by periodic application of herbicides; woody competition mowed by rotary cutters in year 1.
Moisture regime	
W ₀	Replicate located on driest portion of the site. No supplemental water applied.
W ₁	Replicate located on wetter portion of the site and which was occasionally irrigated during dry periods.
W ₂	Replicate located on wettest portion of the site and which was irrigated at 3-day intervals during dry periods in years 2, 3, and 4.

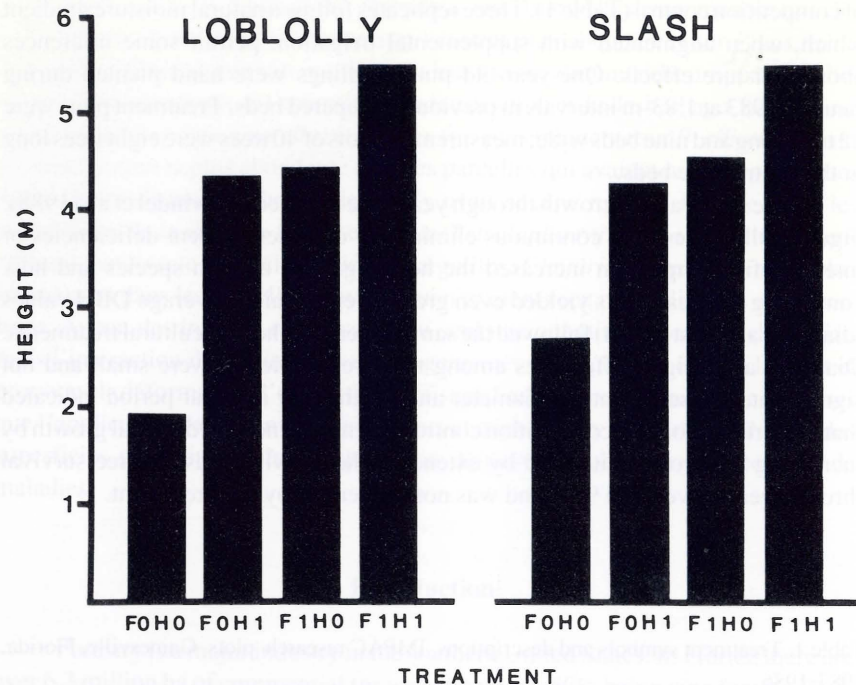


Figure 1. Mean height of loblolly and slash pines after 4 years of intensive fertilization and competition control. IMPAC Research Plots, Gainesville, Florida, 1986. (Drawn from data in Swindel et al. 1988).

Insect incidence and severity, 1984-1986

Our involvement in the IMPAC research project began in the spring of 1985 when project scientists became concerned about the high incidence of tip moth, *Rhyacionia* spp., injury on loblolly pines. Subsequently we recorded insect and disease occurrence for each tree on the 40-tree measurement plots during July 1985 and each winter thereafter. At the first observation we noted any evidence of tip moth activity during 1984 (the second growing season for the plantation) as well as the relative abundance of tip moths, i.e., the proportion of the new shoots infested, during early 1985. The number of active pitch moth¹, *Dioryctria amatella* (Hulst), infestations were also recorded for each tree. Signs and injuries of other insects were noted whenever they occurred.

¹ The Entomological Society of America common name for this insect is southern pine coneworm, but pitch moth is more descriptive of its biology and injury in young pine plantations.

Tip moths

Only 8.3% of the 448 slash pines were infested by the subtropical pine tip moth, *Rhyacionia subtropica* Miller, during the second to fourth growing seasons. In contrast, 81% of 454 loblolly pines were infested by the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), during the same 3 years. Overall incidence on loblolly pine was greatest in year 2 and declined in years 3 and 4, although incidence on the check treatment (F_0H_0) peaked a year later than on the other treatments (Table 2). Second year incidence rates for the four cultural treatments averaged 62, 81, 79, and 62%, respectively. In the following years, however, incidence diminished with increasing intensity of the cultural treatments, their associated growth rates, and overall tree size. Examination of the data with respect to moisture regime shows that every loblolly pine on replicate W_0 , the driest of the three replications, was infested during year 2; incidence ranged from 35 to 89% on plots in replicates W_1 and W_2 . Tip moth incidence on loblolly pines during years 3 and 4 showed no consistent relationship with moisture regime.

The Table 2 data suggest that multiple factors affected tip moth incidence on the loblolly pine plots. One explanation for the observed differences among treatments and moisture regimes during year 2 is that there are interactions among tree size, moisture stress, and tip moth success. Trees on the weed control only (F_0H_1) and fertilizer only (F_1H_0) plots, because they had taller and larger crowns than the control trees, may have had longer, more frequent, and more severe moisture stress than trees on check plots, thereby allowing more larvae to become established in their tips. Trees receiving the combined treatment (F_1H_1), even though they had the largest crowns, apparently received fewer eggs or had some mechanism to resist larval establishment.

Pitch moth

Pitch moth abundance on slash pines increased with the intensity of the cultural practices (Table 3). Few infestations occurred in trees on check plots while trees on the combined treatment plots received four to five times as many attacks as those on the single treatment plots. Active infestations in 1986 (year 4) declined to about one-fourth the 1985 number. Loblolly pines showed similar patterns of pitch moth infestation across treatments and time, but there were only 39 attacks in 1985 and six in 1986. These differences in pitch moth abundance among treatments are explained, in part, by corresponding differences in the occurrence of fusiform rust, *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*, and the incidence of moths in the rust galls (unpublished data). However, many attacks were near the base of fast growing trees and without any sign of a predisposing injury or agent.

Table 2. Tip moth incidence on loblolly pine. Number of trees having one or more tip moth infestations, by cultural treatment and moisture regime, for each of three growing seasons. IMPAC research plots, Gainesville, Florida, 1984-1986.

Treatment	N	Plantation growth year		
		Year 2	Year 3	Year 4
F_0H_0				
W ₀	36	36	27	17
W ₁	37	17	26	32
W ₂	40	17	32	27
Total	113	70 (62%)	85 (75%)	76 (67%)
F_0H_1				
W ₀	40	40	24	16
W ₁	37	33	20	17
W ₂	35	18	29	17
Total	112	91 (81%)	73 (65%)	50 (45%)
F_1H_0				
W ₀	38	38	27	11
W ₁	38	26	17	16
W ₂	38	26	24	19
Total	114	90 (79%)	68 (60%)	46 (40%)
F_1H_1				
W ₀	40	40	26	4
W ₁	38	18	16	20
W ₂	37	13	18	12
Total	115	71 (62%)	60 (52%)	36 (31%)
Total	454	322 (71%)	286 (63%)	208 (46%)

Other insects

The pine webworm, *Tetralopha robustella* Zeller, and a needle midge, probably *Contarinia acuta* Gagné (Gagné and Beavers 1984), were the only other insects noted with sufficient frequency to describe their occurrence relative to the different IMPAC treatments. There were 16 pine webworm nests on slash pines in 1985 and 22 nests in 1986; for loblolly pines the numbers were 1 and 27 respectively. There was no indication that any of the cultural treatments had a greater or lesser number of nests. We have no explanation for the near absence of this insect on loblolly pine in 1985. Midges, on the other hand, were most abundant on the F_0H_0

Table 3. Pitch moth abundance on slash pine. Number of active infestations, by cultural treatment and water regime, for each of three observation dates. IMPAC research plots, Gainesville, Florida, 1985-1986.

Treatment	N	Observation Date		
		7/85	12/85	12/86
F_0H_0				
W ₀	40	1	1	2
W ₁	36	0	0	0
W ₂	39	0	0	0
Total	115	1	1	2
F_0H_1				
W ₀	37	4	5	0
W ₁	37	7	7	2
W ₂	39	0	2	2
Total	113	11	14	4
F_1H_0				
W ₀	39	5	3	1
W ₁	36	5	6	0
W ₂	35	2	1	1
Total	110	12	10	2
F_1H_1				
W ₀	40	10	22	5
W ₁	38	6	4	1
W ₂	38	21	31	8
Total	116	37	57	14
Total	454	61	82	22

and F_1H_1 plots in the slash pine plantings and on the F_1H_0 and F_0H_1 plots in the loblolly pine plantings.

Discussion and conclusions

In this paper we have highlighted only the insect activity noted through the fourth year of a study designed to determine the biological growth potential of loblolly and slash pines. The data suggest that insects by themselves have had relatively little direct effect on tree growth. Additional data (unpublished) from these IMPAC plots, however, suggest that diseases and insect-disease complexes

may seriously reduce productivity if maximum growth treatments are applied to large areas. Fusiform rust by itself kills some trees and deforms others. Tip moth and pitch moth infestations serve as infection courts for the pitch canker fungus, *Fusarium subglutinans* (Wollenw. and Reinking) Nelson, Toussoun and Aaradas, resulting in shoot dieback, top kill, forking, and tree mortality. Future productivity studies should incorporate systemic pesticides or other treatments to exclude insects and diseases in order to determine their impact on tree and stand growth and value.

Acknowledgements

We thank W. Lante, A. Wilkening, and T. Atkinson for their assistance in collecting, managing, and analyzing the data. We also thank B.F. Swindel, USDA Forest Service, Gainesville, and the Intensive Management Practices Assessment Center for encouraging and supporting the insect and disease observations since 1985.

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Root and Root Collar Insects

Some aspects of the occurrence, biology and cold-hardiness of *Hylobius weevils*

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Abstract

In Estonia, two species of pine weevils — *Hylobius abietis* L. (76.8% of the sample) and *H. pinastri* (23.2%) — are the most dangerous pests in conifer reforestation areas. *Hylobius pinastri* is more common in forest site types where spruces prevail. In spring, at the beginning of flight, males predominate; later, females are more numerous. In addition to stumps, logging slash not removed from clear-cut areas offers suitable conditions for the development of pine weevils. Population density of pine weevils was higher and development was faster in the piles where slash was raked up in spring and mixed with soil and ground litter than on stump roots. By the end of the summer of the first year, 60.8% of the weevils on pine branches and 23.3% of those on spruce branches had pupated or were newly emerged adults, whereas stump roots in the same cut area had only larvae. The mortality of pine weevils in the branch piles was higher than that on stump roots.

Cold-hardiness of hibernating larvae averaged -12°C, and was sometimes as low as -19°C, which guarantees successful hibernation under a deep snow covering.

Résumé

En Estonie, deux espèces de charançons, *Hylobius abietis* L. (76,8 %) et *H. pinastri* (23,2 %), sont les deux plus graves menaces aux secteurs reboisés de conifères. *H. pinastri* est plus répandu dans les types forestiers dominés par l'épinette. Les mâles sont plus nombreux au printemps, au début de la période ailée, mais sont ensuite supplantés par les femelles. Outre les souches, les résidus d'exploitation qui ont été laissés dans les parterres de coupe rase offrent des conditions propices au développement des charançons du pin. Leur densité de population était plus élevée et leur développement plus rapide dans les empilements composés de déchets ratissés au printemps et mêlés à de la terre et à la litière que

sur les racines des souches. À la fin de l'été de la première année, 60,8 % des charançons présents sur les branches de pin et 23,3 % de ceux sur les branches d'épinette s'étaient transformés en chrysalides ou étaient des adultes nouvellement émergés, tandis que seules des larves se retrouvaient sur les racines des souches de ce même parterre de coupe. Le taux de mortalité des charançons du pin présents dans les empilements de branches était plus élevé que sur les racines des souches.

La résistance au froid des larves hivernantes était en moyenne de -12°C et atteignait quelquefois -19°C, prouvant qu'elles réussissent à hiverner sous un épais manteau de neige.

Introduction

Weevils of the genus *Hylobius* are the most destructive pests of conifer reforestation areas. The adults accumulate in large numbers in recent clear-cut areas where they oviposit on conifer stumps, roots, and lower sides of stems and branches in contact with the soil, as well as in logging slash mixed with soil and ground litter. At the same time they feed on the bark of young seedlings planted in cut areas causing their death in the year of plantation.

Besides environmental conditions, the abundance and life cycle of pine weevils is influenced by man. First, the technology of felling has changed considerably in recent decades. Earlier, as a rule, felling took place in winter, whereas now it is carried out all year round. Now, during the whole summer, the pine weevils have sufficient material of different quality in the clear-cut areas, in stumps, branches, and in tree trunks. The quality of food and the time of oviposition also influence the length of the weevil's life cycle. Thus, the hatching in the second half of the summer has a 3-year generation period instead of the ordinary 2 years (Lekander et al. 1985). The methods and the time of harvesting play an especially decisive role in the occurrence and the conditions of development of pine weevils. In earlier times, logging slash was routinely burnt. Now, it is raked into rows (piles) and not removed from the felling area, offering additional development material for the weevils (Ozols and Bicevskis 1979; Voolma 1986).

Due to the considerable economic damage it causes, the pine weevil has been intensively studied in different parts of the world, with respect to their spreading, biology, and control methods (Eidmann 1974). The hibernation of pine weevils has been investigated to a lesser extent and only separate aspects have been treated (Schwechten 1933). Mortality in winter exerts considerable influence on the number of weevils; this is why it was also necessary to investigate the problem of cold-hardiness of pine weevils (Luik and Voolma 1986).

Methods

The investigation was conducted in 1981-1985 in areas of South Estonia in the first year after clearcutting. To collect weevils, trap-holes of 25 x 40 x 50 cm were dug in a *Rhodococcum* site type in a pine clear-cut area, and in an *Oxalis*-

Myrtillus site type in a spruce clear-cut area. Beetles were picked from the holes, and their species and sex were determined.

In order to investigate the abundance and generation of pine weevils in the piled logging slash, a detailed analysis of branch material was made in the entire cross section of the pile every 2 m. The pile was situated in the *Rhodococcum* site type. Pieces of branches were measured and the location of weevils was determined. In the same felling area, one pine stump with a diameter of 38 cm was uprooted and the weevils were counted.

To characterize cold-hardiness, the supercooling points (the temperature at which spontaneous freezing occurs) of the pine weevil larvae were determined using a copper-constantan thermocouple (Kuusik 1971). The larvae were taken immediately before the experiment from infested pine billets which had previously been kept in field conditions.

Results and discussion

Species composition and sex ratios

In Estonia there are three species of pine weevils, two of them, *Hylobius abietis* L. and *H. pinastri* Gyll., are important pests. The third species, *H. piceus* DeG., is rare. According to earlier investigations in Estonia (Maavara et al. 1961) the species composition of pine weevils was the following: *H. abietis* — 74%, *H. pinastri* — 24%, and *H. piceus* — 2%.

Similar results have been obtained in neighboring areas: Finland 89.2%, 10.3% and 0.5%, respectively (Langström 1982); and Latvia 74.6%, 25.1% and 0.3% respectively (Ozols 1985). Of the total number of pine weevils analyzed by us (5466), 76.8% were *H. abietis* and 23.2% were *H. pinastri*. In places where pines were prevalent, *H. abietis* fully predominated. In the spruce-dominated forest sites, *H. pinastri* was relatively frequent: in separate samples 20.7-72.3%.

The sex ratio in *H. abietis* (4196) was on the average 1:1.43 and in *H. pinastri* (1270) 1:1.72 in favor of females. In spring, at the beginning of flight, males predominate in both species; later, females become more numerous.

Pine weevil development in piled logging slash

The development of pine weevil is possible in fresh logging slash when mixed with soil and ground litter into large piles. Weevils are most numerous in the piles of branches which contain slash from winter felling raked up in early spring. Table 1 presents data on the occurrence of pine weevils in piles of branches situated in the *Rhodococcum* site type clear-cut area. Trees were felled in winter, wastes were raked in April, a 2-m stretch of the pile was analyzed in detail in the second half of August.

In the large pile, pine weevils colonized 46.7% of the bark surface of pine branches and 35.25% of the bark surface of spruce branches. Analogous investiga-

tions have also been carried out elsewhere. In South Karelia pine weevils colonized, on average, 35%, and in some places even 68% of the branches in a *Myrtillus* spruce clear-cut area (Volkova 1976). In small branch piles, there were no pine weevils. The branches were drying or were inhabited by other xylophages, mainly by bark beetles of the genus *Pityogenes*.

As a rule, the generation period of pine weevils in Estonia is 2 years, hibernating in the last larval instar. In the second half of August, 60.8% of weevils feeding on pine branches and 23.4% of weevils feeding on spruce branches had pupated or were newly emerged adults in the pile (Table 1). Consequently, two-thirds of the pine weevils on pine branches have a generation period of 1 year. Although the development on spruce branches is slower, one-fourth of pine weevils have a generation period of 1 year. Larvae were only found on the roots of pine stumps. Slower development of pine weevils feeding on spruce bark has also been pointed out by other investigators (Geiser and Waldert 1979).

Faster development of pine weevils inhabiting the branch piles can be accounted for by temperature. Temperature is 5-8 °C higher inside the pile than in the stump roots of the same felling area. Similar data have been obtained also in Latvia (Ozols and Bicevskis 1979).

Table 1. Occurrence of pine weevils in piled logging slash and on stump roots

Indicator	Piled logging slash		Pine stumps
	pine	spruce	
Bark surface of branches, m ²	12.02	7.48	
Bark surface inhabited by pine weevils, %	46.7	35.2	
Number of pine weevils	586	323	378
larvae, %	39.2	76.6	100.6
pupae, %	33.1	17.3	-
adults, %	27.7	6.1	-
Population density of pine weevils, insects/dm ²	1.41	1.53	0.81
Pine weevils morality, %	12.5	13.9	0.5
larvae	17.3	16.5	0.5
pupae	14.1	5.9	-
adults	2.1	-	-

The population density of pine weevils in branch piles is considerably higher than on the stump roots. The mortality of pine weevils in the piled logging slash is also higher than that on the stump roots. In spite of this fact, the branch piles raked up in spring increase the weevil population, and the danger of damage to the new seedlings in the clear-cut area.

Cold-hardiness of pine weevil larvae

The data concerning cold-hardiness of pine weevil larvae is presented in Table 2. Cold-hardiness of pine weevil larvae is the highest in the middle of winter, although the increase in cold-hardiness, as compared with the autumn measurement, is not very large. Pine weevil larvae hibernate in their feeding place — stump roots, branch piles, etc. Here they are usually protected from severe frosts and from temperature fluctuations by the snow covering. This is why they do not develop such a degree of cold-hardiness as bark beetles hibernating under the stem bark. For example, the supercooling point of the larvae of the bark beetle *Polygraphus polygraphus* L. in midwinter was as low as -39°C (Luik 1982).

The average supercooling point of the pine weevil larvae in mid-winter was -12.6°C (Table 2).

To study cold-resistance, the larvae were exposed to -15°C . The results indicated that the pine weevil larvae did not survive prolonged periods of low temperatures. Exposure to -15°C for 24 hours caused their death.

In the winter of 1982-1983, when the minimum temperatures in the study area dropped to -23°C , the mortality of pine weevil larvae in pine roots excavated in autumn and kept on a snowless area was 62.2%. At the same time only a few dead specimens could be found on the roots in the soil covered by snow. Consequently, in the conditions of a deep snow covering, cold-hardiness of pine weevils is

Table 2. Seasonal variation of the supercooling points of pine weevil larvae ($^{\circ}\text{C}$)

Date of measurement	$\bar{x} \pm \text{SE}$	x_{\min}	x_{\max}
24.09.1981	-8.6 ± 0.59	-7.2	-12.3
5.11.1981	-9.7 ± 0.70	-7.7	-12.9
3.12.1981	-10.6 ± 0.96	-8.1	-13.7
14.01.1982	-12.6 ± 1.34	-8.5	-19.2
18.02.1982	-10.2 ± 0.76	-7.9	-14.3
2.04.1982	-8.2 ± 1.03	-4.9	-12.4
19.05.1982	-7.9 ± 0.89	-5.1	-13.2
22.06.1982	-7.6 ± 0.90	-6.2	-9.2

sufficient for a successful hibernation, but in the absence of snow even moderate frosts decrease the number of weevils considerably.

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The use of artificial baits to forecast seedling damage caused by *Hylobius abietis* (Coleoptera: Curculionidae)¹

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Abstract

Damage to conifer seedlings by adult weevils of the genus *Hylobius* is of considerable economic importance in reforestation areas in the Holarctic region. In Sweden, planting on clearcuts is commonly postponed for 2 or 3 years in order to avoid serious damage by *H. abietis* (L.), the most destructive species in this area. Insecticides and various mechanical devices are also used to protect seedlings. All these measures are costly; therefore, a method for forecasting the risks of seedling damage in reforestation areas would be useful to forest managers.

The possibility to forecast seedling damage using an artificial bait attracting walking weevils was investigated in a field test including nine adjacent clearcuts with differently sized populations of *H. abietis*. A strong positive correlation was found between seedling damage and the number of weevils caught in traps baited with the synergistic attractants α -pinene and ethanol. It was concluded that trapping during a five-day period prior to planting should be sufficient to predict relative damage risks for individual clearcuts within a region.

Résumé

Les dommages causés aux plants de conifères par les charançons adultes du genre *Hylobius* ont une importance économique considérable dans les zones de reboisement de la région holarctique. En Suède, on retarde souvent de deux ou trois ans la plantation sur les parterres de coupe rase afin d'éviter les graves dommages que peut causer *H. abietis* (L.), espèce la plus destructrice dans ce pays. On a également recours aux insecticides et à divers dispositifs mécaniques pour protéger les plants. Comme toutes ces mesures coûtent cher, une méthode d'estimation des risques de dommages aux plants dans les zones de reboisement serait utile aux gestionnaires forestiers.

¹ Abstract only. Full paper was published in Scandinavian J. For. Res. 2 : 199-213, 1987

La possibilité d'estimer les dommages à l'aide d'un appât artificiel destiné aux charançons ambulants a été étudiée sur le terrain, dans neuf parcelles adjacentes de coupe rase renfermant des populations de taille différente de *H. abietis*. Une forte corrélation positive a été observée entre les dommages aux plants et le nombre de charançons capturés dans les pièges appâtés à l'alpha-pinène et à l'éthanol agissant en synergie. Le piégeage des charançons pendant une période de cinq jours avant la plantation devrait être suffisant pour estimer les risques relatifs de dommages dans une parcelle donnée coupée à blanc dans une région.

A survey of damage by *Hylobius abietis* and *Hylastes* spp. in Britain

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Abstract

Details are given of the results of a survey of insect damage on young planting stock over more than 10 000 ha of recently restocked areas in Britain. In 6019 ha which had been planted with untreated stock, 54% of the plants were subsequently sprayed with Lindane during the first year after planting. Nineteen percent of these plants were killed by insect attack compared with only 3% of plants that had been dipped before planting. *Hylastes* was generally less damaging than *Hylobius*, but was found to be locally important.

Spraying container-grown stock with insecticide before planting was less effective than dipping transplants with the same concentration. The treatment of plants by spraying after planting does not give an acceptable level of protection.

The total cost of *Hylobius* and *Hylastes* damage and protection in British state forests planted during the 1985-86 season is estimated at over £ 0.5 million.

Résumé

Les résultats d'un relevé des dommages causés par les insectes sur plus de 10 000 ha de terrains plantés récemment en Grande-Bretagne sont présentés. Sur 6019 ha où le matériel de plantation n'avait pas été traité, 54% des plants ont par la suite été arrosés au Lindane au cours de la première année suivant la plantation. Dix-neuf pour-cent de ces plants ont été tués par les insectes, comparativement à seulement 3% pour les plants traités par immersion avant la plantation. Les *Hylastes* ont généralement causé moins de dommages que *Hylobius*, quoiqu'ils soient importants à certains endroits.

L'arrosage du matériel en récipient avec un insecticide avant la plantation s'est révélé moins efficace que l'immersion des plants repiqués, à la même concentration. L'arrosage des plants après la plantation n'assure pas un degré acceptable de protection.

Le coût total des dommages causés par les insectes *Hylobius* et *Hylastes* et de

la protection contre ceux-ci dans les forêts domaniales britanniques plantées durant la saison de 1985-1986 est estimé à plus d'un demi-million de livres sterling.

Introduction

Hylobius abietis (the large pine weevil) and *Hylastes* spp (black pine beetles) breed principally in stumps of felled conifers. The adult insects feed on the bark of living plants and, whilst black pine beetles seem to be restricted to coniferous bark, pine weevil adults may feed on any woody or herbaceous plant. Young trees used for restocking are liable to be heavily attacked by adult pine weevils feeding on the stem from the root collar upwards and by adult black pine beetles tunnelling in the main part of the root system from the root collar downwards. The resultant girdling quickly causes plant death (Scott and King 1974). Six species of *Hylastes* are found in Britain (Winter 1983), but are generally less damaging than *Hylobius*. Previous surveys using unprotected plants in 40 upland forest areas showed that annual plant losses from *Hylobius* feeding averaged 33% (Table 1). If measures are not taken to protect transplants on restocking sites during the first 2 years after planting, an average of 50% of plants may be expected to be lost with damage levels varying unpredictably from site to site. Of the 20 million trees planted on restocking sites by the Forestry Commission in 1987, 2 million were containerized as Japanese Paper Pots (JPP); the rest were mainly bare-rooted 3-year-old transplants. The planting season for both is generally between September and June, with most JPPs planted in the autumn and bare-rooted stock planted in the spring. Most of the plants included in the survey were conifers, of which 80% were Sitka spruce (*Picea sitchensis*).

Recommended plant treatments

Plants may be unprotected or treated with various insecticide formulations before or after planting. Insecticides are applied to bare-rooted transplants prior to

Table 1. Percent plant death from attack by *Hylobius* and *Hylastes*

	<i>Hylobius</i>		<i>Hylastes</i>	
	1983	1984	1983	1984
Average	31	36	12	14
Maximum	85	99	58	51
Minimum	1	0	0	0
Standard deviation	21	27	10	15

Results from two surveys using 80 untreated plants in 40 UK forests.

planting by dipping the tops and upper root system in a tank of insecticide formulation diluted in water. Containerized stock is treated by spraying with an insecticide immediately before planting (Table 2). These treatments should provide protection for a complete season. Their main advantage is simplicity, with no reliance on high technology. Transplants may be sprayed with insecticide after planting (Table 3). This treatment is intended to upgrade the level of protection remaining from a dipping treatment following a period of weathering. When used on its own, it gives protection from *Hylobius* damage for only part of the season, and three or four sprays will be necessary to protect the plants during the first two seasons. It is also necessary for the insecticide deposit to dry onto the plant before it is rain-fast. Therefore spraying can only take place in dry conditions and this makes it unsuitable for forests in higher rainfall areas. There may also be a logistical

Table 2. Summary of application techniques for insecticides applied before planting during the survey period

Treatments	Concentration	Usage (ha)	
Planting period		1985-86	1986-87
Dipped in lindane	1.6% ai	606	468
Dipped in permethrin	0.8% ai	40(trial)	158
Dipped in cypermethrin	0.8% ai	40(trial)	0
JPPs sprayed before planting	1.6% ai	644	607
No pre-planting treatment		5082	4442

JPP = Japanese Paper Pot

Table 3. Summary of application techniques of insecticides applied after planting during the survey period

Treatment	Concentration	Usage (ha)	
		1985-86	1986-87
Sprayed as only treatment	0.125% lindane	1800	n/a
Sprayed as back up to pre-planting treatment	0.125% lindane	375	n/a

Experiments have shown that a single post-planting spray with 0.05% permethrin as "Permit" should give a full season's protection, but for the same logistical reasons as Lindane, this treatment is unlikely in practice to give an acceptable level of protection.

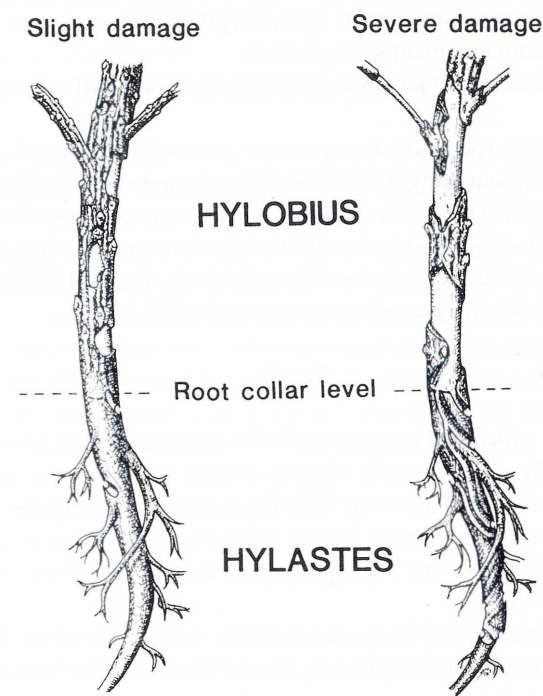


Fig 1. Damage Categories.

problem with post-planting sprays in that it is necessary for treatments over a substantial area to be completed before the insects become active. This may be as early as April when, in many instances, planting will still be in progress.

Survey method

Although the subject of many experiments (Stoakley and Heritage 1987), no large scale systematic survey of the relative effectiveness of the various insecticide treatments in forest practice has previously been undertaken in Britain.

The survey of *Hylobius* and *Hylastes* damage in restocking areas described here was carried out by local forest staff following guidelines suggested by the Forestry Commission Research Division. All sites greater than 6 ha and with a previous crop of conifers which had been restocked during the 1985/86 and 1986/87 planting seasons were earmarked for assessment. For each hectare, a single row of 25 plants chosen at random was lifted and scored separately for damage by *Hylobius* and *Hylastes* on the following basis:

- A No damage
- B Slight damage (small areas of feeding damage)
- C Severe damage (plant stem girdled)

Forest staff were provided with diagrams as a guide to the damage categories (Figure 1).

The scores for plant damage were sent with details of site and plant treatments to the Entomology Branch for summary and analysis. This is an interim report of the survey covering two damage periods for areas planted in 1985 and one damage period for areas restocked in 1986. A further survey will be undertaken in the autumn, after which a full report will be published. A total of 255 700 plants have been assessed for damage, sampling an area of 10 228 ha.

Results

In 6019 ha which had been planted with untreated stock, 54% of the plants were subsequently sprayed with Lindane during the first year after planting. Nineteen percent of these plants were killed by insect attack compared with only 3% of plants that had been dipped before planting. *Hylastes* was generally less damaging than *Hylobius*, but was found to be locally important. A summary of results is given in table 4.

Since *Hylobius* and *Hylastes* attack different parts of a plant, it may receive a fatal level of damage from both insects. For this reason, in the summary of survey

Table 4. Plant death in 1986 and 1987 surveys due to *Hylobius* and *Hylastes* damage

	Area (ha)	Percentage of plants killed		Total
		by <i>Hylobius</i>	by <i>Hylastes</i>	
First season after planting (Two planting seasons combined)				
No treatment before planting	6019	17	2	17
Dip before planting	509	2	0	3
Sprayed before planting	1096	5	1	6
Planted 1985-1986 (second season after planting)				
No treatment before planting	1995	13	0	13
Dip before planting	145	8	0	8
Sprayed before planting	464	2	1	2

data, the total percentage of plants killed is not necessarily the sum of the number of plants with fatal damage by either insect.

The timing of the surveys

Overwintering *Hylobius* adults become active with increasing soil temperatures (Eidmann 1974). Damage to plants can take place as soon as weather conditions are favorable, usually in April, but suitable conditions may occur at any time after February (Scott and King 1974). It is therefore important that surveys of damage are completed well before this time. Unfortunately, it is not possible to organize the first survey until late March and the last of the areas was not surveyed until August. As a result, this survey inevitably included some damage occurring in the current season. Previous experience has shown that, in the first growing season, *Hylobius* damage to untreated plants usually continues until the bark has been completely stripped. The occurrence of a large number of plants scored for slight damage suggests that damage was occurring at the time of assessment and that these plants may eventually have been killed.

Conclusions

Without untreated controls in treatment areas, it is difficult to make valid comparisons between treatments. Forest areas with a history of severe damage are likely to make most use of treated plants and this may explain the relatively low levels of damage to untreated plants when compared with those found in research surveys. Despite these reservations, it is possible to draw broad conclusions from this survey.

1. Damage by *Hylastes* species was lower than expected from earlier surveys conducted by Research Division staff, although this may reflect the difficulties associated with the use of untrained personnel for assessment of damage caused by this insect.

2. Treating stock before planting is the most reliable way of ensuring that plants are protected. Because there is no way of predicting the damage levels, all plants have to be treated. Spraying JPPs before planting is not as effective as dipping transplants with the same concentration of insecticide.

3. Preplanting treatments may require additional applications of insecticide in the second year after planting to ensure adequate protection.

4. The treatment of plants by spraying after planting, in practice does not give an acceptable level of protection.

5. All species of conifer were damaged, with slightly greater attack to untreated Douglas fir (*Pseudotsuga menziesii*).

Table 5. Additional costs of *Hylobius* and *Hylastes* during the planting period 1985-86

Treatments	Usage (ha)	Unit cost	Total (£)
Treated before planting	1330	10	13,300
Sprayed after planting	2175	9	19,575
Total			32,875
Replacement of lost plants and other costs*			504,640
Grand total			£ 537,515

*including extra weeding and value of delayed revenue calculated with a discount rate of 5%.

Cost of insect damage

The total cost of all the methods of protection used, combined with the cost of replacing all plants killed, indicates how important these insects are in Britain. The total cost of *Hylobius* and *Hylastes* in areas planted during the 1985-86 season amounted to over £ 0.5 million (Table 5). This will increase as the area to be restocked annually in Britain by the Forestry Commission increases from 3600 ha in 1979 to a projected 12 800 ha by the year 2005.

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Feeding and oviposition preferences of pales weevil among three coniferous hosts in Pennsylvania, U.S.A.

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Abstract

Pales weevil, *Hylobius pales* (Herbst) (Coleoptera: Curculionidae), is a common pest in Christmas tree plantations in Pennsylvania. Tests were conducted in the laboratory, using freshly-cut host material, to determine whether adult weevils exhibit feeding or oviposition preferences among Scots pine (*Pinus sylvestris* L.), eastern white pine (*P. strobus* L.), and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco).

Preliminary tests demonstrated that, within a host species, feeding preferences did not exist among foliated branches of the five provenances of Scots pine, three provenances of eastern white pine, or three provenances of Douglas-fir tested. Neither was any discrimination observed when pairs of host species were presented simultaneously, or when all three species were exposed together. Adults at least 60 days old, which had completed their preoviposition and maturation feeding period, were presented with bole segments as oviposition substrates. When host material was presented from two species of trees at a time, Scots pine was preferred over both Douglas-fir and eastern white pine; Douglas-fir was preferred over eastern white pine. If material for all three trees was presented simultaneously, no discrimination was evident.

Résumé

Le charançon du pin (*Hylobius pales* [Herbst.]) (Coleoptera: Curculionidae) est un ravageur commun des plantations d'arbres de Noël en Pennsylvanie. On a effectué des essais en laboratoire à l'aide d'échantillons fraîchement coupés d'arbres hôtes afin de déterminer si les charançons adultes avaient des préférences entre le pin sylvestre (*Pinus sylvestris* L.), le pin blanc (*P. strobus* L.)

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et le Douglas taxifolié (*Pseudotsuga menziesii* [Mirb.] Franco) pour l'alimentation et l'oviposition.

Les essais préliminaires ont démontré que les charançons auxquels on présentait des branches feuillées de pins sylvestres de cinq provenances, de pins blancs de trois provenances ou de Douglas taxifoliés de trois provenances n'avaient pas de préférence alimentaire entre les différentes provenances d'une même espèce. De même, on n'a pas observé de préférence lorsque des branches de deux espèces ou de trois espèces étaient présentées simultanément. D'autres essais ont consisté à présenter des segments du fût de ces espèces comme substrats d'oviposition à des adultes âgés d'au moins 60 jours ayant terminé leur phase de préoviposition et d'alimentation de maturation. Lorsque des substrats de deux espèces étaient présentés à la fois, le pin sylvestre était choisi de préférence au Douglas taxifolié et au pin blanc, et le Douglas taxifolié, de préférence au pin blanc. Lorsque des échantillons des trois espèces étaient présentés en même temps, aucune préférence n'a été observée.

Pales weevil, *Hylobius pales* (Herbst) (Coleoptera: Curculionidae), is a serious pest in Christmas tree plantations in Pennsylvania, and is considered by some to be the most serious pest of pine reproduction in the southeastern United States (Speers and Rauschenberger 1971; Thomas 1971; USDA Forest Service 1972; Speers 1973; Flavell 1974). In plantations, whether the trees be for Christmas tree use or for reforestation purposes, economic impact from this pest appears as seedling mortality due to adult feeding in which the main stem is girdled, and as increased costs for protection; in Christmas tree plantations, adult feeding on harvestable trees may reduce their retail or wholesale market value by 10-20% (Corneil and Wilson 1986).

Pales weevil adult feeding has been reported on 29 species in 11 genera (Lynch 1984), but its larval host range is more restricted. In Pennsylvania Christmas tree plantations, the weevil has often caused severe damage in Scots pine, *Pinus sylvestris* L., and occasionally in eastern white pine, *Pinus strobus* L., and Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. During the last 10 to 15 years, Douglas-fir has displaced Scots pine as the preferred species for planting, mainly because it is perceived as having fewer insect and especially disease problems. Douglas-fir is now the major species grown for Christmas trees in the northeastern United States south of Massachusetts (Merrill and Cameron 1986). Because of the increase in plantings of this species, we wanted to assess its susceptibility to pales weevil attack, and to compare that susceptibility with weevil preferences for Scots pine and eastern white pine.

Life cycle of pales weevil in Pennsylvania

The life cycle of pales weevil in Pennsylvania is presented in Figure 1. Adults overwinter in the litter; as temperatures increase in the spring, they become active. Some will feed on young seedlings, if available, but most move to breeding

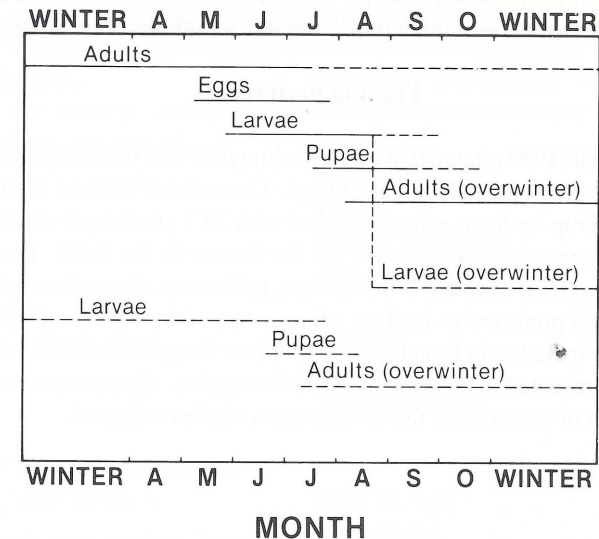


Figure 1. Schematic illustration of the life cycle of pales weevil in Pennsylvania (after Bliss and Kearby 1970).

locations where the eggs are laid. In a Christmas tree plantation, these locations consist mainly of stumps from trees cut late in the fall of the preceding year, but also include cut but unsold trees in less well-managed plantations and the lower 30 to 90 cm of bole field-trimmed from trees lacking living lower branches in plantations with poor weed control. The eggs hatch in approximately two weeks. Larvae feed in the cambial tissues, pass through five instars, and finally, during the prepupal stage, construct a "chip cocoon" which incorporates long, fibrous strands of wood. These cocoons are normally in the cambial area, but may be within the woody portion of the host material. The pupal stage lasts for several weeks, following which adults emerge and feed.

A small portion of the population takes two years to complete its development. Larvae overwinter, pupate in early summer, and give rise to adults by mid summer; these overwinter and breed the next spring. Also a portion of the adult population overwinters a second time.

It is the adults emerging from August through October which cause most of the economic damage. On young seedlings, the adults may completely girdle the main stem and kill the seedling, or severely damage it as a result of feeding on either laterals or leaders. On trees > ca 1.5 m tall, feeding is usually confined to lateral and leader growth; "flagging", or death of tips of branches, occurs. This feeding takes place after shearing to shape trees for marketing has been done, so it creates an aesthetic and disfiguring problem in a tree ready for the market. The adults enter

the litter, often near conifer stumps or under sections of bole left behind after harvest, to overwinter as temperatures and day length decrease in the fall.

Feeding preferences

Lynch (1984) stated that eastern white pine was the favored host for pales weevil in New England and the Lake States. Corneil and Wilson (1984) noted 34.8 attacks per stump on Scots pine compared with 23.7 attacks per stump on eastern white pine, suggesting a preference for the former in the field. Bennett (1980) reported that, at least in potted 2-0 seedlings, pales weevils in some replicated trials (but not others) preferred to feed on white spruce (*Picea glauca* [Moench] Voss) (not a species included in Lynch's [1984] list) or Douglas-fir when either of these species was presented in combination with Scots pine. Bennett gave no indication of oviposition or survival on the several hosts she investigated.

Methods

Weevils used in our tests were obtained from bulk rearings through a single generation to provide adults of known age (Boggs et al. 1986), and they were less than one month old when tested. Prior to use, the adults had been held at 20° C, and allowed to feed on freshly-cut Scots pine boughs.

For feeding preference tests, lateral branches with at least 3 years of growth present were cut from Scots pine, eastern white pine, or Douglas-fir. We had available to us, from research plantations at Penn State University, a number of provenances or varieties of each of these three species (Table 1). Our first need was to determine whether pales weevil adults fed differentially on the different varieties or provenances within a single species of host. In a series of preliminary tests, with only a single host provenance (Scots pine-Spanish) available, we varied both the numbers of adults (0, 4, 8 or 16) in each plastic container (25x16x8 cm), and the sex ratio of these adults (1:0, 1:1, 0:1).

Test host material, with cut ends having been waxed to reduce moisture loss, was placed in plastic containers. Pairs of branches were used within three hours after they were cut from living trees. Moist towelling was placed in the containers to maintain elevated humidity; branches were raised above the substrate. Within a single host species, seven of the ten possible combinations of the five varieties of Scots pine, and all three possible combinations of the three provenances of eastern white pine and the three provenances of Douglas-fir were tested for a period of 48 hours under a 15:9 light-dark cycle. (Day length at the time of year adult weevils normally feed on branches is approximately 15 hours in Pennsylvania.)

For later tests involving simultaneous presentation of the three host species, we used a larger plastic container (34x26x8 cm) and 12 adult weevils per container.

To assess feeding preferences, we weighed the host material immediately prior to and following the 48-hour feeding period. Differences in weights, adjusted

Table 1. Varieties or provenances of host species used in pales weevil feeding preference tests

Species	Variety or provenance
<i>Pinus sylvestris</i> L.	German
	Spanish
	French
	French X Spanish
	Nelson-King
<i>Pinus strobus</i> L.	Virginia
	Pennsylvania
	New Brunswick
<i>Pseudotsuga menziesii</i> (Mirb.) Franco	New Mexico
	Utah-Idaho
	British Columbia

for "normal" weight loss as determined from similar material ("control") held without any weevils feeding on it, were taken as a measure of the amount of feeding done by the weevils.

Results

Preliminary tests. Our preliminary testing gave results which made subsequent tests easier to conduct. We determined:

(1) Within a provenance, rates of feeding on branches from separate trees were consistent. Had we encountered significant variation in feeding between trees within a variety or provenance, differences (if any) between provenances or species could have been masked.

(2) Feeding rates for males alone, females alone, or an equal mix of the two sexes, were not different. Sexual dimorphism of adults is not readily apparent, so the time-consuming separation of the sexes was not required for later trials.

(3) Feeding by 4, 8, or 16 weevils caused reductions in weight of 0.136 g, 0.271 g and 0.430 g, respectively, of the host material. (These values are corrected for normal weight loss.) There appeared to be some inhibition in feeding when 16 weevils were present. We used eight adult weevils per container for subsequent tests because enough feeding was done that reliable data could be gathered, yet feeding was not so heavy as to skew results through excessive dehydration of the plant material as a result of heavy feeding and bark removal, or through competition among adults for available suitable food.

Species comparisons. When branches of host material, selected from pairs of varieties or provenances within a host species, were presented, we were unable to identify any evidence of feeding preferences among provenances (Tables 2, 3). Based on these results, and the availability of plant material for testing, the Spanish variety of Scots pine, the Pennsylvania provenance of eastern white pine, and the British Columbia provenance of Douglas-fir were chosen for subsequent tests where we presented host species to the weevils either as pairs of species, or all three species together.

When plant material was presented to pales weevils as pairs of species (Table 4), or all three species simultaneously (Table 5), we were still unable to detect any feeding preferences of the adults for one species over another. Considering the wide range of genera on which this insect has been reported to feed, the results are not really surprising. A wide host range does not preclude the existence of preferred hosts, but it seems reasonable to conclude that such a range does indicate some lack of discrimination.

Pales weevil feeding causes irregularly-shaped, variably sized wounds on branches, making it impossible to distinguish beginning or end points where two or more wounds overlap. Flagging of tips normally results when more than 50% of the branch circumference is girdled; wounds running longitudinally often cause no flagging. Therefore, flagging alone is not an accurate measurement of feeding. Our methodology was more time consuming than simple counting of frequencies of flags in a plantation, but, we believe, is a more sensitive test of feeding preference given a choice of food sources.

Oviposition preferences

Feeding by adult weevils is important, but it is only a part of the process by which populations perpetuate themselves from generation to generation. Adults require a period of maturation feeding prior to egg deposition; in the southeastern United States Manwan (1964) determined this preoviposition period to last for 19 to 56 days, averaging 37 days. The oviposition period averaged just over 300 days. In our studies, we selected only adults that were at least 60 days old for use in oviposition preference studies.

Methods

We used the same three host species, and the same provenances or variety, used in the feeding preference studies just described. Weevils were given no choice of species, a choice between two species, and a choice among all three species. Test arenas were 17-liter, 25.4-cm-diameter plastic buckets containing 5 cm of moistened sand and vermiculite (equal parts) mixed together. Test bolts, with ends waxed, were inserted vertically into the mix, four to a bucket, and equidistant from each other and the side of the bucket, and two 25-cm² pieces of black plastic were provided as "hiding places" for the adults. Female weevils were introduced at a rate of approximately one/25 cm² of bark surface in a bucket.

Table 2. Choice tests between pairs of varieties of Scots pine^a

Varieties	Mean ^b	F Calculated ^c
Spanish	0.431 a	10.76
French	0.398 a	
Control	0.095 b	
Spanish	0.404 a	14.05
German	0.401 a	
Control	0.121 b	
Spanish	0.376 a	6.21
French X Spanish	0.425 a	
Control	0.110 b	
Spanish	0.385 a	8.71
Nelson-King	0.406 a	
Control	0.089 b	
French	0.399 a	7.71
German	0.387 a	
Control	0.099 b	
French	0.412 a	8.80
French X Spanish	0.422 a	
Control	0.115 b	
German	0.387 a	5.76
French X Spanish	0.415 a	
Control	0.101 b	

a Completely random design, four replications/treatment, 8 adults/replication, 48 h feeding period.

b Mean reduction in weight (gm) of branches. Means within a test followed by a different letter are significantly different at P=0.05 (Duncan's [1955] Multiple Range Test).

c The critical F value for $\alpha=0.05$ is 4.26 (2, 9 df).

Table 3. Choice tests between pairs of provenances of eastern white pine and of Douglas-fir^a

Tree species	Provenances	Mean ^b	F Calculated ^c
White pine	Virginia	0.392 a	17.20
	Pennsylvania	0.399 a	
	Control	0.095 b	
	Virginia	0.421 a	10.20
	New Brunswick	0.435 a	
	Control	0.090 b	
	Pennsylvania	0.475 a	6.01
	New Brunswick	0.454 a	
	Control	0.118 b	
Douglas-fir	New Mexico	0.382 a	6.67
	Utah-Idaho	0.376 a	
	Control	0.088 b	
	New Mexico	0.399 a	8.08
	British Columbia	0.421 a	
	Control	0.088 b	
	British Columbia	0.405 a	18.21
	Utah-Idaho	0.409 a	
	Control	0.121 b	

a Completely random design, four replications/treatment, 8 adults/replication, 48 h feeding period.

b Mean reduction in weight (gm) of branches. Means within a test followed by a different letter are significantly different at $P=0.05$ (Duncan's [1955] Multiple Range Test).

c The critical F value for $\alpha=0.05$ is 4.26 (2, 9 df).

Table 4. Choice tests between pairs of species: Scots pine, Douglas-fir, and eastern white pine^a

Tree species	Provenance or variety	Mean ^b	F Calculated ^c
Scots pine	Spanish	0.410 a	11.12
Douglas-fir	British Columbia	0.420 a	
	Control	0.076 b	
Scots pine	Spanish	0.441 a	10.10
Eastern white pine	Pennsylvania	0.426 a	
	Control	0.114 b	
Douglas-fir	British Columbia	0.387 a	6.75
Eastern white pine	Pennsylvania	0.401 a	
	Control	0.108 b	

a Completely random design, four replications/treatment, 8 adults/replication, 48 h feeding period.

b Mean reduction in weight (gm) of branches. Means within a test followed by a different letter are significantly different at $P=0.05$ (Duncan's [1955] Multiple Range Test).

c The critical F value for $\alpha=0.05$ is 4.26 (2, 9 df).

In preliminary "no choice" trials—no choice as it related to tree species—we compared 18-cm-long sections of bole 3, 4, 5, or 6 years old and sections of the same ages but taken from limbs. Adults were confined for 96 hours in the test arenas, after which material was carefully dissected to count and recover eggs.

In subsequent tests, when different tree species were compared, we used 3-year-old sections taken from tree boles. These tended to be more uniform in diameter than older sections, and were more convenient to prepare. Sections of bole from the three combinations of pairs of species were presented to test ovipositional preferences, and later all three species were presented simultaneously.

Results

Preliminary tests. As with our feeding preference tests, we were unable to detect significant differences in oviposition rates among similar host material from different trees within a species, nor did we find differences relating to age of the bole or limb sections for any of the three species tested. In Scots pine there was a preference for sections taken from the bole over those taken from limbs (Table 6), but for eastern white pine (Table 7) and Douglas-fir (Table 8) we found no differences when comparing bole sections with limb sections.

Bark on the bole of Scots pine trees was much more fissured and rough than

Table 5. Choice test when three species, Scots pine, Douglas-fir, and eastern white pine, were presented simultaneously^a

Tree species	Provenance or variety	Mean ^b	F Calculated ^c
Scots pine	Spanish	0.370 a	9.36
Douglas-fir	British Columbia	0.345 a	
Eastern white pine	Pennsylvania	0.359 a	
	Control	0.101 b	

a Completely random design, four replications/treatment, 12 adults/replication, 48 h feeding period.

b Mean reduction in weight (gm) of branches. Means followed by a different letter are significantly different at $P=0.05$ (Duncan's [1955] Multiple Range Test).

c The critical F value for $\alpha=.05$ is 3.49 (3, 12 df).

the smoother bark on the limbs. Neither eastern white pine nor Douglas-fir showed these differences, bark being more uniformly smooth regardless of the part of the tree from which the test bolt was taken. Hunt and Farrier (1974) reported that pales weevils preferred to oviposit in (the more fissured) bark discs from loblolly pine, *Pinus taeda* L., taken from ca 30 cm above the ground vs. those taken from ca 9 m above the ground. The physical characteristics of the oviposition substrate may well be important to the weevil, but this was not investigated further.

Species comparisons. When sections of boles were presented as pairs of species, Scots pine was preferred over both eastern white pine and Douglas-fir (Table 9). There were 4.5 eggs laid on Scots pine for every one on eastern white pine when these species were presented in the same test arena, and 2.6 eggs on Scots pine for every one on Douglas-fir in paired tests. When Douglas-fir and eastern white pine were compared, Douglas-fir had 2.0 eggs for every one egg on eastern white pine. Qualitative observations indicate that bark on Scots pine is rougher than Douglas-fir, which in turn is rougher than eastern white pine; oviposition preference reflects this same sequence.

When we presented all three host species simultaneously in the test arena, we were unable to detect significant differences in oviposition (Table 9). Numbers of eggs were reduced, especially on Scots pine, but the same trend of most eggs on Scots pine, fewer on Douglas-fir, and the smallest number on eastern white pine remained.

We have no explanation for this loss of preference. It is entirely likely that olfactory cues from the host material play a role in host selection (see Lynch 1984 for a review; also Nordlander elsewhere in these *Proceedings*). In our plastic bucket test arena air movement was minimal; host sections were only ca 7 to 8 cm apart, and it is likely that any host-specific olfactory cues would be obliterated.

Table 6. Oviposition preference among various ages of Spanish Scots pine host material from bole or limbs^a

Tree part	Age (years)	Mean eggs/dm ²
Bole	6	2.45
	5	4.27
	4	1.47
	3	1.00
Limb	6	1.72
	5	0.92
	4	0.17
	3	0.87

ANOVA TABLE

Source of variance	df	M.S.	F calculated	F critical, .05 level
Total (adj)	31			
Treatment	7	0.000649	2.38	2.49
Blocks	3	0.000609	2.23	3.07
Tree part (A)	1	0.001544	5.66	4.32
Age class (B)	3	0.000617	2.26	3.07
A x B	3	0.000382	1.40	3.07
Error	21	0.000273		

a Randomized complete block design; four blocks represented individual trees. Material exposed to adults for 96 h.

Other tests (Boggs, unpublished) indicated that subsequent insect development (measured in terms of numbers of adults produced per square decimeter of bark surface), developmental time, and the proportion completing their development, proceeded best in Scots pine and eastern white pine when rearing temperatures were held at 25° C; good development occurred at 21° . Development took longer, fewer survived, and numbers of adults per square decimeter all were reduced in Douglas-fir. In the field, we have not yet observed chip cocoons in Douglas-fir stumps.

In conclusion, these laboratory studies did not detect feeding preferences by adult pales weevils for material from the three host species tested, but did give evidence of preferences for oviposition. Related studies indicated differences in

Table 7. Oviposition preference among various ages of Pennsylvania eastern white pine host material from bole or limbs^a

Tree part	Age (years)	Mean eggs/dm ²
Bole	6	1.25
	5	1.60
	4	1.67
	3	2.05
Limb	6	1.87
	5	0.77
	4	0.90
	3	1.42

ANOVA TABLE

Source of variance	df	M.S.	F calculated	F critical, .05 level
Total (adj)	31			
Treatment	7	0.000080	0.93	2.49
Blocks	3	0.000024	0.28	3.07
Tree part (A)	1	0.000128	1.49	4.32
Age class (B)	3	0.000008	0.09	3.07
A x B	3	0.000137	1.59	3.07
Error	21	0.000086		

a Randomized complete block design; four blocks represented individual trees.
 1 Material exposed to adults for 96 h.

subsequent development and survival of immature weevils. The potential of pales weevil to feed on, and oviposit and survive in, Douglas-fir in Christmas tree plantations in Pennsylvania must be evaluated in the field under natural conditions. Pales weevil has potential as a pest, and a potential that justifies prophylactic control measures at present. The magnitude of that potential currently is not known.

Acknowledgments

Drs. W. Merrill and H. D. Gerhold, Penn State University, made host material available from plantations under their control; Dr. Merrill reviewed a draft of this paper. To them we extend our thanks and appreciation.

Table 8. Oviposition preference among various ages of British Columbia Douglas-fir material from bole or limbs^a

Tree part	Age (years)	Mean eggs/dm ²
Bole	6	2.02
	5	3.75
	4	3.02
	3	2.85
Limb	6	2.42
	5	5.22
	4	3.30
	3	7.57

ANOVA TABLE

Source of variance	df	M.S.	F calculated	F critical, .05 level
Total (adj)	31			
Treatment	7	0.001317	1.66	2.49
Blocks	3	0.001410	1.78	3.07
Tree part (A)	1	0.002380	3.00	4.32
Age class (B)	3	0.001423	1.79	3.07
A x B	3	0.000856	1.08	3.07
Error	21	0.000793		

a Randomized complete block design; four blocks represented individual trees. Material exposed to adults for 96 h.

Table 9. Oviposition preference between pairs of species (Scots pine, eastern white pine, and Douglas-fir) or among all three species together^a

Tree species	Mean eggs/dm ²	F calculated ^b
Scots pine	42.0	24.37
Eastern white pine	9.3	
Scots pine	18.1	58.64
Douglas-fir	7.0	
Eastern white pine	4.8	24.54
Douglas-fir	9.8	
Scots pine	16.7	4.38
Eastern white pine	4.9	
Douglas-fir	5.4	

- a Randomized complete block design; 4 replicates per treatment. Material was exposed to adults for 96 h.
 b The critical F value for $\alpha=0.05$ is 5.99 (1, 6 df, pairs of species) and 5.14 (2, 9 df, three species together).

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Root beetles, stand disturbance, and management of black-stain root disease in plantations of Douglas-fir

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Abstract

The root bark beetles *Hylastes nigrinus* (Coleoptera: Scolytidae), *Pissodes fasciatus*, and *Steremnius carinatus* (Coleoptera: Curculionidae) are vectors of *Ceratocystis* (*Verticicladiella*) *wagneri*, causal agent of black-stain root disease of Douglas-fir. Stand disturbance provides the link coupling host to vectors and pathogen and mediates the epidemiology of this root beetle—root disease association. Disturbance agents may be environmental, biological, or anthropogenic and include factors such as windthrow, root disease, logging, thinning, and road construction. Forest management practices have intensified the disturbance regime of Douglas-fir forests; consequently, the root beetle—black-stain root disease association is an emerging pest problem. A crop production/pest management system is proposed. Opportunities for pest management are linked with the crop production system at times when pests enter the crop during forest management.

Résumé

Les perceurs de l'écorce des racines *Hylastes nigrinus* (Coleoptera: Scolytidae), *Pissodes fasciatus* et *Steremnius carinatus* (Coleoptera: Curculionidae) sont vecteurs de *Ceratocystis* (*Verticicladiella*) *wagneri*, agent causal de la tache noire des racines du douglas taxifolié. Les perturbations des peuplements constituent le lien entre l'hôte et les vecteurs et expliquent l'épidémiologie de l'association scolytes des racines - tache noire. Les agents perturbateurs peuvent être environnementaux, biologiques ou anthropogènes et comprennent des facteurs comme les chablis, les maladies des racines, l'exploitation forestière, l'éclaircie et la construction de routes. Comme les pratiques d'aménagement forestier ont intensifié les perturbations dans les forêts de douglas taxifoliés, l'association scolytes des racines - tache noire constitue un nouveau problème. Un système de lutte dirigée est proposé. Des possibilités de lutte sont associées au système de production des peuplements dans les circonstances où les arbres sont exposés aux ravageurs au cours de l'aménagement.

Introduction

Disturbance is a natural component of forest ecosystems (White 1979; Pickett and White 1985). Disturbance of forest stands may be caused by environmental or biological agents such as fire, windthrow, insects, and diseases, among others. Associated with disturbed stands is a suite of opportunistic insects and fungi capable of utilizing the resources made available by the injury or death of trees (Schowalter 1983). Under natural conditions, populations of these organisms fluctuate with the distribution, frequency, and intensity of disturbance across landscapes. Forest management has superimposed a new and profound disturbance regime on forest ecosystems. Average levels of disturbance have increased in distribution, frequency, and intensity on a landscape scale (fire is an exception). Simultaneously, populations of organisms limited by the quality and quantity of host material have expanded in response to increases in resource availability in space and time.

Organisms utilizing resources made available by disturbance of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) include a guild of root-colonizing insects, *Hylastes nigrinus* (Mannerheim), *Pissodes fasciatus* LeConte, and *Steremnius carinatus* (Boheman), vectors of the fungal root pathogen *Ceratocystis* (*Verticicladiella*) *wagneri* Goheen and Cobb, causal agent of black-stain root disease of Douglas-fir. Little information exists to suggest that these native organisms are noteworthy pests in natural stands and old-growth forests; however, they have become conspicuous in recently harvested stands and aggrading plantations of Douglas-fir. The temporal and landscape-scale continuity of disturbance provided by forest harvest and intensive forest management have created a situation suitable for expanding populations of root beetles and *C. wagneri*.

Under current forest practices, disturbance of Douglas-fir is widespread and frequent. Stands are harvested providing attractive brood material for *H. nigrinus*, *P. fasciatus*, and *S. carinatus* (Zethner-Møller and Rudinsky 1967; Condrashoff 1968; Witcosky 1985). Stand density management (precommercial and commercial thinning) results in additional episodes of disturbance applied across a stand (Witcosky 1986a). Root diseases associated with the previous stand, or introduced following felling, infect trees in the aggrading plantation providing attractive host material for *H. nigrinus*, *P. fasciatus*, and *S. carinatus*, while high densities of young trees provide abundant root contact for pathogens capable of spreading across roots in contact or adjacent to one another. I suggest that the prevailing disturbance regime appears to be directly related to the emergence of this root beetle—root disease association as a pest problem in the Pacific Northwest of North America.

In this paper I will discuss the biology and epidemiology of the Douglas-fir—root beetle—black-stain root disease association in relation to disturbance and forest management. I will present a crop production/pest management system for management of black-stain root disease and suggest ecological modifications to the disturbance regime and stand community structure to minimize the impact of this root disease.

Pathogen, vectors, and disturbance

Pathogen

Ceratocystis wagneri colonizes the mature sapwood tracheids of infected trees. The fungus spreads from tracheid to tracheid via bordered pit-pairs. *Ceratocystis wagneri* does not colonize any other plant cell tissue (Hessburg 1984). *Ceratocystis wagneri* is a true wilt pathogen; it colonizes the translocative tissues, interrupting movement of water from roots to foliage (Hessburg 1984). As the circumference of xylem with black-stained sapwood increases, terminal growth of infected trees decreases (Witcosky and Hansen 1985).

Ceratocystis wagneri spreads from tree to tree through root grafts, root contact, and through the soil for short distances (Hicks et al. 1980; Hessburg and Hansen 1986a). In the case of root contact or soil spread, *C. wagneri* infects hosts through the natural openings present when xylem elements are ruptured during the emergence of rootlets (Hessburg and Hansen 1986a).

Ceratocystis wagneri spreads from tree to tree at rates of approximately 2 m/year within established infection centers (Hessburg and Hansen 1986b; Hansen et al. 1986). New foci of infection are initiated by insects (Witcosky and Hansen 1985; Witcosky et al. 1986b).

Vectors

Hylastes nigrinus, *P. fasciatus*, and *S. carinatus* colonize infected trees during the 1 to 4 years of decline and death of hosts (Witcosky and Hansen 1985). Insects sequentially colonize the root system as roots become heavily infected. Volatiles associated with infection appear to act as attractants for host seeking beetles (Witcosky et al. 1987). Feeding and oviposition wounds resulting from this sequential process are likely to contribute to aggregation and oviposition (Witcosky 1985), as reported by Tilles et al. (1986) for *Hylobius abietis* (L.).

In areas where black-stain root disease is established, 1 to 5% of *H. nigrinus*, *P. fasciatus*, and *S. carinatus* may become infested with *C. wagneri* upon emergence and dispersal (Witcosky et al. 1986b). *Hylastes nigrinus* and *P. fasciatus* have brief periods of flight from April-June. *Steremnius carinatus* is active throughout most of the year but is most abundant in traps from May to August (Witcosky et al. 1986a).

Disturbance

Hylastes nigrinus, *P. fasciatus*, and *S. carinatus* readily colonize trees cut during thinning, harvest, and road construction, or those killed by root diseases and windthrow (Zethner-Møller and Rudinsky 1967; Condorashoff 1968; Witcosky and Hansen 1985; Witcosky et al. 1986a,b). In addition, *H. nigrinus* and *S. carinatus* wound the roots of adjacent, standing trees following disturbance (Zethner-Møller

and Rudinsky 1967; Witcosky 1986a,b). Since root systems of living or recently cut trees are susceptible to infection, *C. wagneri* may enter disturbed stands via the roots of cut hosts or on the roots of crop trees (Witcosky 1986a,b).

Disturbance following precommercial thinning

The activity of *H. nigrinus* in precommercially thinned stands spans 2 years (Figure 1); immigration and oviposition occur during the first year; brood emergence and dispersal occur the following year. *Hylastes nigrinus* adults have been recovered from the roots of crop trees for 2 years following precommercial thinning (Witcosky 1985; Witcosky et al. 1986b). In one plantation, 23 *H. nigrinus* (13 females, 10 males) were observed wounding 12 trees, seven months after thinning. In another plantation, 46 *H. nigrinus* (29 females, 17 males) were recovered from 35 crop trees, 13-21 months after thinning. Twenty-four percent of the trees injured in 1983 were wounded again the next year; 70-92% of trees injured in 1984 had been injured the previous year. Apparently, thinned stands remain attractive to *H. nigrinus* during the first and second seasons of flight following disturbance (Figure 1), suggesting that the effects of disturbance are not limited simply to the year of thinning. Perhaps crop trees remain stressed for several years after thinning. Alternatively, wounds sustained by crop trees during the second flight season may reflect injuries and stress from wounds incurred during the previous flight season.

The response of *S. carinatus* to precommercial thinning is shown Figure 2. Populations of *S. carinatus* increased significantly in the first and second years following disturbance and remained high during the third year. By the second year and well into the third year, however, populations of *S. carinatus* in the unthinned plots were higher than those observed in the first year of the study. The impact of such increases of *S. carinatus* upon adjacent, undisturbed stands is unknown.

Disturbance following harvest

Seedlings planted directly above the roots of harvested old-growth trees have become infected with black-stain root disease. Frequently, these seedlings lacked any evidence of insect wounds. The source of inoculum appeared to be infected roots of the old-growth Douglas-fir. The roots of these trees were colonized by *H. nigrinus* and *S. carinatus* and were infected to a minor degree with *C. wagneri*. All evidence indicated that these trees had not been infected prior to felling because the colonization pattern of the infected root was typical of that observed in artificially inoculated roots of cut trees (Witcosky et al. 1986b). This suggests that vectors introduced *C. wagneri* into the roots of old-growth trees during colonization.

Disturbance caused by root disease and windthrow

Established and expanding infection centers provide temporal continuity to the disturbance regime of a stand. As *C. wagneri* spreads from tree to tree, suitable

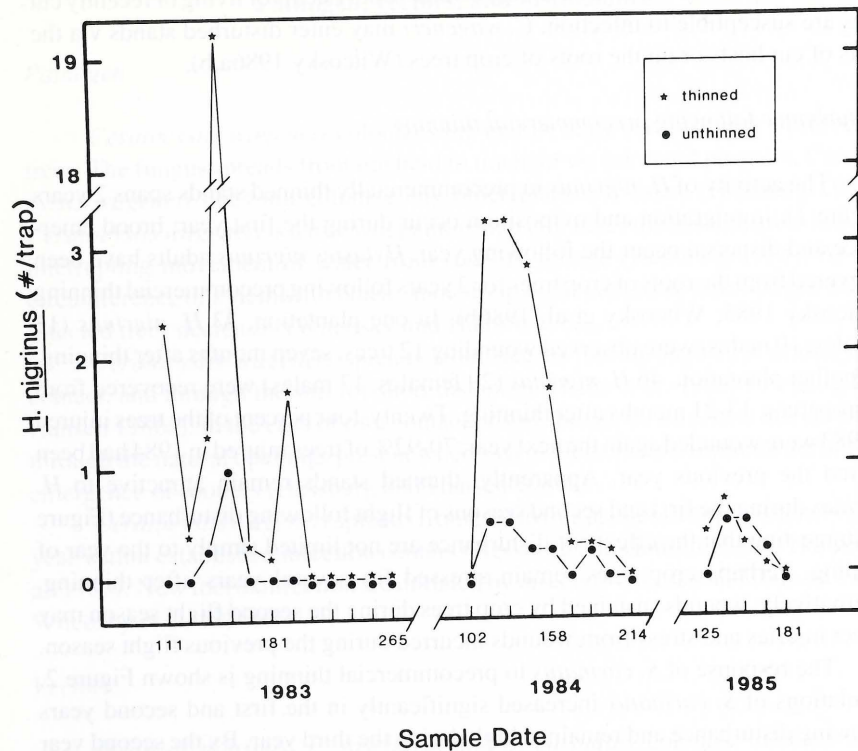


Figure 1. Mean number of *Hylastes nigrinus* caught per trap on stick traps during 1983-1985 in precommercially thinned and unthinned 2-ha plots in a 12-year-old plantation of Douglas-fir (n=6 thinned plots and 2 unthinned).

ovipositional material is provided for host-seeking beetles. Vectors are attracted to the vicinity of infected hosts by volatiles released from diseased hosts (Witcosky et al. 1987) and perhaps by the feeding and oviposition wounds of other root beetles. Healthy trees adjacent to infection centers also are at an increased risk of injury and infection (Witcosky et al. 1986b). This observation is supported by two excavations in which *H. nigrinus* wounds were observed on newly infected trees near established foci indicating that "satellite" foci are initiated adjacent to established, expanding foci. Furthermore, a roadside survey detected wounds more often on crop trees adjacent to established foci but on the opposite side of the road than on crop trees more distant from established foci along the road. This suggests that trees in the vicinity of established foci are at a greater risk of injury by vectors.

New foci of *C. wagneri* also may develop when hosts are stressed by other biological agents which influence the behavior of vector populations. Excavations of several Douglas-fir sustaining virtually lethal infections of *Phellinus weirii* (Murr.) Gilb. were found to be infected with *C. wagneri* secondarily, on the few

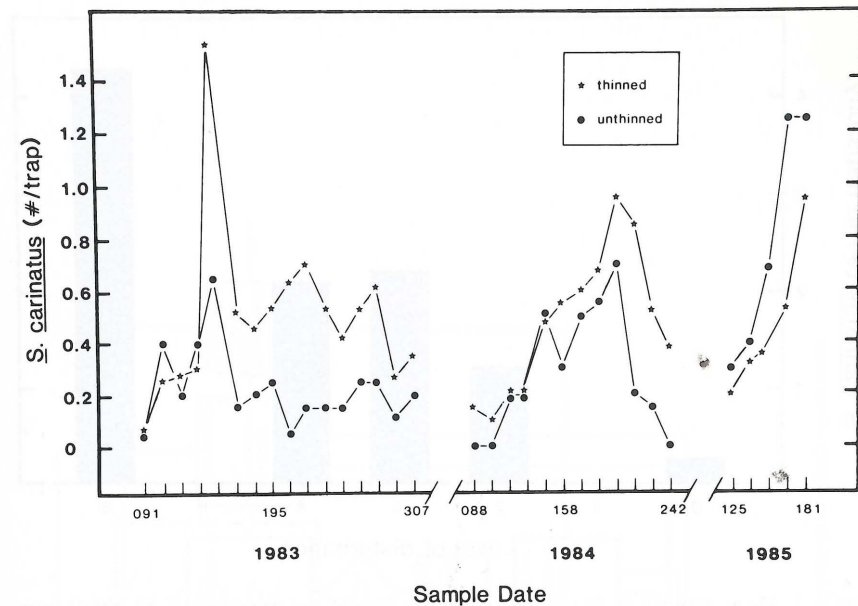


Figure 2. Mean number of *Stereomnium carinatus* caught per trap in pitfall traps during 1983-1985 in precommercially thinned and unthinned 2-ha plots in a 12-year-old plantation of Douglas-fir (n=6 thinned plots and 2 unthinned).

living roots sustaining the tree. *Hylastes nigrinus*, *P. fasciatus*, and *S. carinatus* colonized these roots and may have introduced *C. wagneri* into them during feeding or oviposition.

In a mark-and-release study, *S. carinatus* was trapped to observe patterns of activity associated with various levels of stand disturbance (Figure 3). The levels of disturbance were the number of Douglas-fir dying from root disease or a combination of root disease and windthrow within a gridwork of 50 pitfall traps. In general, the number of *S. carinatus* caught in traps increased as the level of disturbance increased in this 24-year-old plantation.

Disturbance and the initiation of new infection foci

Finally, new foci are associated with factors such as roads, tractor logging, and low wet sites (Hansen et al. 1986; Witcosky et al. 1986b). Factors important under these circumstances are poorly understood; however, stress induced production and release of volatiles which act as attractants for host-seeking beetles may be a possible mechanism (Witcosky et al. 1987).

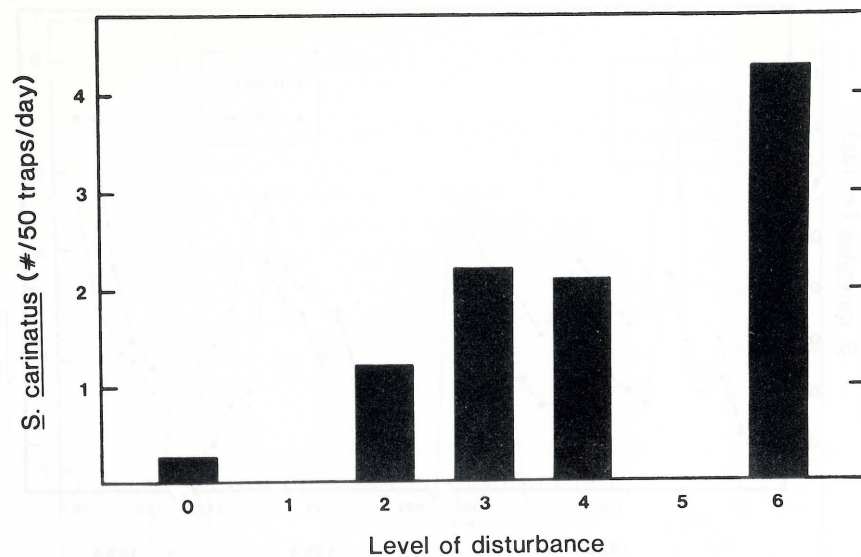


Figure 3. Mean number of *Steremnius carinatus* caught per gridwork of 50 pitfall traps located in disease foci experiencing varying levels of tree mortality (=disturbance) in a 24-year-old plantation of Douglas-fir in 1982.

A crop production/pest management system

It is clear that certain harvest activities and management practices are intimately linked to the epidemiology of black-stain root disease through its vectors. This coupling leads to an increased risk of establishing black-stain root disease in newly regenerated plantations, spreading of the pathogen throughout a plantation, and spreading of the pathogen to adjacent plantations and across landscapes.

The root beetle—black-stain root disease association is an emerging pest problem of Douglas-fir in the Pacific Northwest. Although most evidence suggests that the disease is aggravated by intensive forestry practices, black-stain root disease may be amenable to control by appropriate silvicultural and pest management alternatives. Figure 4 presents a crop production system for a long-term crop like Douglas-fir. Opportunities for pest management are linked with the crop production system at the time when pests enter the crop during forest management. This crop production/pest management scheme is designed to weaken the links between intensive forest practices and the epidemiology of black-stain root disease and its vectors.

The principal component of the crop production system is an inventory of plantations which contains specific stand and disease foci data. The inventory is coupled to a stand growth model, such as DFSIM (Curtis et al. 1981), which

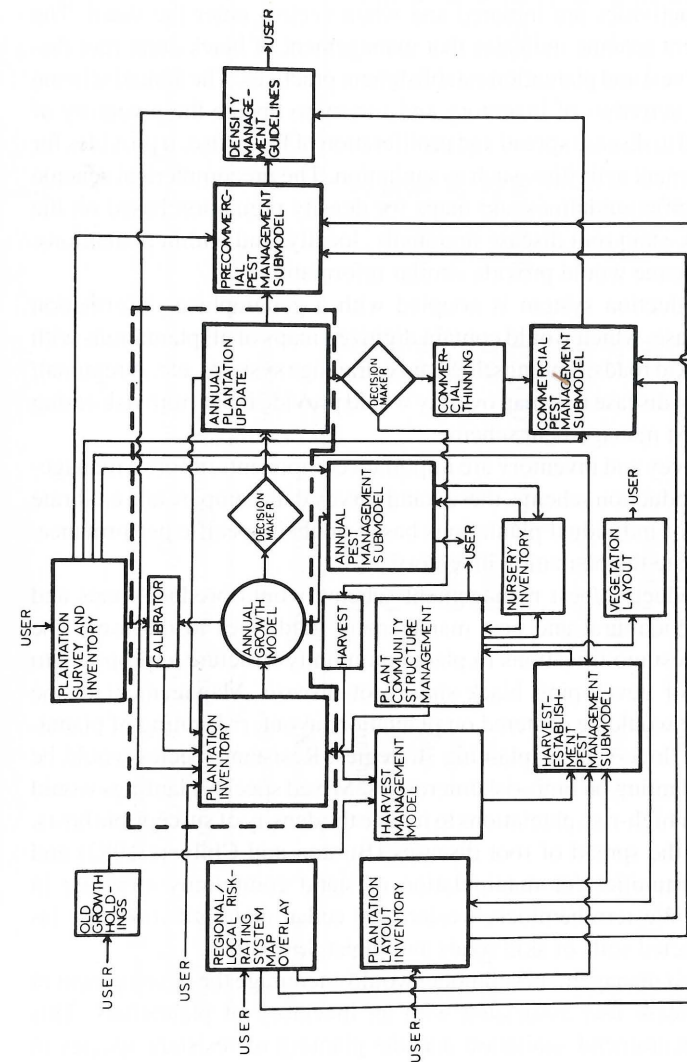


Figure 4. A crop production/pest management system for management of black-stain root disease in plantations of Douglas-fir.

simulates growth annually. The annual plantation update from such a simulation would be separated into three classes of data: (1) growing plantations; (2) plantations slated for precommercial thinning; and (3) plantations slated for commercial thinning or harvest.

Coupled to the crop model are four pest management submodels, the harvest-establishment, annual, precommercial, and commercial pest management schemes. Each pest management scheme is coupled to the crop production model at a time when silvicultural activities are initiated and when vectors enter the stand. The harvest-establishment scheme indicates that management of black-stain root disease begins with harvest and plantation establishment practices. The annual scheme exploits the annual activities of inventory and survey to update the inventory of holdings with regard to disease spread and proliferation of foci. Also, it provides for annual pest management activities, such as sanitation. The precommercial scheme would develop specific guidelines and maps for density regulation based on the distribution of black-stain root disease regionally, locally, and within plantations. The commercial scheme would provide similar information.

The crop production system is coupled with a geographical information system (GIS) data base, which would contain digitized maps of all plantations with networks of roads, skid roads, landings, log hauls, drainage systems, etc. A regional/local black-stain root disease risk map overlay would provide input from risk-rating systems for each pest management scheme.

Plantation survey and inventory are important components of forest management. In this crop production scheme, these stand survey data compare and calibrate model predictions for individual plantations based on their specific performance. Calibrated data update the plantation inventory.

This crop production/pest management scheme would produce maps and provide specific silvicultural and pest management guidelines to the user. The scheme would suggest modifications to plant community structure appropriate to minimize the risk of developing black-stain root disease. Management in the establishment phase would be centered on plantation layout, risk-rating of plantations, and two- and three-species planting strategies. Resistant species would be recommended for planting on high-risk microsites. Mixed species plantings would be recommended for high-risk plantations to reduce the density of susceptible hosts. This would reduce the spread of root diseases (Burdon and Chilvers 1982) and provide more opportunities for manipulation of stand community structure in subsequent entries. Western hemlock, western red cedar, and hardwoods are favored on the compacted soils of skid roads and moist, low sites.

The annual pest management submodel would encourage the development of an inventory of disease foci associated with an inventory of plantations. This submodel would recommend sanitation and the planting of resistant species in infection centers.

Precommercial thinning may result in the proliferation of foci of black-stain root disease (Witcosky et al. 1986a,b). Since completion of thinnings may not be possible during the least favorable period for the spread of the pathogen, a structured

Table 1. The influence of time of precommercial thinning of Douglas-fir on the mean number (standard error) of *Hylastes nigrinus*, *Pissodes fasciatus*, and *Steremius carinatus* caught during peak capture in plantations of Douglas-fir, Douglas County, Oregon, 1983-85

Plantation	Month of thinning	Condition of host material	<i>H. nigrinus</i>	<i>P. fasciatus</i>	<i>S. carinatus</i>
BURD	Sept/Jun	Green	16.0	1.3	1.6
5340	Sept/Jun	Green	56.0	2.5	1.3
R5	Aug	Green	27.0	0.2	1.0
R19	Dec	Green	23.3	1.3	3.8
BLM	Oct	Green	48.0	2.3	3.5
		Mean	34.0a (17.1)	1.5a (0.9)	2.2a (1.3)
R11	Jun	Defoliated	2.0	0.1	5.3
R2	Jun	Defoliated	4.5	0	0.6
R12	Jul	Defoliated	8.0	0	1.9
R1	Jul	Defoliated	4.3	0	1.4
		Mean	4.7b (2.5)	0.03b (0.5)	2.3a (2.1)

Means within columns followed by different letters are significantly different ($P < 0.05$; Wilcoxon rank-sum test).

Table 2. The influence of time of precommercial thinning of Douglas-fir on the mean number (standard error) of wounds on crop trees and attacks on stumps by *Hylastes nigrinus*, Douglas County, Oregon, 1983-85

Plantation	Condition of host material	Proportion of trees wounded	Mean wounds per tree	Mean wounds per wounded tree	<i>H. nigrinus</i> attack intensity on stumps
BURD	Green	0.11	0.11	2.5	10.4
5340	Green	0.17	0.17	2.7	—
R5	Green	0.12	0.12	2.1	21.5
R19	Green	0.12	0.12	2.2	11.8
BLM	Green	0.17	0.17	2.4	—
	Mean:	0.14a (0.03)	0.14a (0.1)	2.4a (0.2)	14.6a (6.0)
R11	Defoliated	0.02	0.02	1.0	2.0
R2	Defoliated	0.01	0.02	2.0	3.0
R12	Defoliated	0.01	0.01	1.0	2.1
R1	Defoliated	0.03	0.03	1.0	4.5
	Mean:	0.02b (0.01)	0.02b (0.1)	1.3b (0.5)	2.9b (1.2)

Means within columns followed by different letters are significantly different ($P < 0.05$; Wilcoxon rank-sum test).

approach would be followed. Recommendations for thinning would be designed to minimize the risk of disturbance and subsequent immigration of vectors. Plantations would be risk-rated, both regionally and locally, and those at greatest risk would receive treatment during June-July. Data gathered over 3 years of plantation thinnings suggest that June-July is the best time for thinning (Tables 1,2). Fewer *H. nigrinus* and *P. fasciatus*, but not *S. carinatus*, were caught by traps placed in plantations thinned in June-July relative to plantations thinned in August-January. For *H. nigrinus*, the proportion of crop trees wounded, mean number of wounds per tree, mean number of wounds per wounded tree, and intensity of attack on stumps and roots of cut trees were reduced when thinning occurred in June-July. Apparently, during the nine months prior to the spring flight the host material ages and loses much of its attractiveness to *H. nigrinus* and *P. fasciatus*. The precommercial management scheme would utilize plantation mapping, black-stain root disease foci inventory, stand density and composition, spatial structure, and regional and local abundance of black-stain root disease to measure risk. Pest management tactics applied to established foci of *C. wagneri* during the thinning process should minimize felling of diseased hosts. Sanitation by tree removal or chemical treatment may be favored. Resistant species should be favored within and near infection centers. Interplanting of resistant species at plantation establishment would provide opportunities for modifying thinning to favor resistant species on microsites or in stands where black-stain root disease is present and causing significant mortality. Interplanting with a nitrogen-fixing shrub capable of capturing and holding a site until overtopped and shaded out by Douglas-fir could possibly eliminate the need for precommercial thinning.

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Minimizing *Otiorhynchus* root weevil impact in conifer nurseries

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Abstract

Black vine weevil (*Otiorhynchus sulcatus* (F.)) and strawberry root weevil (*O. ovatus* (L.)) are the most ubiquitous and damaging species in the genus. Larvae of these flightless, parthenogenetic species destroy roots; adults may cause unacceptable defoliation during 4 weeks of maturation feeding and a 3-month oviposition period. They are both generally distributed in much of Europe and North America and in parts of Australia, New Zealand, and Japan where they are occasional pests of conifers in nursery production. Although some insecticides have shown promise for controlling larvae in field plantations of nursery crops, a control strategy based on vigilance for adult activity and thorough-coverage, foliar sprays of effective insecticides is suggested as the main line of chemical defense. Parasitic fungi and nematodes, although effective against root weevil larvae in containerized plants and in greenhouses, are not effective under field conditions.

Résumé

Le charançon noir de la vigne (*Otiorhynchus sulcatus* [F.]) et le charançon de la racine du fraisier (*O. ovatus* [L.]) sont les espèces les plus répandues et les plus destructrices du genre *Otiorhynchus*. Les larves de ces deux espèces d'insectes non volants, à parthénogenèse détruisent les racines, tandis que les adultes peuvent causer une défoliation inacceptable à la phase d'alimentation de maturation qui dure 4 semaines et à la période d'oviposition durant 3 mois. Les deux espèces ont une distribution générale dans la majeure partie de l'Europe et de l'Amérique du Nord ainsi que dans certaines parties de l'Australie, de la Nouvelle-Zélande et du Japon où elles attaquent parfois les conifères dans les pépinières. Certains insecticides ont donné des résultats prometteurs contre les larves dans des plantations établies sur le terrain avec des plants produits en pépinière; néanmoins, la stratégie de répression recommandée est axée sur la surveillance de l'activité des adultes et la pulvérisation abondante d'insecticides chimiques efficaces sur le feuillage. Les champignons et nématodes parasites, bien qu'efficaces contre les larves des charançons des racines dans des plants en récipient et dans des serres, ne sont pas efficaces en conditions naturelles.

Introduction

The palearctic genus *Otiorhynchus* Germar contains some of the most damaging root weevils encountered in Australia, Europe, New Zealand, and North America (Smith 1932; Sampo and Casale 1975; Warner and Negley 1976; Nielsen and Montgomery 1977; Evenhuis 1978; Penman and Scott 1979; Bedding and Miller 1981; Simons 1981; Bogato 1984). More recently, damage reports have been recorded from Japan (Masaki et al. 1984) and North Africa (Bedding and Miller 1981).

Many of the important species, including all representatives in North America, are parthenogenetic and flightless, characteristics that contribute to their pest status. Although weevils may walk up to several hundred metres during natural dispersal (Nielsen 1969), most of their range extension has occurred through movement of infested plant material (Maier 1978). Adults are nocturnal and remain beneath debris on the soil surface or within the canopy of tightly sheared plants during the day. Eggs are laid in or on the soil surface; larvae cause damage by consuming small roots and girdling larger roots. Adults chew notches in the margins of leaves that may result in aesthetic injury, or damage if weevil density is high enough to cause significant defoliation. In the Pacific Northwest in the USA, feeding by adults has been considered more damaging than larval root feeding (R. L. Campbell, personal communication).

Black vine weevil, *Otiorhynchus sulcatus* (F.), and strawberry root weevil, *O. ovatus* (L.), are the two most ubiquitous and damaging species in the genus. Their biologies and seasonal life histories are similar; *O. sulcatus* is recognized as the more important pest world-wide. Both species were relegated to manageable status with the introduction of organochlorine insecticides in the 1950's. However, development of resistance (Nielsen et al. 1975) and bans on the use of these products have resulted in a resurgence of root weevil problems throughout their range since the mid-1970's.

Otiorhynchus ovatus is generally distributed in Europe, causing economic damage to strawberry, cane berries, and beets (Warner and Negley 1976). It is the most widely distributed root weevil in North America, occurring in all Canadian provinces and in all but 10 southern states in the continental U.S. (Warner and Negley 1976). In North America it is called the strawberry root weevil, primarily because early reports dealt with its pest status on that crop. However, it is a general feeder and has been observed as a serious pest of conifer seedlings in the Pacific Northwest (Wilcox et al. 1934; D.G. Nielsen, personal observation), British Columbia (Shrimpton 1985; Rutherford et al. 1987), and in the eastern USA (Nielsen and Heller 1978).

Otiorhynchus sulcatus is more polyphagous than *O. ovatus* and has been reported primarily as a pest of grape and ornamental plants in central Europe, small fruits and nursery crops in Scandinavia, and nursery crops and landscapes in North America. It is the most important nursery pest in Ohio (Miller and Nielsen 1987), and is commonly responsible for restriction of more dollar value of nursery crops

than all other pests combined (Ohio Department of Agriculture, personal communication). It is distributed primarily along the east and west coasts of North America above Mexico, and in the Great Lakes States and Provinces in the USA and Canada. Recently, it has received renewed research interest in Australia, New Zealand, Japan, the USA, and throughout much of Europe. *Otiorhynchus sulcatus* seems to thrive in areas with well drained soils and moderate temperatures (Montgomery and Nielsen 1979).

Life cycle and seasonal life history

Both species overwinter primarily as large larvae; some adults overwinter in buildings or in protected locations outdoors where winter temperatures are moderate (Garth and Shanks 1978). Few small larvae (younger than 4th instar) and adults overwinter in climatic zones 4 and 5. Spring larvae are voracious feeders, completing development sometime in late April or May in latitudes of northeastern Ohio. Pupation occurs several centimetres beneath the soil surface in an earthen cell. Adults emerge ca. 2 weeks later and soon work their way above ground to begin a 4-week preoviposition feeding period (Cram and Pearson 1965; Penman and Scott 1976; Maier 1981; Nielsen and Dunlap 1981). Oviposition begins in July and may continue until hard frost. Fecundity of *O. sulcatus* varies with host plant (Nielsen and Dunlap 1981); wild grape (*Vitis aestivalis* var. *argentifolia* (Munson) Fern.) and other weeds are suitable hosts (Smith 1932; Nielsen and Dunlap 1981; Masaki et al. 1984).

Adult activity can be monitored by recording abundance of adults or leaf notches on broadleaf hosts. In landscapes and nurseries, leaf notch monitoring can be efficient, if favored adult hosts like rhododendron (*Rhododendron* spp.), euonymus (*Euonymus fortunei* (Turcz.) Hand.-Mazz.), or hosta (*Hosta* spp.) are near weevil infestations. Alternatively, pit-fall traps (Nielsen et al. 1978) or trap-boards (Maier 1983) can be used to detect and census weevils. Trap boards are the better choice for practitioners, because they are cheap and not influenced by rain.

Otiorhynchids in conifer nurseries

Conifer nurseries near established vineyards, strawberry fields, landscape nurseries, oldfields, or forests containing wild host plants are most susceptible to colonization by *Otiorhynchus* weevils. During the mid-1970's, a major producer of conifer seedlings in western Pennsylvania incurred widespread loss of Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco), Colorado spruce (*Picea pungens* Engelm.), and Alberta spruce (*Picea glauca* var. *albertiana* (S. Br.) Sarg) seedlings and transplants from root damage caused by *O. ovatus* and *O. sulcatus*. The young trees were growing adjacent to a deciduous hardwood forest on a well-drained (loam & gravel) hilltop near Indiana, Pennsylvania. Acephate (14.8 and 29.6 kg a.i./ha) and bendiocarb (14.8 kg/ha) were applied as drenches, using 2.4 litres of water/m² of bed, followed by a like amount of water immediately after application on 6 May

1977. The soil was moist but not saturated at treatment. Larvae were nearing pupation. None of the treatments provided significant reduction in larval/pupal density (Nielsen and Heller 1978).

A similar study with field production yews (*Taxus media* 'Densiformis') growing in well-drained old Lake Erie lake bed characterized as Berrian fine sand and infested with large *O. sulcatus* larvae was more promising. Carbofuran (Furadan 4F) at 22.4 and 44.8 kg a.i./ha and bendiocarb (Turcam 76 WP) at 44.8 kg/ha significantly reduced larval density when applied with 1 litre of finished material/m² of soil surface when larvae were nearing pupation (Nielsen and Dunlap 1985a). Oxamyl (Vydate 2L) was ineffective. All plots were cultivated just prior to and immediately following application.

Several factors may have caused the discrepancy in results between these two trials. Root mass associated with well-established transplant beds might inhibit movement of toxicant to larval feeding sites. Lack of pre- and post-treatment cultivation may have resulted in insecticide degradation through ultraviolet breakdown and inhibited downward movement of water and toxicant. Soil factors may have also contributed to variable results. Toxicity studies have shown that both carbofuran and bendiocarb are highly toxic to *O. sulcatus* larvae (Nielsen and Boggs 1985b; Nielsen and Roth 1985); soil type has been shown to influence toxicity (Nielsen and Boggs 1985a).

A better approach for controlling larvae in field plantings is to treat infested areas when larvae are small. Two applications (mid-August and mid-October) of granular carbofuran or bendiocarb at 11.2 kg ai/ha to cultivated, sandy soil significantly reduced *O. sulcatus* larval density on taxus; terbufos and single applications of bendiocarb or carbofuran were ineffective (Nielsen and Dunlap 1982). Late September application of carbofuran (liquid or granular), the high rate of its isomer known as Advantage (4EC), or bendiocarb WP at 11.2 or 22.4 kg ai/ha to sandy, old Lake Erie lake bed soil virtually eliminated a dense *O. sulcatus* larval infestation on field taxus (Nielsen and Dunlap 1985b). Again, soil was cultivated pre- and post-treatment, and only 1 litre of finished material (or water with granular treatments) was used per m² of soil surface. Shanks (1979) reported similar results with carbofuran granules against *O. sulcatus* larvae in cranberry bogs. All 12 treatments with isofenphos (Oftanol 5G and 2F) resulted in a 2-fold to 3-fold increase in larval density. This unexpected result has not been explained; potential usefulness of isofenphos against *Otiorhynchus* larvae has not been pursued further.

Results of drench trials to control root weevil larvae have shown some potential. Saunders (1970) worked with *O. sulcatus* larvae infesting containerized Colorado spruce growing in a 1:1 peat:sand potting mix. Carbofuran at 5.6 kg a.i./ha equivalent provided a high level of control. In Northern Ireland, Blackshaw (1984) used chlorpyrifos drenches to control *O. sulcatus* larvae infesting containerized plants for up to 20 weeks. Chlorpyrifos was effective against large *O. sulcatus* larvae when root balls of infested yews were immersed in a solution containing 2.5 g a.i./L for 30 seconds (Nielsen and Dunlap, unpublished).

Controlling adults and minimizing oviposition

Although some insecticides and treatment strategies have shown promise for controlling *Otiorhynchus* larvae, this practice is problematical and should not be used as a first defense against root weevils. Instead, insecticidal sprays can be used to kill weevils after they emerge above ground and before their eggs mature (Nielsen 1980). Basic toxicity studies (Nielsen 1983; Parella and Keil 1984) and field evaluations (Nielsen and Montgomery 1977) indicate that carbofuran and bendiocarb are toxic to and efficacious against *O. sulcatus* adults. Effectiveness sometimes varies with host (Nielsen and Dunlap 1985c). Shanks and Chamberlain (1988) reported that toxicity of pyrethroids to *O. sulcatus* adults also depends upon host factors. Bendiocarb (Turcam and Dycarb 76 WP) has been registered for use in the nursery and the landscape industries in the USA for a number of years and is proving to be effective in vine weevil adulticide programs in both production and maintenance of landscape plants (Nielsen, unpublished information from growers and landscape managers). It should be equally effective and economical in conifer nurseries, if done according to principles of integrated pest management. Steps required for implementing a successful *Otiorhynchus* weevil adult control program, in chronological order, include:

- (1) Determine whether a significant adult population is overwintering at the nursery. Use trap boards (see #3).
- (2) Apply a thorough-coverage, hydraulic spray to plant foliage in all infested areas of the nursery ca. 2 weeks after overwintered weevils become active in spring (mid-May in climatic zones 4 & 5; three weeks earlier in zone 6).
- (3) Deploy trap-boards (ca. 30 x 30 x 1 cm thick) beneath the canopy of infested plants at least 3 weeks before adult emergence is expected. *Otiorhynchus ovatus* adults may begin emerging ca. 2 weeks before *O. sulcatus*. Observe duff beneath boards during the day at weekly intervals. During hot weather, boards should be checked in the morning before heat drives weevils to more protected locations (Shrimpton 1985).
- (4) Record date when new adults are first observed (beneath trap-boards or elsewhere).
- (5) Apply a thorough-coverage, hydraulic spray to all infested plants ca. 3 weeks after first adult emergence. Spraying at night will be most effective, because that is when adults feed and oviposit. (Note: Scrutiny of plants for presence and abundance of weevil adults and monitoring pit-fall traps from before adults began emerging above ground until after oviposition began, indicated that weevils begin to wander about the time their eggs mature (Nielsen 1980). So, although it is not necessary to spray nurseries as soon as new adults emerge, they should be killed before their eggs mature to prevent reinfestation and to minimize local dispersal).
- (6) Repeat the adulticide spray at 3-week intervals until no new adults are detected beneath trap boards 3 days after the last spray. Adults of both species may begin emerging in mid to late May in climatic zones 4 and 5 (3 weeks earlier in zone 6) and continue to emerge for 8 to 10 weeks. Most production and landscape

maintenance personnel use three or four sprays during spring and summer to achieve desired results. A similar strategy has been suggested by others (Sampo and Casale 1975; Penman and Scott 1976; Nielsen et al. 1978; Parrella and Keil 1984).

Otiorhynchus weevil infestation in conifer nurseries may be difficult to detect before damage occurs, because leaf feeding is more cryptic than on broadleaf plants. Early symptoms of root weevil infestation on yews and members of the Pinaceae include reduced growth rate, retarded bud break, and chlorosis. Weevil larvae are large enough to detect only from late October through pupation the following spring or summer. Managers of conifer seedling nurseries can improve detection procedures by planting euonymus, hosta, or another preferred, broadleaf adult host in locations convenient for observation near seedling and transplant beds. Trap boards could be deployed beneath these plants to further facilitate detection of first adult emergence and to follow their seasonal activity.

Since *O. sulcatus* and *O. ovatus* are polyphagous and complete development on many native plants, nursery managers should not only practice clean cultivation in production areas but should also destroy host plants growing in the perimeter of beds and the nursery to minimize immigration. If weeds exist in perimeter and production areas, they should also be sprayed when using adulticides (Makasi et al. 1984).

Novel control tactics

Otiorhynchus weevils have traditionally been controlled with conventional insecticides. Diflubenzuron has caused reversible sterility of weevils fed treated foliage (Zepp et al. 1979), but has not been registered for this use. Other biologically rational tactics evaluated include parasitic fungi and nematodes.

The hyphomycetous fungus *Metarhizium anisopliae* (Metschn.) Sorok., var. *anisopliae* (strain no. 85) was significantly better than other strains and species against *sulcatus* larvae at 15°C (Soares et al. 1983). However, infectivity and mycosis were reduced at cooler temperatures where larvae commonly develop, indicating its current limitation to plants grown inside structures. To date, the literature does not contain information indicating that parasitic fungi are consistently effective against root weevil larvae out-of-doors.

Insect-parasitic nematodes have shown even more promise against *Otiorhynchus* larvae in greenhouse and container production. Bedding and Miller (1981) achieved 100% parasitization of *O. sulcatus* larvae infesting containerized plants by using aqueous suspensions of infective juvenile *Heterorhabditis heliothidis*, isolate T327. Rutherford et al. (1987) had similar results with *Heterorhabditis* nematodes against *O. sulcatus* and *O. ovatus* larvae infesting containerized lodgepole pine (*Pinus contorta* Dougl.) and Douglas-fir, respectively. The nematodes were not effective against a natural infestation of *O. ovatus* larvae infesting a field of 2-0 Douglas-fir. As in the field failure with parasitic fungi, lack of control was attributed to the ineffectiveness of the nematodes at low temperature. Perhaps strains of parasitic nematodes or fungi selected to operate at low temperature will provide a

novel tactic for controlling field infestations of *Otiorhynchus* larval infestations. Since nematodes evaluated are more infective against large than small larvae (Rutherford et al. 1987), and since large larvae are only present in the field when soil temperatures are cool (fall, winter, and early spring), infectivity at low temperatures is an essential requirement for nematodes to be useful against field infestations. Currently, they are not a viable option for minimizing *Otiorhynchus* root weevil impact in conifer nurseries.

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Seedling Damage

Biology, outbreak characteristics and damage caused by the black army cutworm (Lepidoptera: Noctuidae)

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Abstract

The black army cutworm feeds on conifer seedlings causing mortality, dieback, and deformity. Outbreaks occur 1 or 2 years after a site has been burnt. Larvae feed on herbaceous vegetation which regenerates after fire, and on inter-planted seedlings when other vegetation has been depleted. Thirteen species of parasitoids have been recovered from larval collections; one tachinid and two ichneumonids are quite abundant. The degree of damage is dependent on age and species of seedlings and amount of competing vegetation as well as cutworm population density. An outline of a management system for this problem is given which involves classifying site susceptibility, monitoring population density with pheromone traps, and manipulating time of planting.

Résumé

La légionnaire noire, qui se nourrit de semis de conifères, tue et déforme les jeunes plants et en dessèche les rameaux. L'espèce infeste un secteur de un à deux ans après sa destruction par le feu. Les larves consomment la végétation herbacée qui repousse après l'incendie, et les semis formant une plantation intercalaire, après épuisement des autres types végétaux. Parmi les treize espèces de parasitoïdes figurant dans les prélèvements larvaires, on remarque l'abondance particulière d'un tachinidé et de deux ichneumonidés. L'étendue des dommages dépend de l'âge et de l'espèce des semis, et de l'abondance de la végétation compétitive, ainsi que de la densité démographique des légionnaires noires. On présente l'aperçu d'un plan de gestion visant à éliminer le problème, et comportant le classement du degré de

vulnérabilité du terrain, la surveillance de la densité démographique à l'aide de pièges de phéromones, et la modification de la période de plantage.

The black army cutworm, *Actebia fennica* (Tauscher), goes through rapid population changes on specific sites. Larvae appear suddenly on sites burned 1 or 2 years previously and begin devouring vegetation, including newly planted seedlings. Seedling mortality caused by severe defoliation may result in the need for partial or complete replanting to maintain desired stocking standards. Less severe defoliation results in stem deformities and height growth losses, thus reducing the seedlings' ability to compete for site resources. At the present time, it is impossible to predict where infestations will occur, the level of seedling damage which may be sustained or long-term impacts of the damage. Consequently, foresters have had to deal with black army cutworm infestations on a crisis basis by arbitrarily delaying planting, spraying with a pesticide, or replanting at a later date without adequate information as to the consequences of those decisions.

This insect has a circumpolar distribution. It has been collected from Canada, the northern United States of America, Scandinavia, the United Soviet Socialist Republics, Manchuria, Mongolia and northern Korea (Pulliainen 1963). Canadian outbreaks have occurred in British Columbia, Ontario and Newfoundland (Ross and Illytzyk 1977; Clarke and Carew 1985). Within British Columbia, outbreaks have been reported primarily from moist spruce sites in central and eastern locations (Figure 1). As more of the forest comes under a cut and burn style of management, the distribution of outbreaks will probably expand, particularly northward; there is a need to define susceptible sites more specifically.

Eggs of *A. fennica* are laid in the duff from mid-July through mid-September and take about two months to hatch under laboratory conditions (Ross and Illytzyk 1977; Wood and Nielson 1956). There are six larval instars. The overwintering stage may vary with environmental conditions. Wood and Nielson (1956) indicated that first or second instar larvae were the overwintering stage, while Maxwell (1950) noted that overwintering might occur in the egg stage. In British Columbia, second, third and fourth instar larvae can be found actively feeding as soon as snow melts in spring and the herbaceous cover begins to grow. Larval phenology varies with site and year (Figure 2). At first, the larvae chew minute holes in the leaves, but later consume all the leafy parts of the plant. Mature larvae pupate in the duff in late June and three or four weeks later the adults emerge to mate and lay eggs.

Mating is facilitated by a highly attractive pheromone. Pheromone trapping indicates that low densities of moths are found in most forest openings. In transects of traps extending from openings into the forest, the catch rate of male moths drops to zero abruptly at the forest edge (Figure 3).

Densities of black army cutworm change drastically in response to fire. One to two years after a prescribed or wild fire, thousands of larvae per hectare can suddenly appear and consume nearly all green vegetation, including any planted seedlings (Ross and Illytzyk 1977). The distribution of larvae is extremely contagious so that vegetation damage is quite patchy. It appears that this insect

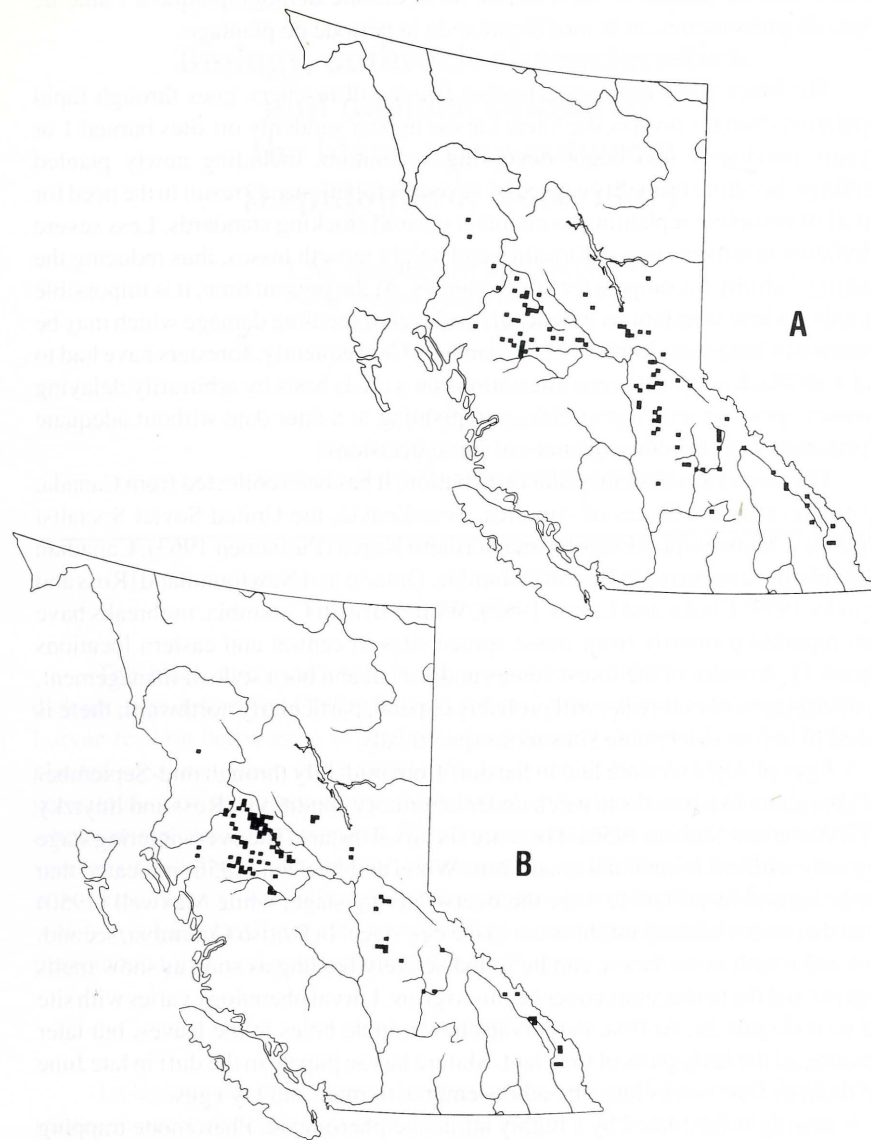


Figure 1. Distribution of collections of black army cutworm in British Columbia based on Forest Insect and Disease Survey, Pacific Forestry Centre records (1953-1988) plotted by 10 km Universal Transverse Mercator grid: A, distribution of larvae or pupae detected during surveys of cutblocks (n=151); and B, location of adult male pheromone trap collections (n=198). Maps produced by FIDS Technology Development Project, Petawawa National Forestry Institute, Petawawa, Ontario.

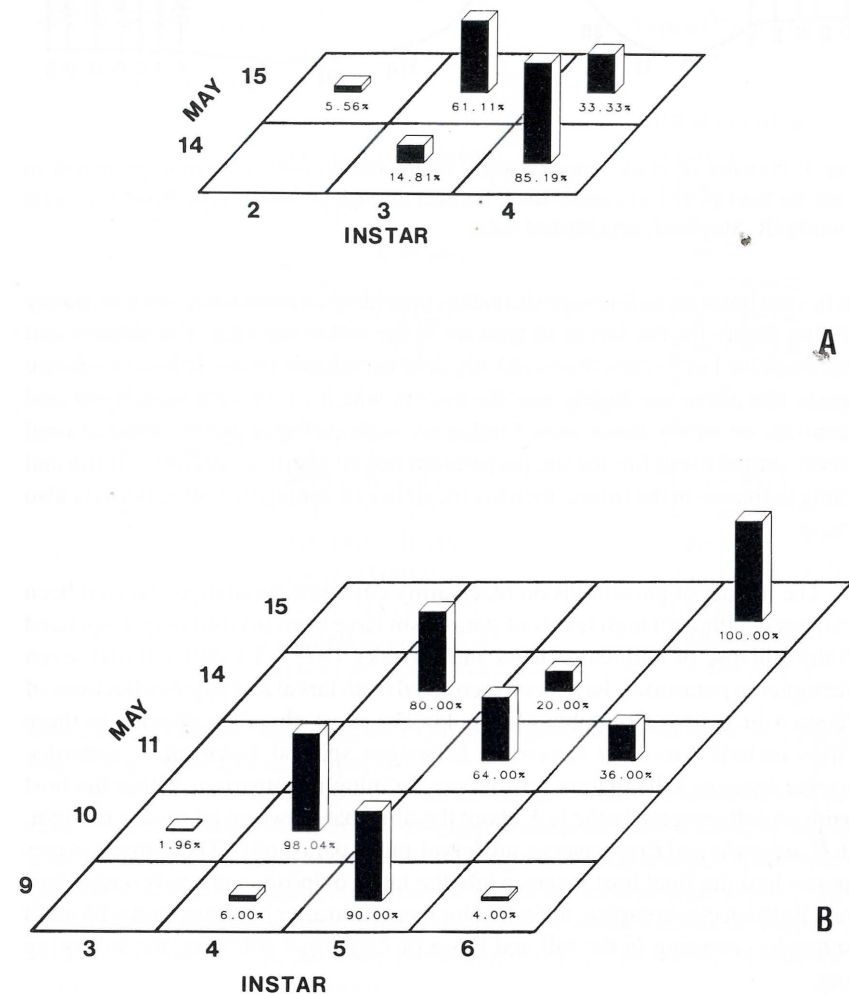


Figure 2. Stage of development and date of collection of black army cutworm larvae recovered from infested cutblocks. Vertical bars represent the proportion of the larvae collected in each instar. A. Instars present on two sites in the Quesnel Forest District, May 14-15, 1986; and B. Instars present on five sites in the Golden Forest District, May 9-15, 1988.

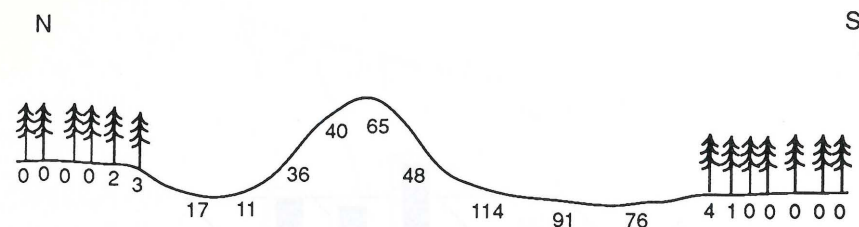


Figure 3. Number of black army cutworm moths caught over a seven-night period in pheromone traps placed in a north-south transect through an area cut and burnt two-years previously (R. Shepherd, unpublished data).

searches out burnt areas for oviposition thus providing an abundance of fresh, newly emerging plants for the larvae to feed on in the following year. Populations can remain high for 1 or 2 years, then suddenly drop to endemic levels. Indirect evidence suggests that these are highly mobile insects which every year search out and concentrate on newly burnt sites. Outbreaks were probably never detected until foresters started using fire for site preparation before planting seedlings. If fire and planting increases in the future, then the incidence of damaging outbreaks may also increase.

The impact of parasitoids on black army cutworm populations has not been investigated, although high levels of parasitism have been occasionally associated with the collapse of outbreaks (Ross and Illytzy 1977). Six dipteran and seven hymenopteran parasitoids have been recovered from larval and pupal collections of *A. fennica* in British Columbia (Table 1). The most abundant species in these rearings include *Nowickia latigena*, *Erigorgus* sp. and *Eutanyacra suturalis*. *Nowickia latigena* kills mature host larvae, forming its puparium within the host remains. Adults emerge in the fall, about the time that cutworm adults are in flight. Both *E. suturalis* and *Erigorgus* sp. are larval-pupal parasitoids. The former species oviposits into the final host instar, while the latter oviposits into early-instar host larvae. Both species complete their development soon after host pupation with adult *E. suturalis* emerging in the fall and those of *Erigorgus* emerging the following spring.

There are several variables which affect the amount of damage which occurs to the regeneration. During an infestation, feeding on seedlings occurs when the amount of preferred herbaceous vegetation is not sufficient to satisfy the feeding demands of the larvae so that damage is related, in part, to the types and quantities of associated vegetation. When defoliation does occur, newly planted seedlings appear to succumb easier than those planted several months prior to the infestation, regardless of species. When the time of planting is similar, spruce, *Picea* spp., seems to be the preferred species, followed by lodgepole pine, *Pinus contorta* Dougl., and

Table 1. Parasitoid species reared from black army cutworm in British Columbia. Those species ovipositing into and emerging from host larvae are designated 'Larval' while species ovipositing into host larvae and emerging from host pupae are designated "Larval-Pupal" (L. Humble, unpublished data).

Parasitoid Species	Type of Parasitoid
HYMENOPTERA	
BRACONIDAE	
<i>Glyptapanteles alticola</i> (Ashm.)	Larval
<i>Microplitis</i> sp.	Larval
ICHNEUMONIDAE	
<i>Dusona laticincta</i> (Cresson)	Larval
<i>Erigorgus</i> n. sp.	Larval-Pupal
<i>Eutanyacra suturalis</i> (Say)	Larval-Pupal
<i>Ichneumon creperus</i> Cresson	Larval-Pupal
<i>Ophion</i> sp.	Larval
DIPTERA	
TACHINIDAE	
<i>Epalpus signifer</i> (Walker)	Larval-Pupal
<i>Nowickia latigena</i> (Tothill)	Larval
<i>Nowickia tahoensis</i> ((Reinhard)	Larval
<i>Mericia ampelus</i> (Walker)	?
<i>Periscepsia helymus</i> (Walker)	Larval
<i>Winthemia fumiferanae</i> Tothill	Larval-Pupal

Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. Survival of defoliated seedlings varies from species to species.

The more severe the defoliation, the more severe are associated types of damage such as bark feeding and destruction of terminal and lateral buds. The long-term impacts of mortality are lower stocking levels and unequal distribution of seedlings, which in some cases may be offset by natural regeneration. Height growth reductions and stem deformities reduce the seedlings ability to compete with surrounding vegetation, but since the vegetation itself is also defoliated the net competitive situation is unknown.

Solutions for this problem will vary for different sites. They currently include delay of planting until larvae have finished feeding, planting of an alternate species, spraying with chemical insecticide, or improving the competitive advantage of damaged seedlings with a herbicide spray. We foresee that the most common management strategy for this problem will be one of scheduling planting on susceptible sites to avoid the problem without substantially increasing the risk of severe vegetative competition. We are attempting to do this through the following studies:

1. Obtain a better description of short-term and long-term impacts of damage to define the type of damage which can be sustained.
2. Obtain a better understanding of the site conditions, harvesting and burning sequences, quantity and quality of herbaceous vegetation, and dynamics of cutworm population densities as related to seedling damage.
3. Develop a site description and pheromone monitoring system which will enable us to detect populations soon enough to avoid intolerable damage.

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Effects of defoliation, decapitation, and partial girdling on root and shoot growth of pine and spruce seedlings

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Abstract

One-year-old seedlings of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) were defoliated, decapitated, or girdled partially in order to simulate different types of insect damage. Immediate growth effects were evaluated in a growth chamber. Another set of seedlings treated in a similar way were planted in a nursery and were followed for four growing seasons.

Seedling survival was high, except for the partially girdled spruce seedlings. For both species, total defoliation or partial girdling drastically reduced root growth during the first weeks after the treatment. This effect was also seen after the first field season. After four field seasons, decapitated pines were still smaller than the controls whereas all spruces and the other pines had recovered. The results were interpreted in terms of growth patterns and carbohydrate availability, and the impact of different types of insect damage on planting success and stand establishment was discussed.

Résumé

Des plants d'un an de pin sylvestre (*Pinus sylvestris*) et d'épinette de Norvège (*Picea abies*) ont été défoliés, décapités ou annelés partiellement pour la simulation de différents types de dommages causés par les insectes. Un groupe a ensuite été mis dans une chambre de culture pour évaluation des effets immédiats sur la croissance, tandis qu'un autre a été planté dans une pépinière et a été suivi pendant quatre saisons de croissance.

Les taux de survie des plants ont été élevés, sauf pour les plants d'épinette partiellement annelés. Chez les deux espèces, la défoliation totale et l'annélation partielle ont réduit considérablement le développement des racines au cours des premières semaines suivant le traitement. Le même effet a été observé après la première saison de croissance sur le terrain. Après quatre saisons, les pins qui avaient été décapités étaient encore plus petits que les témoins, alors que toutes les épinettes et les autres pins avaient retrouvé une taille normale. Les auteurs expliquent les résultats en fonction des caractéristiques de croissance et de la

quantité d'hydrates de carbone disponibles et ils analysent les effets de différents types de dommages causés par les insectes sur le succès du plantage et l'implantation des peuplements.

Introduction

Newly planted seedlings are subject to a multitude of pest organisms causing different types of damage, and threatening the survival and development of the new tree generation. In Scandinavia, needle losses caused by fungi or defoliators, stunted height growth due to mammal browsing and shoot die-back or stem wounds resulting from weevil gnawing, are of major concern in conifer reforestation (e.g., Eidmann and Klingström 1976). Although seedling survival following insect attack, by pine weevil for example, has been intensively studied (Lindström et al. 1986, and references cited therein), little is known about the effects of different damage types on the establishment and early development of newly planted seedlings. Any kind of damage during this sensitive phase of stand establishment may be of decisive importance for the survival and further role of the seedling in the developing stand (Lyly and Saksa 1982; Kauppi 1984).

The present study reports a pilot experiment on the impact of artificial defoliation, decapitation, and partial girdling on root and shoot growth of 1-year-old seedlings of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.).

Material and methods

Laboratory experiment

Dormant 1-year-old seedlings of Scots pine and Norway spruce were obtained from a commercial nursery in Central Sweden. The seedlings were grown in rigid plastic containers (type HIKO, substrate volume 50 ml, plant density 767m^{-2}) in a plastic greenhouse in 1983 and were refrigerated over the winter until 17 April 1984. The next day, seedlings were taken into room temperature and were watered and transplanted in experimental containers as described below.

The root growth capacity (RGC) of the seedlings was studied using a technique originally developed by Stone and Jenkinson (1971) as modified for containerized seedlings by Mattsson (1986). The seedlings are allowed to grow for three weeks in a standardized substrate of sand and peat at a soil temperature of approximately 20°C , a day length of 18 hours, and an average illumination of $300\text{E}\mu\text{m}^{-2}\text{s}^{-1}$. Then the substrate is washed off the roots and all new roots are clipped off and collected in water to prevent shrinkage. The root length and/or dry weight is then determined.

In the present study, five seedlings were transplanted in a row of nine containers (HIKO) filling every second container. This container row was placed in an RGC-cassette filled with the standard substrate of a 1:1 (volume basis) sand

and peat mixture. Altogether, 20 cassettes were prepared with pine and 20 with spruce seedlings. Five cassettes of each tree species were assigned to each treatment in a random way. The treatments were (Figure 1): 1, control; 2, 100% defoliation (all needles were clipped with a pair of scissors); 3, decapitation (the leader shoot was clipped below the terminal buds); and 4, partial girdling (bark and phloem was removed using a forceps at the lower stem in the following manner: the xylem was exposed in four patches approximately 1 cm in length and 1 to 2 mm in width; two of the patches were on opposite sides of the stem and the other pair of patches above and perpendicular to the first pair).

All treatments were carried out on 18 April and the cassettes were then placed in the two RGC-baths in a random way. The seedlings were left to grow for three weeks, and were watered twice a week, but not fertilized. On 9 May 1984, the substrate was carefully washed off the roots and all new roots protruding below the container bottom were cut and collected in a petri dish filled with water. The roots from the five plants in a cassette were pooled and measured with an automatic root length scanner (Comair, Australia), or in case of very poor root growth, measured by hand with a ruler. The roots were then oven-dried (24 h, 105°C) and weighed to the nearest mg.

Experimental planting

An experimental planting with 1-year-old seedlings of Scots pine and Norway spruce was carried out at Älvbacka nursery in central Sweden. The plants were containerized seedlings similar to those used in the laboratory experiment. They were cold stored until 25 May 1984, when the following treatments were applied to the seedlings before planting (Fig. 1): 1, control; 2, defoliation of approximately two-thirds of the foliage leaving the upper one-third intact; 3, total defoliation of the needles; 4, decapitation of the leader shoot below the terminal buds; and 5, partial girdling consisting of two pairs of "gnawing" patches as described for the laboratory study above. The defoliation and topping treatments were done with a pair of scissors, and the girdling with a forceps. Seedlings were assigned to the treatments in a random way.

The experimental design was a 5×5 latin square with four seedlings in each experimental unit. The spacing was 40 cm, and the pines and spruces were planted in two separate experiments with the same statistical design. All the 100 pines and spruces were planted on 25 May 1984, and at that time shoot elongation and needle flush had started both in the pines and spruces. The seedlings were neither watered nor fertilized during the study period.

In October 1984, the survival and height growth of all seedlings were noted. The seedlings of two replications for each tree species were carefully dug up and taken in plastic bags to the laboratory. All new roots which had grown out from the container were clipped and collected in water. Root lengths for each seedling were measured and weighed as described above. The stem height (from the cotyledonal

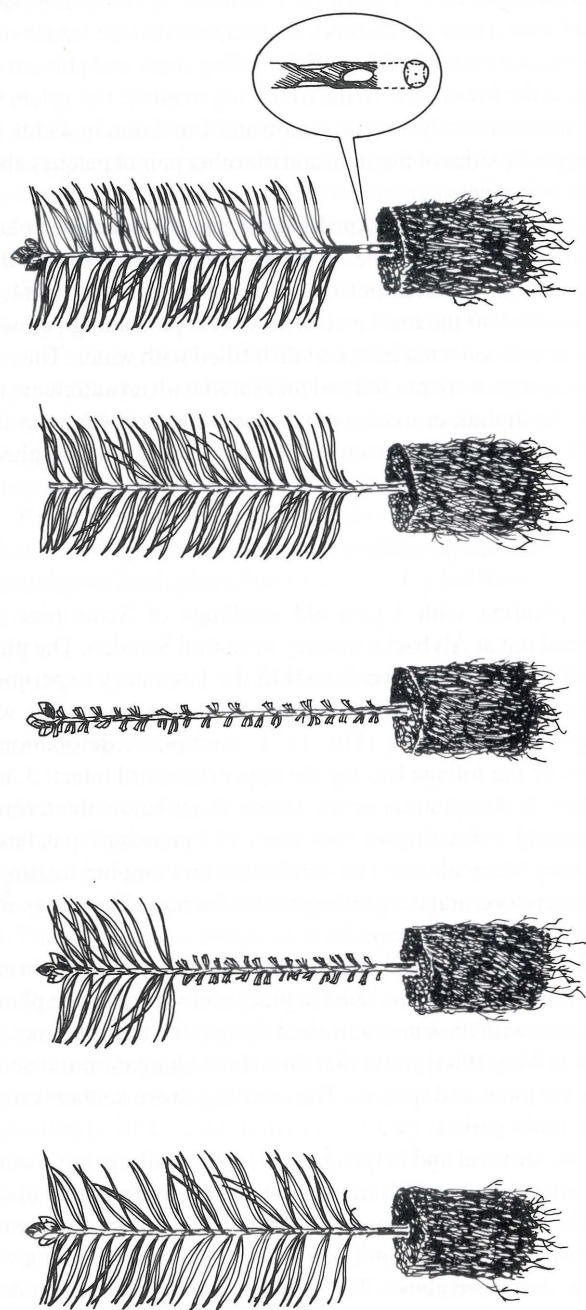


Figure 1. Schematic representation of the treatments applied to pine and spruce seedlings in the laboratory and nursery experiments. From left to right: control, partial defoliation (nursery experiment only), total defoliation, decapitation, and partial girdling.

node), current leader length, and stem diameter at the base were measured for each seedling.

The remaining three replications were remeasured (plant condition, total height, leader growth, and stem diameter) in the autumn of 1985, 1986 and 1987.

Results were analysed using analysis of variance followed by Tukey's multiple comparison test. Linear regressions were computed for root length/weight comparisons.

Results

Root growth in the laboratory

All pine and spruce seedlings included in the RGC study survived the test period of three weeks. In both tree species, root growth was drastically reduced in the defoliation and girdling treatments (Table 1). The decapitation did not affect root growth in pine, but may have increased it in spruce although the difference was significant neither for dry weight nor for root length. The root lengths were strongly correlated with root dry weights for both pine ($R^2=0.98$) and spruce ($R^2 = 0.95$).

Experimental planting

Survival. After the first field season, all control and decapitated seedlings of both tree species were alive (Figure 2). A few of the partially and totally defoliated

Table 1. Growth of new roots in Scots pine and Norway spruce seedlings after three weeks in a controlled environment

	Scots pine		Norway spruce	
	Root dry weight (mg)	Root length (dm)	root dry weight (mg)	Root length (dm)
Control	34.0	12.4	29.0	9.2
Total defoliation	0.8 ^a	0.1a	2.0a	0.6a
Decapitation	34.3	14.3	42.2	11.7
Partial girdling	11.2 ^a	4.8 ^a	3.8 ^a	0.8 ^a
F-value	20.09***	16.34***	30.86***	49.40***
HSD	8.1	7.3	14.3	3.3

a) mean significantly different from the control at $p \leq 0.05$, Tukey's multiple comparison test, honestly significant difference (HSD).

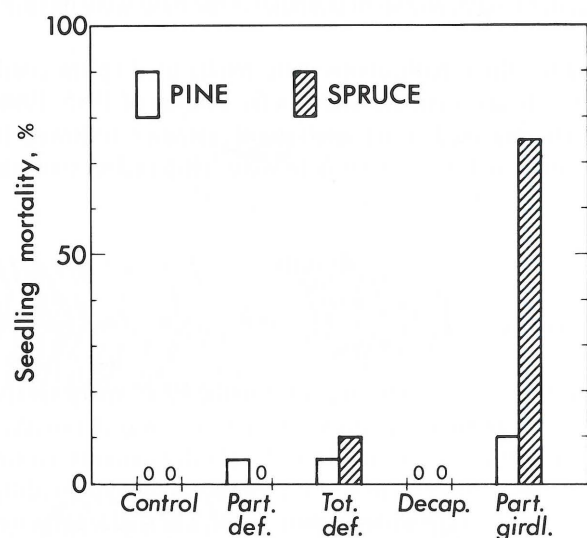


Figure 2. Seedling mortality in different treatments in percentage of 20 seedlings after the first growing season in the nursery.

seedlings had died in both species. The survival of the partially girdled seedlings was 90% in pine but only 25% in spruce. No further mortality occurred during the second field season, but in the third season two more defoliated pine and spruce seedlings died, probably due to accidents during weeding of the experiments.

Growth after one field season. In autumn 1984, root growth of pine seedlings was negatively affected in all treatments as compared with the control seedlings (Table 2); the difference was, however, significant only for the defoliated and decapitated seedlings. In spruce, the tendency in root growth was similar to that observed in pine although only the few surviving partially girdled plants differed significantly from the controls. Root growth of the partially defoliated seedlings was obviously not affected by the treatment.

A regression analysis of root weights (data not shown) in relation to root lengths showed that the high correlation observed in the RGC study still persisted after the first field season; R^2 was 0.94 and 0.93 for pine and spruce, respectively.

The height growth of the pine seedlings during the first field season was not affected by the treatments, except for decapitation which resulted in a significant reduction in total height and leader growth (Table 2). For spruce seedlings, no significant differences in height or leader growth were observed, although total lengths were lower in the topped or girdled treatments (Table 2).

None of the treatments had any clear effect on stem diameter. In both species a weak tendency towards increased stem diameter was seen in the partially

Table 2. Shoot and root growth for Scots pine and Norway spruce seedlings, which were dug up after one field season in the nursery

Treatment	Scots pine				Norway spruce			
	Total height (mm)	Leader length (mm)	Stem diam. (mm)	Length of new roots (dm)	Total height (mm)	Leader length (mm)	Stem diam. (mm)	Length of new roots (dm)
Control	145.1	48.8	3.5	61.8	154.9	50.6	3.0	58.8
Partial defoliation	158.8	55.4	3.8	44.6	152.9	44.8	3.4	61.6
Total defoliation	144.5	44.8	2.8	25.8 ^a	151.8	58.8	3.2	31.2
Decapitation	81.8 ^a	20.0 ^a	2.9	35.6 ^a	119.8	45.3	2.9	49.9
Partial girdling	157.4	55.4	3.9	37.8	126.0	33.5	3.4	19.0 ^a
F-value	11.04 [*]	14.52 ^{**}	5.59 [*]	8.92 [*]	2.00 ^{ns}	2.27 ^{ns}	0.72 ^{ns}	6.29 [*]
HSD	54.1	21.6	1.1	24.2	64.3	33.1	1.4	39.6

a) mean significantly different from the control at $p \leq 0.05$

defoliated or partially girdled plants; decapitation or total defoliation (in pine only) caused the opposite pattern. No means were, however, significantly different from those of the controls.

Further height growth. After four field seasons, the differences in seedling height observed after the first field season were still present in pine but not in spruce plants (Figure 3). In pine, the height of decapitated seedlings differed significantly from that of the controls, and defoliated or girdled plants were not significantly smaller than the controls.

In spruce, the control plants were also highest in all years. No means differed, however, significantly from each other, and the ranking between the other treatments changed from year to year, but the totally defoliated spruces were smallest during the last two inspections.

Discussion

The different injury types elicited somewhat different growth reactions in pine and spruce seedlings. For pine, survival was high despite the fact that the seedling vitality was rather poor judging from the root growth capacity of the control seedlings (cf. Mattsson 1986). The high mortality of the partially girdled spruce plants indicated that they were more sensitive to this type of injury than the pines (cf. Dormling 1963). This result is in contrast with the observations made by other authors, such as Eidmann (1969) and Lekander and Söderström (1969) showing that spruce plants are more tolerant to damage caused by *Hylobius abietis* (L.) (Col., Curculionidae) than pine plants. However, this higher tolerance of spruce may be attributable to size differences between pine and spruce seedlings used in practical plantations, whereas the seedlings of both species in this study were roughly of the same size. The artificial wounding at planting may on the other hand not be fully comparable to weevil damage under field conditions.

For both species, the partial girdling severely reduced root growth in the laboratory study, and this effect also showed up after one growing season in the nursery, whereas shoot length and diameter were not affected by the partial girdling. Cerezke (1974) observed decreased radial increment of lateral roots as well as reduced height growth in 25- to 30-year-old lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* engelm.) after girdling treatments simulating larval feeding of *Hylobius warreni* Wood. Reduced height growth resulting from *Hylobius* damage has been reported by Selander and Kalo (1979).

The total defoliation resulted in a drastic decrease in root growth in the laboratory as well as in the nursery study, whereas the partial defoliation did not significantly reduce root growth in either species. Similar results have been reported for lodgepole pine seedlings by Carlson (1977).

Although it is well known that defoliation causes losses in height and diameter growth (e.g., Ericsson et al. 1980), few studies refer to young plants. Hoffman and

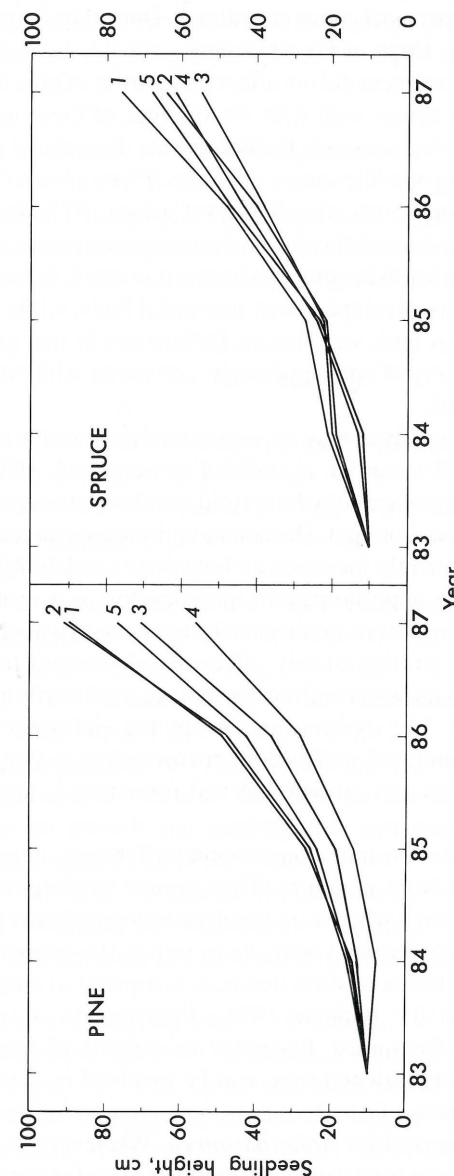


Figure 3. Height development of seedlings of different treatments (1 = control, 2 = partial defoliation, 3 = total defoliation, 4 = decapitation, and 5 = partial girdling) during 4 years in the nursery. (n = 5 in 1984 and n = 3 in 1985-87).

Steiner (1965) observed only modest height and diameter growth losses for 1 and 2 years, respectively, in defoliated 2-year-old Scots pine. The present findings agree well with their observations. Also the spruce seedlings tolerated defoliation treatments without major losses in height growth. Thus, young trees seem to suffer less from severe defoliation than older trees (cf. Kulman 1971). This may be due to compensation through free growth which is common in young trees, and particularly in Norway spruce (personal communication, I. Dormling, Swedish University of Agricultural Sciences, Dept. of Forest Genetics, Stockholm, Sweden).

The decapitation treatment did not affect root growth of pine in the laboratory study. This observation agrees well with the findings of Gezelius et al. (1981). However, after one growing season in the nursery the decapitated pines displayed low root growth. Topping of white spruce seedlings (*Picea glauca* (Moench) Voss) resulted in increased root growth after 30 days (Carlson 1977). In our study, root growth of spruce was close to normal during the first growing season. Decapitation had no effect on height growth in spruce, whereas it severely reduced it in pine. In spruce, new leader shoots developed from internodal buds, while the recovery in pine through adventitious buds was slower. Differences in free growth may also have favoured the recovery of spruce plants as compared with pine (I. Dormling personal communication).

The above growth effects may be understood as a result of carbohydrate allocation patterns (cf. Ericsson et al. 1980; Ericsson et al. 1985). Defoliation decreases the main source of carbohydrates (old needles) causing a shortage in the sinks (buds, new needles, root tips). Decapitation decreases (at least temporarily) the sink size and consequently increases carbohydrate availability to other sinks, e.g., root tips. Later, the opposite pattern may develop as a result of a smaller photosynthate production due to a smaller needle biomass, as was observed for pine in this study. A partial girdling mainly affects the downward transportation of photosynthates, whereas the water and nutrient uptake is indirectly affected through a reduced root growth. The dynamic pattern of the sink-source balance in a disturbance situation is not well understood, but according to Waring and Pitman (1985), for example, fine root growth and bud formation is favored over stem growth.

Our results also demonstrate considerable differences in growth reactions between Scots pine and Norway spruce. Thus, spruce seedlings seem to be very sensitive to girdling damage whereas they tolerate topping better than pine seedlings. The results also indicate that young plants respond to severe defoliation with relatively small growth losses of short duration, compared to those of older trees with similar defoliation (cf. Kulman 1971). Free growth is suggested as an explanation, especially for spruce. Excessive availability of growth promoting factors (light, water, and nutrients) may also be involved in the rapid recovery. Young trees may also have a faster root growth restoration following defoliation, as Redmond (1959) observed for *Abies balsamea*. Whatever the reasons, young pine and spruce plants seem to be capable of compensating for considerable needle losses without losing height growth.

From the reforestation point of view, the present results stress the importance of protecting seedlings against girdling injury caused, for example, by pine weevils in order to obtain good survival and rapid plant establishment. Moderate defoliation seems to be tolerated well, whereas total defoliation leads to slower plant establishment and reduced height growth. A leader loss is easily repaired in spruce, but will result in height growth losses in pine. Further studies are needed to evaluate these conclusions under field conditions, where the damage effect may be enhanced by environmental factors imposing additional stress on the damaged seedling.

Acknowledgements

We are indebted to Ingegerd Dormling, Anders Mattson, John B. Scarrat and Olle Tenow, for comments on the manuscript. This study was supported by a grant from the Swedish Council for Forestry and Agricultural Research (SJFR).

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Shoot and Tip Insects

Biology and impact of western pine shoot borer, *Eucosma sonomana*, in the western United States

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Abstract

Western pine shoot borer, *Eucosma sonomana* Kearfott, damages yellow pines in the western United States by mining the pith of elongating terminal shoots, causing loss of about 25% of 1 year's vertical growth per attack. Some shoots are killed or weakened and lateral shoots become dominant. The insect occurs at low population levels. Trees are first attacked at 5 to 10 years of age. After trees are 15 to 20 years old, about 50% of terminal shoots are attacked.

Recognition of western pine shoot borer as a pest coincides with the development of managed pine plantations. It is an atypical forest pest in that population levels are stable over most of a rotation, damage is chronic, and damage is inconspicuous. Treatment with synthetic pheromone reduces population levels by 75%.

Adults mate early in spring. Females select the larger terminal buds for oviposition sites. Larvae hatch from eggs and enter the elongating shoots shortly after bud burst. In mid-summer they chew out, drop to the ground, pupate, and diapause. Insect development correlates with host development and with heat accumulation.

Résumé

Le perce-pousse occidental du pin (*Eucosma sonomana* Kearfott) ravage les pins ponderosa de l'ouest des États-Unis en creusant des galeries dans la moelle des pousses terminales en croissance, provoquant la perte de près de 25% de l'accroissement en hauteur (vertical) de l'année par attaque. Certaines pousses sont éliminées ou affaiblies et les pousses latérales deviennent dominantes. Les niveaux de populations de cet insecte sont faibles. Il commence à ravager des arbres âgés de 5 à 10 ans. Environ 50% des pousses terminales des arbres de 15 à 20 ans sont ravagées.

L'identification du perce-pousse occidental du pin comme ravageur coïncide avec la mise en valeur de plantations de pins aménagées. Cet insecte est singulier

car ses niveaux de populations sont stables pendant la majeure partie d'une révolution, mais les ravages qu'il cause sont chroniques et peu évidents. L'application d'un traitement aux phéromones synthétiques a réduit les populations de 75%.

Les adultes s'accouplent tôt au printemps. Les femelles choisissent les bourgeons terminaux les plus gros pour pondre leurs oeufs. Les chenilles sortent des oeufs et pénètrent dans les pousses peu de temps après le débourrement. Au milieu de l'été, elles émergent, se laissent tomber sur le sol, se transforment en chrysalides et entrent en diapause. Le développement de cet insecte correspond à celui de son hôte et à l'accumulation de chaleur.

Introduction

The western pine shoot borer, *Eucosma sonomana* Kearfott, is a recently recognized pest of ponderosa pine, *Pinus ponderosa* Laws, and other western yellow pines (Stoszek 1973; Stevens and Jennings 1977). Recognition of its pest status more or less coincided with the development of managed and, thus closely observed, pine plantations. The insect mines terminal shoots and reduces their vertical growth. Damage is low per year, but it is chronic and significant over the course of a tree rotation. Vertical growth of all regenerating ponderosa pine in western North America is reduced at least 5% and over 12% in many stands. Thus, the western pine shoot borer is not a minor pest, even though it never threatens the destruction of a stand and may even be largely unnoted. In managed and thinned stands, which are generally considered more resistant to bark beetles, it may be the most serious overall pest. Western pine shoot borer requires long-term rather than crisis management strategy.

Biology

The seasonal history of western pine shoot borer is now well defined by studies done in central Oregon (Mitchell and Sower 1988). Adults emerge about April 1 before any significant development of ponderosa pine occurs. Eggs are deposited beginning around the last week in April when ponderosa buds start to expand. By the first week in May, the adult flight is 50% over, egg laying continues, and some larval mines are present in buds and shoots which are elongating. By the first week in June, moth flight has ended and first, second, and third instar larvae are present in 10- to 20-cm-long shoots. Larval development continues through June with emergence from the shoot beginning around July 1. This schedule differs with annual weather variation, but all the above events closely correlate with the accumulation of warmth (degree-days above 5.5°C). From August through March of the next year, western pine shoot borer diapauses as a pupae below surface litter.

Distribution

Western pine shoot borer was attracted to pheromone-baited traps in the western United States at every tested location having *Pinus* present (Sartwell et al. 1980). Thus, we infer that western pine shoot borer may be a pest of all yellow pines in western North America. Common host trees definitely include ponderosa, lodgepole (*P. contorta* Dougl.) and jeffrey (*P. jeffreyi* Grev.) pines. In our experience, the relation of western pine shoot borer to lodgepole pine differs somewhat from its relation to ponderosa pine. In vigorous lodgepole stands, infestation rates of western pine shoot borer may average higher, ca. 75%, than the common 45 to 65% rate for ponderosa stands. Further, the insect appears to infest and develop completely in smaller lodgepole terminals, and multiple infestations of single terminals are more common (observations of R. Mitchell).

Population stability

Pine shoot borer population density levels are stable from year to year. First infestation of a stand occurs as trees reach 5 to 10 years of age. In rapidly growing stands where trees produce robust terminal buds, shoots will be infested with western pine shoot borer earlier than in a stand with slower growing trees. Population levels then increase slowly until trees are 15 to 25 years old. Population levels in ponderosa pine stands in this age group vary; anywhere from 0 to near 100% of the terminals may be infested, but, commonly, rates of 45 to 65% of terminals are sufficiently damaged to be identified by external observation (Sower et al. 1984).

We suggest here, without proof, that infestation levels may generally correlate with the number of suitable shoots available in a given plantation and that the number of such shoots increases with age up to 15 to 25 years. When the number of robust shoots stabilizes, the western pine shoot borer population also stabilizes. Where western pine shoot borer populations have been reduced artificially, infestation rates have tended to double each year until normal levels are again reached in 3 to 4 years (Sower and Overhulser 1986).

Tree morphology

Western pine shoot borer is particularly damaging on a per-insect basis because the insect strongly favors the dominant terminal shoot for attack. In one study, average numbers of infested laterals averaged only about 1-1/2 times the number of infested terminals, even though the number of laterals on a tree greatly outnumbered the single terminal (Sower et al. 1984). Attacks on lateral shoots have little overall impact on a tree. In contrast, attacks on the terminal shoots can have substantial effect on tree growth and development. In addition to reducing vertical growth, the weakened terminal can lose dominance, which causes forking and other distortions in tree form (Stevens and Jennings 1977).

Symptoms

Damage is caused by larvae burrowing in the pith of terminal shoots during the time of rapid shoot growth. Larval mining in the pith generally results in weakening of the shoot and loss of vertical growth (Stoszek 1973; Sower and Shorb 1984). Characteristically, the larval mine occurs in the distal one-half to two-thirds of the shoot, but feeding may occur anywhere within the shoot. External symptoms of attack are shortening of needles distally to the beginning of the larval mine and reduced vertical growth of the shoot (Stoszek 1973). These morphological changes give the affected shoots a characteristic clubbed appearance. Other external symptoms we have observed include exit holes near the center of the shoot and a distinct swelling of the tree stem near the exit hole. This swelling is not apparent until the shoot is in its second season. Terminal shoots sometimes will break off where the stem is weakened by the exit hole. Mined shoots may be killed outright, and the occurrence of dead terminal shoots or dead lateral shoots in the top whorl can also be attributed to western pine shoot borer, at least in ponderosa pine. We have observed that dead terminals in lodgepole pine are at least as likely to be due to attack by the lodgepole terminal weevil, *Pissodes terminalis* Hopping.

Oviposition site selection

Two observations suggest that female western pine shoot borers select the potentially largest shoots, from among those available, for oviposition sites: first, shoots from the larger terminal buds are much more likely to be attacked than are smaller lateral shoots even though the buds are adjacent at the time of oviposition; second, in younger pine stands we have observed that the dominant trees, which have the more robust terminals, are more likely to be attacked. Thus, we (Sower and Shorb 1984) hypothesized that females were selecting the relatively tallest tree or the largest buds, or both, as the best oviposition sites.

A study in central Oregon in a young ponderosa pine plantation (Sower and Mitchell 1987) showed that where almost exactly 50% of terminal shoots and 15% of laterals in the first whorl were infested, the average shoot length of infested (26.5 cm) vs. uninfested (27.2 cm) was about the same. Pre-infestation bud lengths for terminals that were later attacked were significantly larger (45 mm) than those not subsequently attacked (40 mm). There was a good correlation between terminal bud size and incidence of shoot borer attack. An even better correlation was found between the summed lengths of terminal and immediately adjacent lateral buds in early spring and the subsequent infestation rate for the shoots. We conclude the insects are attracted to the larger bud masses and, once there, favor the larger, central, and more vertical terminal bud. We do not know what the attraction mechanism is. Infestation patterns were also somewhat related to tree height, but we believe this relation may occur simply because larger trees tend also to have larger buds in even-aged stands. In uneven-aged natural stands, western pine shoot borer is present in a very wide range of tree sizes so tree height, *per se*, cannot be a primary

method of selection. We conclude that western pine shoot borer selects shoots mainly on the basis of relative bud size.

Impact

A realistic estimate of western pine shoot borer impact on ponderosa pine growth is difficult. The assessment is complicated by the fact that females select for the largest terminal buds as oviposition sites; thus the potentially more robust shoots may be infested, lose 25% of their growth, and still be longer than an inherently weaker uninfested shoot on an adjacent tree. A simple direct comparison of lengths of infested vs. uninfested shoots may therefore result in an underestimate of actual damage. Further, the more subtle effects on tree morphology are equally difficult to quantify.

Stoszek (1973) made the first estimate of vertical growth loss by projecting potential growth of each shoot from a measurement of the longest previous terminal of each tree and contrasting this to actual growth. He estimated a vertical growth loss of up to 25%. In further studies, Sower and Shorb (1984) first correlated tree height (in even-aged stands) to the average vertical growth of uninfested shoots and used this correlation to predict potential vertical growth of shoots. An estimate of growth loss was then made on the basis of the difference between projected and actual growth. We found a vertical growth loss of 27% (or 9 cm) for each infestation identifiable by examination of external symptoms. This loss was spread over 2 years, 12% (or 4 cm) in the year of infestation and an additional 15% (or 5 cm) in the next year. We also estimated growth loss in the first year by an alternate method: projecting potential growth by counting the number of needle scales. The number of needle scales per shoot is predetermined when the bud is set in the fall (Sacher 1954), and the number of needle scales correlates with the ultimate length of the shoot. On impacted shoots, the needle scales are shorter and needles occur closer together. Using this method, we estimated a vertical growth loss of 20% the year of attack for shoots producing a mature larva.

Our vertical growth loss estimate is generally in agreement with that of Stoszek (1973) and with the recent study by Koerber et al. (in preparation) who report a vertical loss of 20% per infestation and 27% per infestation among the fastest growing trees. We generally estimate a loss equivalent to 25% of 1 year of vertical growth for each externally diagnosed attack on a leader. Ponderosa pine plantations that have more than 50% of terminal shoots damaged are common; these plantations are losing over 12% of their total vertical growth every year. Further, selection of the largest buds has the effect of slowing the development of otherwise dominant trees in an even-aged plantation.

Assessment of impact beyond that of direct vertical growth loss of a living terminal shoot is even more difficult. The long-term effect of distorted tree morphology is not included in the above estimates. Further, it is difficult to reliably convert vertical growth loss in young trees into volume loss of mature timber, although Stoszek (1973) has made an attempt. Koerber et al. (in preparation) show

that the basal width of an infested stem remains the same but the length decreases; thus over several years, a shorter, more sharply tapered stem with lower volume is produced. Loss of vertical growth and volume will be discussed further by Williams et al. (1989) in these proceedings.

Monitoring

Western pine shoot borer population levels can be estimated using pheromone-baited traps, by observation of shoots, and by dissection of shoots (Sower et al. 1984). Use of pheromone traps is an objective method usable by inexperienced surveyors. Traps are also the easiest method for an area-wide or preliminary assessment. Direct observation is the most common method used, and to assess damage at a specific site, it is the most direct. Visual surveys are simple, quick, and can be made any time of year except while shoots are elongating. The disadvantage of the visual survey is that some shoots are difficult to score accurately, particularly by inexperienced observers. Subjective errors may also be made, even by experienced observers. For example, we miss about 26% of infested shoots, scored visually, that are found infested on careful dissection. For damage assessment, this error is not serious because the infestations missed are those where the larvae do not completely develop and do little damage. We recommend using visual surveys for specific plantations, and trap surveys for area-wide surveys. For research purposes dissection may be required, depending on the objectives.

Disruption

Mating disruption with synthetic pheromone controls western pine shoot borer (Overhulser et al. 1980; Sartwell et al. 1980; Daterman 1982; Sower et al. 1982). Results have been consistent with several formulations applied both by aircraft and by hand. Generally, treatment dosages of 3 to 20 g/ha of active ingredient have resulted in 70 to 85% fewer terminal shoots infested. Where small treated plots are surrounded by susceptible western pine shoot borer host type, treatment tends to be less effective, presumably because of oviposition by immigrating females. Treating buffer zones around such plots may be necessary. Following treatment, damage again increases within 1 or 2 years, and most benefit of treatment is realized within 2 to 3 years (Sower and Overhulser 1986). Two pheromone formulations are available for use against western pine shoot borer. No other control agents have been found effective or registered in the United States.

Thus far, the pheromone disruption control has been used in only one series of treatments (by The Weyerhaeuser Co.) done for the purpose of promoting timber growth. Annual treatments have been made, however, to several high-value sites in Idaho and Montana since 1983.

Outlook

In the past, the damage caused by western pine shoot borer was unknown or ignored because of its inconspicuous nature and the general lack of understanding of the biology and impact of the pest. In the future, we will likely increase even-aged, plantation management of most western pine shoot borer host trees; therefore, the insect will become more important. As awareness grows, more pheromone treatments will likely be done to reduce damage.

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Damage appraisal and management of the western pine shoot borer, *Eucosma sonomana*, in pine plantations in California: a case study

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Abstract

The infestation frequency by western pine shoot borer, *Eucosma sonomana* Kearfott, following the establishment of pine plantations, and the degree of suppression and recovery of these infestations after mating disruption treatments of one growing season and five consecutive seasons, were studied in northeastern California. Treatment consisted of aerial spraying of pheromone (dodecenyl acetate). Height and radial-growth rates of pine trees with different periods of protection from infestation were compared with growth rates of unprotected trees in the same plantation. Shoot borer infestations began when the trees were about 5 years old and 1.3 m tall. Approximately 20% of the terminal shoots were infested when the trees reached age 10, and 60% when trees reached age 20. Trees comprising the tallest 50% of the stand were attacked more frequently than trees in the shorter half of the stand. Reductions in height growth of infested terminal shoots averaged 20% over all study trees and 27% in the taller half of the stand. Treated areas were associated with 66 to 84% fewer terminal shoot infestations. Trees protected for 5 years showed an average height-growth increase of 25.6% per year. Trees receiving one treatment showed an average height growth increase of 19.6% per year over the next 5 years. Timber-stand volumes were simulated for a rotation of 70 years by using the PROGNOSIS growth and yield model. Growth simulations were tested for one application and five applications during stand-age intervals 16-20, 21-25, 26-30, and for an untreated control. On the basis of economic assump-

tions appropriate for market conditions of northeastern California, the treatments had benefit:cost ratios ranging from 7 to 0.5, with a single treatment applied to the youngest stands yielding the most, and multiple treatments to the oldest stands the least benefits.

Résumé

La fréquence d'infestation par le perce-pousse occidental du pin (*Eucosma sonomana* Kearfott), après l'établissement de plantations de pins, et le degré de suppression et de guérison de ces infestations, après les traitements visant à perturber la reproduction de l'insecte au cours d'une saison et de cinq saisons de croissance consécutives, ont été étudiés dans le nord-est de la Californie. Le traitement consistait en une pulvérisation aérienne de phéromone (dodécénylacétate). La hauteur et la vitesse de croissance radiale des pins, à divers espacements de protection contre l'infestation, ont été comparées avec le taux de croissance d'arbres non protégés de la même plantation. Les infestations par le perce-pousse ont commencé lorsque les arbres avaient environ 5 ans et qu'ils mesuraient 1,3 m. À 10 ans, environ 20% des pousses terminales étaient infestées, et 60% à 20 ans, les arbres les plus grands du peuplement ont été attaqués plus souvent que les arbres de l'autre moitié plus petite. La réduction de la hauteur de croissance des pousses terminales infestées était en moyenne de 20% sur tous les arbres de l'étude et de 27% sur les arbres de la moitié la plus grande. Les zones traitées ont connu une réduction de 66 à 84% de l'infestation des pousses terminales. Les arbres protégés pendant 5 ans ont connu une augmentation de la hauteur de croissance de l'ordre de 25,6% par année. Les arbres qui ont reçu un seul traitement ont connu une augmentation de la hauteur de croissance de 19,6% par année au cours des cinq années suivantes. Les volumes exploitables ont été simulés pour une rotation de 70 ans à l'aide du modèle de croissance et de rendement PROGNOSIS. Les simulations de croissance ont été testées respectivement pour une application et cinq applications au cours des intervalles d'âge de peuplement de 16-20, 21-25, 26-30, et pour un peuplement témoin non traité. D'après les hypothèses économiques appropriées aux conditions du marché du nord-est de la Californie, les traitements avaient des rapports rendement/coûts de 7 à 0,5, un seul traitement étant appliqué aux peuplements les plus jeunes à très bon rendement, et des traitements multiples aux peuplements les plus vieux à faible rendement.

Introduction

The western pine-shoot borer, *Eucosma sonomana* Kearfott, is a widespread pest of young pines in western North America. Ponderosa pine, *Pinus ponderosa* Doug. ex Laws., and Jeffrey pine, *P. jeffreyi* Grev. and Balf., are among the recorded hosts in California (Sartwell et al. 1980). Damage results from larval mining in the pith of the terminal and upper-lateral shoots of the trees. Mining of the terminal shoots has been reported to cause vertical growth losses of about 25% (Stoszek 1973; Sower and Shorb 1984). Young ponderosa pine trees become susceptible to

attack by the western pine-shoot borer when they reach 4 feet (1.2 m) in height and are infested with increasing frequency until they are at least 30 feet (9 m) tall. An infested terminal shoot has been observed on a felled 90-foot (27.4-m) tree.

A method of reducing *E. sonomana* infestations based on the use of synthetic sex pheromones to disrupt mating of the moths has been developed (Overhulser et al. 1980; Sower et al. 1982). The approximately 80% population reductions resulting from treatment, together with a slow recovery rate of the insect population (Sower and Overhulser 1986), suggest that substantial increases of ponderosa pine growth rates might be obtained by protection of the trees from frequent infestations by *E. sonomana*.

This paper describes the increase of infestations of tree terminals by *E. sonomana* after the establishment of pine plantations in northeastern California, and the degree of protection of tree terminals resulting from mating-disruption treatments of two durations.

Materials and methods

Height and volume growth rates of trees with different periods of protection from infestations were compared with growth rates of unprotected trees in the same plantation. We used this information to estimate the stand growth and yield consequences at 70 years of applying the two pheromone treatments at several periods in the early part of stand rotation with the PROGNOSIS growth and yield simulation model (Wykoff et al. 1982). Economic analyses determined the benefit/cost ratio of the treatment alternatives for these periods of early stand growth and development.

Study design and treatments

These studies were conducted in the Deer Hollow plantation on the Lassen National Forest in northeastern California. The plantation was established in 1961 following brushfield conversion. By the summer of 1982, the plantation was stocked moderately well and the trees were approaching crown closure. The average basal area of trees ranged from 18 to 35 square feet per acre (4.0 to 8.0 m²/ha), and the average tree height was 24 feet (7.3 m).

In April 1982 the plantation was divided into three treatment areas. Two areas — one of 150 acres (61 ha) and one of 200 acres (81 ha) — were treated with synthetic *E. sonomana* pheromone; the third area comprising 210 acres (85 ha) was left untreated. Four plots were established within each treatment area to monitor the insect infestation. Each plot consisted of 100 trees situated in a rectangular pattern established by starting at a randomly chosen point and tagging every third tree in every other row; broken and multiple top trees were rejected. Each April from 1982 to 1986, the 200 acre area was treated annually (5X) with pheromone (dodecenyl acetate) at the rate of 4 g in 6000 laminated flake releasers per acre. The pheromone flakes were applied by an Ag Cat fixed wing aircraft carrying two Hercon flake

dispensers at a cost of \$10.00 per acre. The 150-acre area was treated only in 1982 and the third area remained untreated.

Data collected at each plot

In September 1986, 25 trees were randomly chosen from the 100 study trees on each plot and felled. Stem analyses conducted on each felled tree included measurements of total tree height and heights to 1977 and 1982 branch whorls, and lengths of each internode from 1977 to 1986. The pith in the cross section of each of these internodes was examined for signs of larval mines. Measurements of stem diameters were taken at the stump and 1.3 m (breast height) levels, and on the 1977, 1982, and 1986 internodes. A subsample of 10 trees out of the 25 felled trees was randomly selected to measure the lengths of all internodes between the 1976 internode and the internode containing the 1.3-m level. The piths in these internodes were also examined for signs of larval mines.

Growth analyses

Data on western pine shoot borer infestations and tree growth from each plot allowed us to compare treatment effects on young pine trees. These data were used in the PROGNOSIS growth and yield model to project treatment effects to stand harvest at 70 years. The PROGNOSIS model has been calibrated for several forest regions in the western United States. The Southern Oregon, Northeast California (SORNEC) version of PROGNOSIS (Johnson et al. 1986) was calibrated for the area encompassing the study site. Because the TOPKILL growth modifier option (Wykoff 1986), explained below, is not fully compatible with the SORNEC version, variables describing tree growth and mortality were adjusted in the Northern Idaho version so that results closely matched those obtained in SORNEC. The "adjusted" Northern Idaho version of PROGNOSIS was used to project treatment effects to stand harvest.

Simulated stands were created by using the Regeneration Establishment Model (Ferguson and Crookston 1984), which creates a regenerated stand without the need for a tree list. Mechanical site preparation, as performed on the actual site, was specified in the model. A stocking density of 220 trees per acre was created after initial mortality. This was the average stocking for the study site.

The effects of infestation by the western pine shoot borer on the height growth of trees were represented by using the TOPKILL growth modifier option (Wykoff 1986). Although the shoot borer does not usually kill tree tops or leaders, this option can approximate the reduction in tree-height growth on a multiyear basis. TOPKILL allows the reduction of stem heights of all or part of a stand. The reductions are represented by a normal distribution with the means and standard deviations being specified. The means and standard deviation of the distribution of the infestation frequencies were calculated for each of the three treatments. These values were

multiplied by the average growth loss per infestation to estimate the TOPKILL mean and standard deviation coefficients.

Our data contained shoot borer infestation, tree-height, and radial-growth information for stands from age 10 to 25 years, with treatment response information for ages 21 to 25 years. To simulate the long-term impact of treatments over a wider age range, two additional treatment response periods were modelled. A 16-year to 20-year period and a 26-year to 30-year period — two periods where treatment response data were not available — bracketed the 21-year to 25-year period for which data were available. We assumed that the percentage of trees infested within the zero, one, and five application treatments would be similar for the three age ranges. We also assumed the amount of height growth loss due to infestations by the shoot borer was the same for the 26-year to 30-year period as for the 21-year to 25-year period.

Economic efficiency analysis

Performing an economic analysis requires estimates of costs and returns for alternatives under consideration. In this study we compared the present net value (PNV) obtained from the zero, one, and five pheromone treatment alternatives for three time periods within the first 30 years of a 70-year rotation. Project cost estimates for nonpheromone treatment items, such as planting, were obtained from local managers and Forest Service staff. Costs of \$225/acre were used individually for site preparation and plantings. A single entry clearcut at age 70 was the silvicultural regime used in the simulations. The project cost estimate for the pheromone treatment was \$10/acre, which was the actual cost of the experimental application. Aircraft costs were a high percentage of the costs of actual applications. In an operational program these high fixed costs could be averaged over many more acres, thus lowering the per acre application costs. We calculated the costs at which the treatments would break even, so that the profitability of treatments using other cost assumptions could be determined.

The analysis performed for stumpage price projection was based on the assumption of both constant and changing prices. A base level assumption of current prices of \$200 per thousand board foot (MBF) and a real price increase of 1% per year were used. Prices in the area of the study site are higher than for some surrounding areas because of local mill demand, good road access, and moderate terrain. A sensitivity analysis was performed to determine the change in projected returns for alternatives with incremental price changes and discount rates.

Results

1. *Eucosma* attacks and tree height

Stem analyses indicate that *Eucosma* infestations in the Deer Hollow plantations began when the trees were 5 years old and approximately 4.5 ft. (1.3 m) tall.

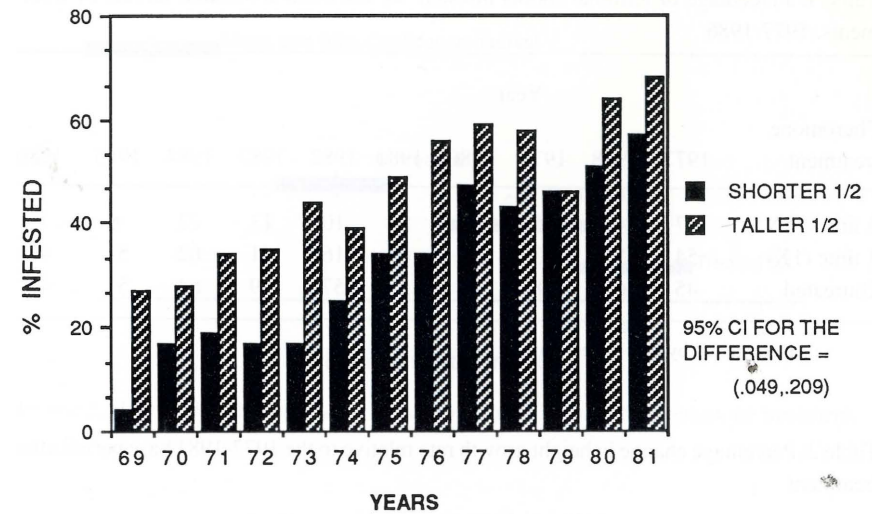


Figure 1. *Eucosma sonomana* attacks in relation to tree size

Approximately 20% of the terminal shoots were infested when the trees reached age 10, and 60% of the terminals were infested when the trees reached age 20, one year (1981) before the treatments were applied.

In the course of examining and measuring the trees we noted the taller trees were more often infested than smaller trees on the same plots. A year-by-year comparison between relative tree height and infestation frequency showed that each year those trees which comprised the tallest 50th percentile of the plantation were attacked more frequently by the insect than trees which made up the shorter half of the plantation (Figure 1). The 95% confidence interval for the differences in attack frequencies did not contain zero, thus indicating that the differences in attack frequencies are real and not due to random error. Consequently our study is consistent with the hypothesis that *Eucosma* selectively attacks the fastest growing trees in the plantation.

2. Treatment effects

Our study areas showed similar infestation histories before treatment (Table 1). Both the 5X and the 1X treatments reduced infestations to the same degree in 1982 (Table 1). Treatment effects on the frequency of infestation, as indicated by the 1X treatment, appear to have lasted 2 years in this study (Table 1). Our observations support those made by Sower and Overhulser (1986) that most benefits of single treatments were realized within two and at most three insect generations; plots treated in successive years continued to have reduced infestation levels.

A comparison of tree growth rate after treatment with its growth 5 years before treatment reveals that trees on the treated areas show a larger increase in height

Table 1. Percentage of terminal shoots infested¹ by *Eucosma sonomana* larvae, by treatments, 1977-1986

Pheromone treatment	Year									
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
5 times (5X)	47	49	45	57	55	10	13	22	8	8
1 time (1X)	54	53	43	48	65	16	41	62	51	43
Untreated	45	61	48	49	57	57	59	64	51	42

¹ Determined by tree dissections.

Table 2. Percentage change in height growth rate relative to the 1977-1981 base period after treatment

Year	Pheromone treatment		
	5X	1X	Untreated
1982	+38	+32	+18
1983	+43	+42	+13
1984	+28	+16	+1
1985	+49	+40	+27
1986	+43	+27	+21

growth than the untreated trees (Table 2). The increase in height growth of the trees treated 5 years ranged from 28 to 49%. The trees receiving one treatment increased height growth 32 and 42% in the 2 years after treatment, while the maximum change in height growth in untreated trees was plus 27% in 1985.

To obtain a detailed measure of height growth response to treatment we calculated a growth index for each sample tree by subtracting the growth during the 1977-81 pretreatment period from the growth in 1982-86 treatment period. The difference divided by the 1977-81 growth provides an index which relates the performance of each tree during the treatment period to its previous growth rate. For example, a tree which grew 4 feet in height from 1977 to 1981 and 5 feet from 1982 to 1986 has an index of 0.250. The volume growth response of the trees was estimated by the same basic calculation producing an index of volume increase of each tree.

A height growth index of 0.174 was calculated for the untreated trees, indicating that their mean height growth rate was higher from 1982 to 1986 than in the 5 previous years. The ANOVA for testing the treatment means was statistically significant (0.05), and the mean untreated height growth index and five-year

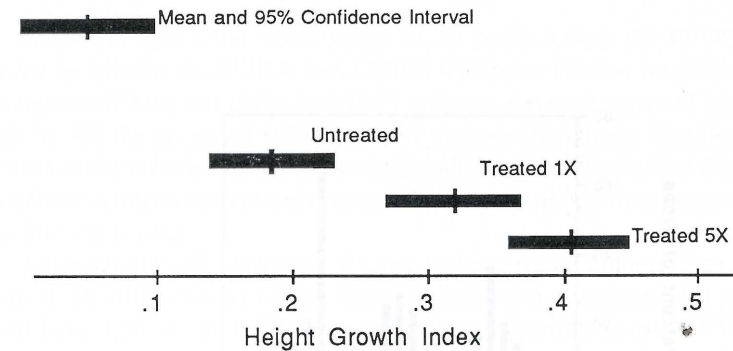


Figure 2. Height growth response to protection from *Eucosma* by pheromone treatment.

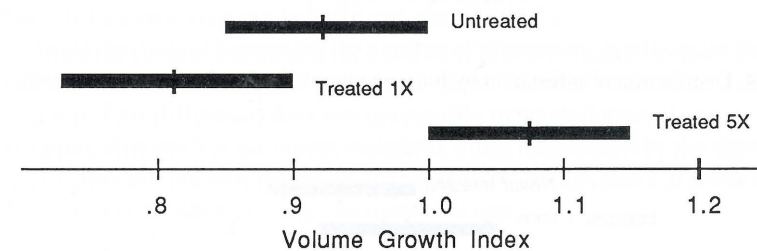


Figure 3. Volume growth response to protection from *Eucosma* by pheromone treatment.

treatment differed significantly (Tukey's test, $P < 0.05$) (Kleinbaum and Kupper 1978) (Figure 2). If these results are thought of as percentages, the trees in the 5X treatment grew at a rate 22.9% faster than untreated trees. The ANOVA for the volume indexes was also statistically significant (0.05); the multiple comparison test showed a significant difference between the 1X treatment and the 5X treatment but not between the control and the 5X treatment (Figure 3). ANOVAS, using number of *E. sonomana* attacks as classes, provided no evidence that radial growth was affected at any location along the tree boles.

The growth response to treatment is a function of the number of uninfested internodes produced on each tree during the study period. The treatments were less than 100% effective (Figure 4). Both the height growth and volume growth indices show logical relationships to infestation frequency. ANOVA was significant (0.05) for both height and volume growth indices (Figures 5 and 6). Trees which were free of infestation or infrequently infested grew faster in both height and volume than those infested more frequently. The uninfested means were significantly different from those infested three and four times using Tukey's LSD procedure. The difference in height growth between uninfested trees and those infested four times is 18.5%. The volume growth difference is 25.1%.

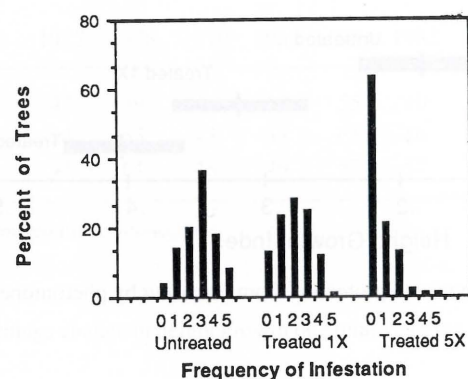


Figure 4. Distribution of infestation by *Eucosma* in relation to pheromone treatment.

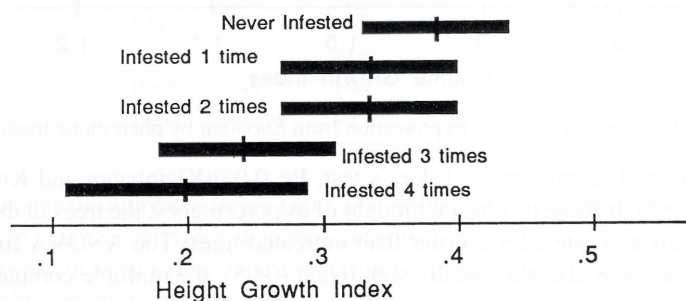


Figure 5. Height growth in relation to frequency of *Eucosma* infestation.

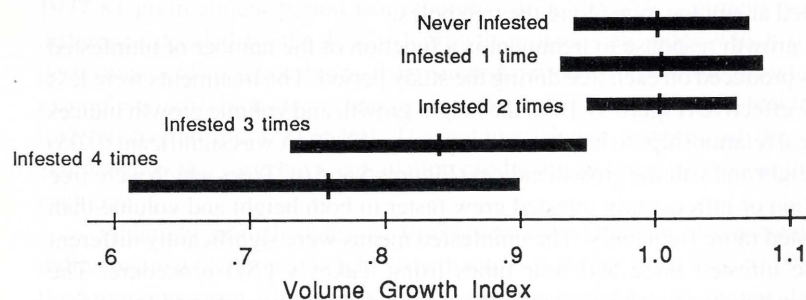


Figure 6. Volume growth in relation to frequency of *Eucosma* infestation.

3. Growth and yield simulations

Treatment effects on stand yields at 70 years. Using the PROGNOSIS software installed at the USDA Fort Collins Computer Center, we projected the thousand board foot and cubic foot (CF) volumes for each series of treatments (Table 3). All the projected volumes of the various pheromone treatments were greater than the volumes for the no treatment alternative. The greatest differences in yield between no treatment and pheromone treatment alternatives occurred in the 16- to 20-year period.

Although the 5X treatment always yields greater volume than the 1X treatment, the difference in volume between these two treatments also varies by period (Table 3). In the 16- to 20-year period, five applications increased CF volume 58% and MBF volume 43% over the single application treatment. For the 21- to 25-year period, five applications increased the CF volume by 213% and MBF volume by 130% over the single year treatment. For the 26- to 30-year period, the relative difference between one and five applications is largest, with a 253% increase in CF volume and a 245% increase in MBF volume (Table 3).

Since the costs of increasing the number of pheromone applications from one to five increase by 400%, the marginal returns decline with each additional application. This difference does not necessarily mean that more than one pheromone application per 5 years is uneconomical. Since infestations by the shoot borer the year following pheromone treatment are still lower than those in control plots, applications every other year may be most efficient.

Table 3. Effects of pheromone treatment alternatives on yields at 70-year rotation

		Age of plantation					
		16-20		21-25		26-30	
Yield	0X	1X	5X ¹	1X	5X	1X	5X
Total cubic feet	7241	7369	7443	7280	7363	7258	7301
Marginal cubic feet ²	—	128	202	39	122	17	60
Total board feet	27484	28804	29404	27718	28024	27577	27805
Marginal board feet ²	—	1320	1920	234	540	93	321

¹ Number of pheromone applications.

² Yield increased by treatment.

The marginal increases in timber volume at harvest are the basis of all the following estimates of economic efficiency. The initial computer analysis was done on a basis of a 1987 timber price of \$200/MBF, a 4% discount rate, and a 1% real price increase. The costs assume no real price changes over time; that is, the costs will change at the same rate as overall inflation (Table 4). Except for the break-even costs of pheromone applications, all the economic results have been discounted back to the time of stand establishment. This results in slight differences in the costs of pheromone treatments among the three time periods; the longer the treatment is delayed, the less the discounted cost. For example, the discounted cost of a single \$10 treatment in the middle of the 16- to 20-year period is \$4.93, for the 26- to 30-year period it is \$3.33. The discounted benefits at the beginning of the rotation are about 6% of the undiscounted returns in 70 years.

The net discounted benefits for all alternatives, including no treatments, varied from a high of \$298.48 for a single treatment in the 16- to 20-year period to a low of \$261.17 for five treatments in the 26- to 30-year period. The marginal discounted benefits, which are calculated by subtracting the present net value of the no treatment alternative from the treatment alternatives, show the benefits or losses attributable to the treatments alone. Since the same value is subtracted from all treatments, the relative rankings do not change. Both treatment alternatives applied in the 16- to 20-year period show substantially greater marginal PNV than any other alternative at the \$200/MBF level. Although the net returns for 1X and 5X treatments are similar, \$29.53 for one application and \$24.66 for five applications, the five application treatment required five times more initial investment. Similar

Table 4. Economic performance (dollars per acre) of pheromone treatment alternatives for 70-year rotation¹

Benefits, costs	0X	Age of plantation					
		16-20		21-25		26-30	
		1X	5X ²	1X	5X	1X	5X
Present benefits	710	745	760	716	724	713	719
Present costs	441	446	466	446	462	445	457
Present net value	269	298	294	270	262	268	261
(benefit-cost)							
Marginal PNV	—	29	25	1	-7	-1	-8
Break even							
application							
cost ³	—	70	20	12	7	7	5

¹ Assumes a \$200/MBF price in year 0 (the year of planting); 1% real price inflation; 4% discount rate

² Number of pheromone applications.

³ Undiscounted cost (cost at time of application) per application.

to the marginal increases in volume, there was a trend of higher value for earlier treatments. Within treatment periods, the increased volume produced by five applications was not enough to offset the increased costs under the specified economic assumptions.

Because the PNV figures represent discounted benefits and costs, it is useful to examine the treatment efficiencies on the basis of the treatment cost at which the marginal returns would equal the marginal costs. Break-even costs were calculated by inflating the marginal PNV by the discount rate to the year or years of application and adding the assumed cost of \$10/application/year. Values for treatments consisting of five applications were divided by five to express break-even costs in terms of cost per application. For the base economic assumptions, these results range from \$70.00 to \$5.00 (Table 4).

Sensitivity analysis. Different assumptions concerning the future value of timber will obviously affect the overall PNV of plantation projects such as these. However, the different future price assumptions can also affect the relative efficiency of the treatments under consideration. To demonstrate and display these effects, we calculated the PNV, marginal PNV, and break-even costs for year zero, with timber prices of \$100, \$200 (the base value), \$300, and \$400 per MBF (Table 5). We assumed a constant 1% real increase in stumpage price over the rotation. Because there are substantial differences between the marginal volumes produced by treating in different periods, the changes in timber prices do not alter the relative efficiency of treating in different periods.

In the base level assumptions, the one application treatment had a higher PNV than the five application treatment of the same period. Because the five application treatment produces higher yields, at some price level, the additional timber volume produced would more than pay for the cost of one or more additional applications. At the \$300/MBF price, this occurs for the treatments in the first period; at the \$400/MBF price, both alternatives in the second period have the same return.

Discussion

Previous studies have shown that infestation by larvae of the western pine shoot borer reduced height growth rates in pine plantations, and that applications of the insect's sex pheromone in the spring effectively disrupt mating by the adults and reduce the number of terminal shoots infested. This study provided data that concur with the results of previous work, and in addition used these data in a growth and yield simulator to model the impact of shoot-borer damage on stand volumes, and calculated the economic efficiency of the pheromone treatments. We identified stand age/treatment time combinations with favorable benefit/cost ratios. In this case, we determined that a single treatment applied to the youngest stands yielded the largest and multiple treatments applied to the oldest stands yielded the smallest benefits.

This study was conducted on fairly small field plots, but we believe greater benefits would be obtained from large-scale projects. Treatments applied by aircraft

Table 5. Sensitivity analysis of economic performance (dollars per acre) of pheromone treatment alternatives

	Age of plantation						
	16-20		21-25		26-30		
Benefits, costs	0X	1X	5X ¹	1X	5X	1X	5X
\$100/MBF, 1% price inflation (same as \$200/MBF, 0% inflation)							
Present net value	-86	-74	-86	-88	-100	-88	-98
Marginal PNV	—	12	0	-2	-13	-2	-12
Break-even application — costs ²	35	10	5	3	4	3	
\$200/MBF, 1% price inflation							
Present net value	269	298	294	270	262	268	261
Marginal PNV	—	30	25	1	-7	-1	-8
Break-even application — costs ²	—	70	20	12	7	7	5
\$300/MBF, 1% price inflation							
Present net value	624	671	673	628	624	624	620
Marginal PNV	—	47	49	4	0	0	-4
Break-even application — costs ²	105	30	20	10	11	8	
\$400/MBF, 1% price inflation (same as \$200/MBF, 2% price inflation)							
Present net value	984	1048	1058	991	991	986	984
Marginal PNV	—	64	74	7	7	1	0
Break-even application — costs ²	140	40	27	7	14	10	

¹ Number of pheromone applications.² Undiscounted costs (cost at time of application) per application.

include high fixed costs which would be averaged over more acres, thereby lowering per acre costs. If large areas were treated, the increased edge to center distance might slow reinvasion and retard insect population recovery, resulting in increased tree growth rates for longer periods after treatment. Results of the type produced here can be useful in guiding the design and scope of future field experiments.

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Site and stand relationships and influences on pine tip moth infestation rates

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Abstract

Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), infestation rates were measured on a site and individual tree basis. Factors influencing tip moths on a site/stand basis included intensity of site preparation, tree age, site index, soil texture at 61 cm, soil texture times the depth of the A horizon, tree height, and maximum rooting depth. Individual tree factors influencing tip moth included percent silt; soil levels of copper, manganese, iron, and phosphorus; foliar levels of phosphorus and magnesium; tree height; number of flushes; and average xylem moisture potential. Pines on sandy sites had the lowest infestations, clayey sites had moderate infestation levels, and loamy sites had the highest in 1985 and 1986 seasons.

Résumé

On a étudié les infestations du perce-rameau du pin (*Rhyacionia frustrana* [Comstock]) en fonction des caractéristiques des stations et des arbres. Les facteurs influant sur les perce-rameaux au niveau des stations ou peuplements comprennent l'intensité de la préparation du terrain, l'âge des arbres, l'indice de station, la texture du sol à 61 cm, le facteur de la texture du sol par la profondeur de l'horizon A, la hauteur des arbres et la profondeur maximale d'enracinement. Les facteurs influant sur les perce-rameaux au niveau des arbres comprennent le pourcentage de limon, la teneur du sol en cuivre, en manganèse, en fer et en phosphore, la concentration foliaire de phosphore et de magnésium, la hauteur de l'arbre, le nombre de cycles d'accroissement (pousses) et le potentiel hydrique moyen du xylème. Les pins poussant sur sols sableux étaient les moins infestés, tandis que ceux qui poussaient en terrains argileux, moyens et loameux étaient les plus touchés en 1985 et 1986.

Introduction

Three common species of *Rhyacionia* tip moths occur in the southeastern United States. These are the Nantucket pine tip moth, *R. frustrana* (Comstock), the

pitch pine tip moth, *R. rigidana* (Fernald), and the subtropical pine tip moth, *R. subtropica* (Miller). In east Texas, Meeker (1987) documented the occurrence of all three species in loblolly pine, *Pinus taeda* L., plantations. In the eastern United States, all species of native and exotic pines are attacked by Nantucket pine tip moth except eastern white pine, *Pinus strobus* L., and longleaf pine, *Pinus palustris* Mill. Slash pine, *Pinus elliotii* Engelm., is highly resistant to attack. Insect attacks on recurrently flushing species have marked results on current shoot elongation, including tip dieback and in intensive attacks, tree mortality. Loblolly pine and shortleaf pine, *Pinus echinata* Mill., are the favored hosts of Nantucket pine tip moth in the southern and southeastern United States (Yates et al. 1981).

Site and stand influences

Habitat characteristics, both site and stand factors, qualitatively and quantitatively influence the amount of tip moth damage. The more suitable the host trees are to the site, generally the less severe the damage (Wakeley 1928; Yates 1960). Shading and natural regeneration of host trees, and increased levels of competing vegetation reduce tip moth incidence (Yates 1960; Miller and Stephen 1983). The rate of tip moth infestation is directly related to degree of intensity of site preparation, with greatest infestations occurring on sites most intensively prepared (Hertel and Benjamin 1977). Open-grown stands have higher infestation rates compared to those grown under some type of cover (Berisford and Kulman 1967; Lewis 1976). Intensive vegetation management results in increased Nantucket pine tip moth infestation rates (Hertel and Benjamin 1977; White et al. 1984; Berisford 1987).

Wakeley (1928) states that host trees grown in dense stands definitely minimize tip moth damage. White et al. (1984) investigated site/stand characteristics and found site preparation intensity (SOSOC), site index (SI), tree age (AGE), tree height (HT), depth of the A horizon times the soil texture code (AHXSO), and soil texture at 61 cm (SO61) as significant factors in classifying plantations as either low or high hazard to tip moth attack (Table 1). He concluded that "those areas best suited for pine growth are most susceptible to NPTM attack" (White 1982). Wilson (1984), in a validation study of the models by White et al. (1984), for Jasper and Newton counties as well as Nacogdoches County, Texas, incorporated depth of soil profile of active soil formation and number of trees per hectare as characteristics significantly affecting grouping of stands into either high or low hazard to Nantucket pine tip moth. Wilson stated that sites suitable for best growth were highly susceptible during periods of high tip moth activity, whereas during low periods of tip moth activity those sites exhibiting low growth potential were most susceptible.

In South Carolina, Hood (1986) also found site preparation intensity, site index, and depth to A horizon as well as soil calcium to be the most significant variables for predicting tip moth incidence. Intensive site preparation, low site index, shallow A horizon, and low soil calcium led to high tip moth infestations

Table 1. Discriminant function equations for site and stand relationships of Nantucket pine tip moth, Nacogdoches County, Texas (from White et al. 1984)

1. $D = +0.79892(\text{SOSOC}) + 0.14840(\text{AGE}) + 0.06347(\text{SI}) - 8.77476$
2. $D = -0.90141(\text{SOSOC}) + 0.09991(\text{SI}) - 0.12681(\text{SO61}) - 0.32188$
3. $D = +0.73617(\text{SOSOC}) + 0.06917(\text{SI}) + 0.00785(\text{AHXSO}) - 8.468$
4. $D = +1.05285(\text{SOSOC}) - 0.08534(\text{HT}) + 0.37319(\text{AGE}) + 0.07665(\text{SI}) - 0.07308(\text{SO61}) - 10.44189$
5. $D = +1.16561(\text{SOSOC}) - 0.07554(\text{HT}) + 0.35610(\text{AGE}) + 0.10082(\text{SI}) - 0.34172(\text{SO61}) - 0.02260(\text{CLDEP}) - 10.07965$

Calculated values ≥ 0 are high-hazard sites for Nantucket pine tip moth (infestation $\geq 8\%$); calculated values less than 0 are low-hazard sites for tip moth (infestation $< 8\%$).

(Hood 1986). Rapid growth of host trees enable them to reach a threshold height sooner, at which point the trees have grown out of susceptibility to tip moth attack (Lashomb and Steinhauer 1974). Infestation rates decrease with increases in height approaching and exceeding a threshold height of about 4.5 m (Berisford 1987).

Fertilizing with nitrogen has resulted in slight reductions in tip moth attack, while application of phosphorus resulted in decreased infestation rates (Pritchett and Smith 1972; Kulhavy and W.G. Ross, unpublished).

Discriminant function analysis

In Texas, discriminant function analysis was used to determine site/stand variables most important in delineating between high and low infestation levels on an individual tree basis on sandy, clayey and loamy sites. Host tree species, age of host trees, and intensity of site preparation, factors significantly affecting the degree of tip moth infestation (White et al. 1984; Wilson 1984; Hood 1986), were similar across the three sites. An 8% whole-tree infestation rate was used to establish high and low infestation groups for the discriminant function analysis (Andersen 1980; White et al. 1984; Wilson 1984).

Analysis of the site/stand variables measured in 1985 indicated the following variables were most important in discriminating between classes on an individual tree basis:

- PSILT - Average percent silt for all depths combined down to 150 cm.
- PT - Foliage content of phosphorus in ppm.
- CUS234 - Average ppm copper in the soil for depths 30, 60, and 120 cm combined.
- MNS234 - Average ppm manganese in the soil for depths 30, 60, and 120 cm combined.

- MGT - Foliage content of magnesium in ppm.
- FES4 - Average ppm iron in the soil at 120 cm.
- FLSHS - Number of flushes occurring during growing season.
- FES3 - Average ppm iron in the soil at 60 cm.
- CUS1 - Average ppm copper in the soil at 15 cm.
- HT - Total tree height at end of the growing season in cm.
- PS1 - Average ppm phosphorus in the soil at 15 cm.

For all 221 sample trees, 67 were misclassified using the equation developed from stepwise discriminant function analysis. Classification was poorest for trees on the clayey site and best on the loamy site.

In 1986, with the incorporation of soil moisture content and xylem moisture potential variables, stepwise discriminant function analysis indicated that the following variables were most important in discriminating between high and low infestation rate on an individual tree basis across all sites:

- CUS234 - Average ppm copper in the soil for 30, 60, and 120 cm depths combined.
- FES2 - Average ppm iron in the soil at 30 cm.
- PSILT - Average percent silt for all depths combined down to 150 cm.
- MGT - Foliage content of magnesium in ppm.
- FES3 - Average ppm iron in the soil at 60 cm.
- XMPA4 - Average xylem moisture potential at 1600 hours in bars.
- XMPA3 - Average xylem moisture potential at 1300 hours in bars.
- XMPA2 - Average xylem moisture potential at 1000 hours in bars.
- PT - Foliage content of phosphorus in ppm.
- ZN2 - Average ppm zinc in the soil at 30 cm.
- PS1 - Average ppm phosphorus in the soil at 15 cm.

For all 219 sample trees, the equation derived misclassified 61 or 28% of the trees. The 1986 equation resulted in a similar percentage of correct classifications of individual trees for each site: 71% for trees on sandy sites, 72% for trees on clayey sites, and 73% for trees on loamy sites.

In 1985, all but PS1, PT, MN234, and CUS1 were negatively correlated with tip moth infestations; in 1986, all but PS1 and PT were negatively correlated with tip moth using Pearson's Correlation Coefficients.

The three soil types examined produced three contrasting systems resulting in three distinctive stands of host type and corresponding levels of pine tip moth infestations. The sandy soil type had the lowest nutrient levels and soil moisture contents due to the highest percentage of sand size particles. These host trees were under the greatest moisture stress of the three sites and exhibited the shortest and thinnest growth. Resulting pine tip moth infestations were low ($< 8\%$) in both years.

The clayey site had the highest nutrient levels and soil moisture contents below 60 cm due to the highest percentage of clay size particles. As a result, host trees exhibited moderate moisture stresses but were the largest in all growth para-

meters sampled for both years. Resulting pine tip moth infestations were moderate (10.84%) in 1985 and low (7.42%) in 1986.

The loamy soil type, with moderate amounts of sand and clay but the highest percentage of silt, had moderate nutrient levels and soil moisture contents below 60 cm. Periodic rains resulted in the highest soil moisture contents during the critical summer months and therefore the lowest tree moisture stresses which produced hosts of moderate height and diameter. Pine tip moth infestation rates were the highest on the loamy site for both years (20% and 12%) but also exhibited the largest decrease between years.

Poor growth of host trees corresponded to low infestation rates. Where host tree tips were easily overcome by attacks, populations remained low because of low desirability of host type, lack of sufficient host type, and mortality due to interactions between site/stand factors and climatic characteristics.

Moderate growth of host trees corresponded to the highest tip moth infestation rates. Moderate growth produced a desirable host, flushing in synchrony with emergence of successive generations of moths, and reduced host resistance.

Vigorous growth of host trees corresponded to moderate and low infestation rates in 1985 and 1986, respectively. A highly desirable host is produced under vigorous growth, but success of attacks is limited. Apparently, extremely rapid growth of host trees to some extent enables them to outgrow pine tip moth attacks or simply recover from successful attacks without suffering the death of a tip. The rapid growth also enables host trees to escape susceptible stages sooner.

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Impact of pine tip moth control, weed control, and fertilizer on growth and form of loblolly pine

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Abstract

Loblolly pines, *Pinus taeda* L., which have been attacked by pine tip moths, *Rhyacionia* spp., are often damaged and may suffer permanent growth or form loss. A study in the Piedmont Plateau of Georgia, USA compared growth and form of loblolly pines which had been treated with different combinations of insecticides for tip moth control, herbicides for weed control, and fertilizer. Trees receiving tip moth control and weed control were significantly taller and had larger diameters than any other combinations after 3 years. Treatments which produced the largest gains included herbaceous vegetation (weed) control followed by tip moth control and fertilizer. Trees in treatments which included tip moth control had significantly better form than those with no control.

Résumé

Les pins taedas (*Pinus taeda* L.) qui ont été ravagés par des perce-rameaux du pin (*Rhyacionia* spp.) subissent souvent des dommages irréparables qui entraînent une perte de croissance et (ou) de forme permanente. Une étude menée sur le plateau Piedmont en Géorgie aux Etats-Unis comparait la croissance et la forme de pins taedas qui avaient été soumis à différentes combinaisons de traitements insecticides (lutte contre le perce-rameau du pin), herbicides et fertilisants. Les arbres soumis aux trois types de traitement étaient beaucoup plus hauts et avaient un diamètre très supérieur à celui des arbres soumis à toute autre combinaison de traitements après 3 ans. Les traitements qui ont été les plus profitables sont la lutte contre la végétation herbacée (mauvaises herbes), suivie de la lutte contre les perce-rameaux du pin et, enfin, la fertilisation. Les arbres faisant partie des traitements comportant des mesures de lutte contre les perce-rameaux avaient une forme très supérieure à celle de ceux qui n'en faisaient pas partie.

Introduction

Pine tip moths, *Rhyacionia* spp., may cause significant damage in the early years of pine plantation establishment in the southern United States. Tip moth larvae destroy growing buds and shoots, causing tree deformation, reduced height growth and occasional tree mortality (Yates 1960). The Nantucket pine tip moth, *R. frustrana* (Comstock), is the most ubiquitous pest of young pines in most of the southern United States. The pitch pine tip moth, *R. rigidana* (Fernald), and the subtropical pine tip moth, *R. subtropica* (Miller), are often sympatric with *R. frustrana*, but they are usually much less abundant (Baer and Berisford 1975, Miller and Wilson 1964). In the South, the favored hosts for both *R. frustrana* and *R. rigidana* are loblolly, *Pinus taeda* (L.), and shortleaf, *P. echinata* (Mill.), pines. Slash pine, *P. elliotii* (Engelm), although occasionally attacked, is quite resistant to both these species. However, slash pine is the preferred host for *R. subtropica* (Powell and Miller 1978). The Nantucket pine tip moth is the only economically important tip moth in the South where it may have two to five generations annually.

The impact of Nantucket pine tip moth attack on tree growth has received considerable attention. Beal (1967) reported that trees in loblolly and shortleaf pine plantations protected from tip moths significantly outgrew attacked trees at some locations during the first 6 years after planting. Ten years after planting on northeast Florida sandhills, unprotected loblolly pines were 2.8 m shorter, about 3.81 cm smaller in d.b.h. and contained only slightly more than one-fourth as much wood as protected pines (Burns 1975). Remeasurement of these same sites at age 16 found that differences between trees in treated and untreated plots, while still present, had decreased considerably (Williston and Barras 1977). Mean tree heights were 13 m for treated loblolly and 11.60 m for untreated checks, and plot volume averaged 150 m³/ha for treated loblolly and 129 m³/ha for untreated trees. In a recent study, loblolly pines protected from tip moth attack for 3 years had ca. 13 m³/ha more volume than unprotected trees at age 12 (Cade and Hedden 1987).

The influence of silvicultural systems on tip moth infestations and resulting stand damage has been widely reported. Wakeley (1928) states that: "There is definite evidence that growing trees in dense stands minimizes the damage." Beal et al. (1952) and Berisford and Kulman (1967) found that loblolly pine plantations had heavier tip moth infestations than stands originating from natural reproduction. Hansbrough (1956) showed that tip moth infestations in loblolly plantations were heavier in those with the widest tree spacings. Several observers have suggested that grasses, forbs, and brush may act as mechanical barriers to tip moths (Graham and Baumhoffer 1927; Beal et al. 1952; Foil et al. 1961; Warren 1963). Hertel and Benjamin (1977), White et al. (1984), and Hood et al. (1988) found that tip moth attacks were positively correlated with intensity of site preparation.

Recent technological developments in pine plantation management have dramatically increased rates of growth. Schmidtling (1984) found cultural treatments as well as genetic differences affected all measures of growth through 22 years in loblolly pine. The effects of fertilization combined with cultivation were

not only significant, but large. Trees receiving cultivation and high rates of fertilization were an average of 7.8 m taller than those receiving no treatment. Heights continued to diverge throughout the experiment (approximate maximum difference between treatments: age 5, 4 m; age 9, 7 m; age 22, 8 m). From these data, Schmidting concluded that early cultivation combined with fertilization was analogous to a long-term change in site quality.

Some preliminary studies have suggested that significant interactions may occur among fertilization, weed control, and tip moth control. For instance, no significant differences were found in height of loblolly pines at age 8 between untreated checks and trees treated with carbofuran to prevent tip moth attacks (J. F. Godbee, unpublished). However, when carbofuran treatments were combined with fertilization, treated trees significantly outgrew those treated with fertilizer alone as well as the checks, suggesting a possible synergistic effect. Terry et al. (1984) reported similar results when trees receiving weed control, tip moth control and a combination of both treatments were compared to trees receiving no treatment.

In the future, intensive forest management will include some degree of vegetation control and, possibly, fertilization on certain sites. Therefore, based on the aforementioned studies, high tip moth populations are likely to occur. We report here the results of a study initiated in 1985 to evaluate the effects of different combinations of vegetation control, tip moth control and fertilization on growth and form of loblolly pine.

Materials and methods

The research site was located in the lower Piedmont Plateau in Washington County, Georgia. The site was planted in January 1985 with improved 1-0 bareroot loblolly pine seedlings following operational site preparation. Four blocks were delineated, containing six treatment plots each with nine rows of 11 planting spaces. The interior 25 trees (five rows x five spaces) were designated as measurement trees. Treatments were randomly assigned to plots and consisted of: (1) untreated checks, (2) herbicide (weed control) and fertilizer, (3) herbicide, fertilizer, and insecticide (tip moth control), (4) insecticide only, (5) herbicide and insecticide and (6) fertilizer and herbicide.

Plots that received herbaceous vegetation (weed) control were treated at planting time with Velpar® (hexazinone) (0.56 kg/ha) and Oust® (sulfometuron methyl) (0.21 kg/ha) applied in a 1.22-m-wide band centered over each row of seedlings. Fertilized plots received 10-10-10 fertilizer at 500 kg/ha. Tip moths were controlled during the first generation of the first year with soil applications of Furadan® (carbofuran). Subsequent control was by foliar applications of Pydrin® (fenvalerate) which were accurately timed by models based on pheromone trap catches and accumulated degree-days (Gargiullo et al. 1983, 1985).

When most larvae of the first and last generations for each year had pupated, the terminal and each shoot in the uppermost whorl of lateral branches were scored as infested or uninfested.

Height growth was determined at the end of each growing season, a.b.h. was measured after the 3rd growing season and form was evaluated at the end of the 3rd growing season by the method of Berisford and Kulman (1966). Four form classes were based on the numbers of forks present per tree as follows: 1- no forks, 2- one fork, 3- two to four forks, and 4- five or more forks. A fork was defined as a node with one or more laterals larger than one half the diameter of the main stem.

Results and discussion

Tree growth was generally in proportion to the intensity of silvicultural treatments received (Table 1). The largest trees (height and diameter) were in weed control and tip moth control plots and the smallest trees were in untreated check plots. Some trees were more than 3.5 m tall after three growing seasons. The largest growth gains relative to untreated checks were due to weed control followed by tip moth control and fertilization.

Although height differences among treatments were substantial, differences in tree form were equally impressive (Table 2). Treatments which included tip moth control had an average form rating of 1.1 which was significantly better than all other treatments which averaged 3.1 or about two to four forks per tree.

It is evident that control of competing vegetation can result in substantial gains in early growth of loblolly pine. Additional growth gains are realized from tip moth control, plus the form is significantly improved. Fertilization provides additional growth and appears to convey some resistance to tip moths probably manifested as poor survival of early instars (D.W. Ross, unpublished). The economic feasibility of these cultural treatments, singly or in combination, cannot be evaluated at this point. However, the gains in additional growth and wood quality seem promising. These research plots will be reevaluated at 5 and 10 years and plans have been made for evaluations at rotation age which is estimated to be 18 to 24 years. Final economic assessments can be made only at that time.

Table 1. Heights and diameters of loblolly pines receiving various combinations of tip moth control (TMC), weed control (herbicides) and fertilizer. Heights were measured after each of three growing seasons and diameters (breast height) were measured after the third season

Treatment	Height			Diameter
	1985	1986	1987	1987
TMC + herbicide	0.62 ^a	1.63 ^a	2.98 ^a	3.10 ^a
TMC + herbicide + fertilizer	0.58 ^a	1.53 ^{a,b}	2.87 ^a	2.79 ^a
TMC + fertilizer	0.60 ^a	1.39 ^b	2.66 ^b	2.39 ^b
TMC	0.48 ^a	1.17 ^c	2.24 ^c	1.62 ^c
Fertilizer + herbicide	0.41 ^a	1.11 ^c	2.13 ^c	1.60 ^c
Check	0.46 ^a	1.04 ^c	1.88 ^d	1.09 ^d

Within columns, values followed by the same letter are not significantly different ($P < 0.05$).

Table 2. Percentage of tip moth infested shoots in the top whorl of loblolly pines 1985-87 and form class. Trees had been treated with various combinations of tip moth control (TMC), weed control (herbicides) and fertilizer

Treatment	Percentage of Shoots Infested			Average Form Class
	1985	1986	1987	
Check	34.73 ^a	76.97 ^a	75.27 ^a	3.2
Fertilizer + herbicide	20.79 ^b	76.93 ^a	60.05 ^a	3.1
TMC + herbicide	4.12 ^c	19.59 ^b	7.84 ^b	1.1
TMC + herbicide + fertilizer	1.13 ^c	7.11 ^c	5.79 ^b	1.1
TMC + fertilizer	1.12 ^c	3.80 ^d	4.06 ^b	1.0
TMC	0.81 ^c	11.05 ^c	5.82 ^b	1.1

Within columns, values followed by the same letter are not significantly different ($P < 0.05$).

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Evidence for tip moth (*Rhyacionia frustrana*) resistance in loblolly pine (*Pinus taeda*)

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Abstract

Field plots were established in five locations in eastern North Carolina (U.S.A.) between 1985 and 1987 to test loblolly pine (*Pinus taeda* L.) for resistance to pine tip moth (*Rhyacionia frustrana*) in 1- to 3-year-old plantations. Twelve families were planted at each location in a randomized block design with each plot split between a protected (insecticide-treated) and an unprotected treatment. Significant differences among families were found in tip moth infestation level for four of the five locations. Family differences were more pronounced for the first insect generation than for the second or third. Family ranks for tip moth infestation were relatively stable across locations and years for test ages 2 and 3 years. High negative correlations were found between annual height increment and first generation tip moth infestation level. Families ranked similarly for annual height growth increment in the protected and unprotected treatments, except for families which appeared to exhibit a high degree of tolerance or intolerance to insect damage. These data provide a basis for developing a model for screening families for tip moth resistance by using response to first generation tip moth infestation levels.

Résumé

Des parcelles ont été établies sur le terrain de 1985 à 1987 dans 5 endroits de l'est de la Caroline du Nord (É.-U.) pour vérifier la résistance du pin taeda (*Pinus taeda* L.) au perce-rameau du pin (*Rhyacionia frustrana*) dans des plantations de 1 à 3 ans. Douze familles ont été plantées dans chaque endroit selon un plan en blocs aléatoires, chaque parcelle étant divisée en deux traitements (protection à l'aide d'insecticide et aucune protection). Des différences significatives du degré d'infestation des différentes familles ont été relevées dans 4 des 5 endroits. Les différences entre les familles étaient plus marquées pour la première génération

d'insectes que pour la deuxième ou la troisième. Le classement des familles selon leur degré d'infestation était relativement stable d'un endroit et d'une année à l'autre, à l'âge de 2 et 3 ans. Des corrélations fortement négatives ont été découvertes entre l'accroissement annuel en hauteur et le degré d'infestation par des perce-pousses du pin de première génération. Le classement des familles selon leur accroissement annuel en hauteur était similaire dans les traitements avec et sans protection, sauf chez les familles ayant un seuil élevé de tolérance ou de vulnérabilité aux dégâts causés par cet insecte. Ces données sont à la base de l'élaboration d'un modèle de sélection de familles résistantes au perce-pousse du pin qui utilise la réaction aux degrés d'infestation par le perce-pousse du pin de première génération.

Introduction

Pine tip moth causes damage to the terminal and lateral buds of young loblolly pine trees, resulting in reduced growth and loss of photosynthetic area (Williston and Barras 1977; Hedden et al. 1981). In coastal North Carolina, the insect has three generations per year and constitutes an economic problem for at least the first 3 years of plantation life. Numerous insecticides have been shown to effectively control tip moth (Brown and Eads 1975; Merkel and Hertel 1976). However, their use has been limited mostly to high value, intensively managed nurseries, seed orchards, Christmas tree plantings, and genetic tests. Chemical control in forest plantations has been precluded by the relatively small economic margins available for reducing damage (Cade and Hedden 1987). However, many industrial forest owners are establishing plantations in large blocks, using seedlings with common genetic identities — most often as half-sib families. If different genetic sources (families) could be shown to possess sufficient variability in their resistance to pine tip moth, resistant families could be allocated to known high hazard sites. In this manner, damage could conceivably be reduced at virtually no cost. This study was designed to determine if differences in infestation levels occur among 12 half-sib families of loblolly pine.

Methods

Field plots were installed in five locations in eastern North Carolina (U.S.A.) in 1985 to 1987 to test loblolly pine for tip moth resistance. All locations had moderate to high organic soils; planting sites were drained, intensively site-prepared by piling and burning the residual slash, and bedded. An aerial application of sulfometuron methyl for herbaceous weed control was applied to all sites in May of the year of planting. Two locations were installed in 1985 (Jones and Beaufort), two in 1986 (Abbott and Jackson), and one in 1987 (Washington). One-year-old nursery seedlings from 12 half-sib families were planted in replicated plots in March. Families included in the study were from genetically improved parents, and were well represented in operational plantings in the area. In 1985 and 1987, the same families were planted at all locations; in 1986, 4 of the 12 families were

replaced by other families due to seedling shortages. The experimental design was randomized block with split plots. At each location, either 36-tree plots with three blocks (1985) or 24-tree plots with four blocks (1986-87) were installed. All trees in a given plot were of the same family identity; each block contained 12 plots, or one plot per family.

Except for the Jones location, plots were split, with one-third of the trees on each plot receiving insecticide treatments to protect them from pine tip moth. At Beaufort, the protected trees received insecticide treatment in the second year (1986) only; in the remaining locations, insecticide treatments were applied in both the first and second years. The first year insecticide treatment consisted of 0.5 g active ingredient (AI) of carbofuran granules applied to each seedling at the time of planting. Second year insecticide applications to the protected trees consisted of one of the following: (1) carbofuran application at a rate of 5 g AI per cm of basal diameter per tree, or (2) foliar applications of fenvalerate timed to coincide with each tip moth generation as recommended by Garguillo et al. (1984).

Tree heights were measured at the beginning of each growing season and the end of each tip moth generation — late June, early August, and October. In addition, the length of each growth flush was recorded. Tip moth damage was recorded at each measurement period in the first growing season by recording the infestation status of the terminal bud only. Thereafter, the number of infested and uninfested buds in the terminal whorl of branches immediately below the terminal bud was also recorded.

All data was summarized on a plot basis. The following variables were used in the analysis: (1) percent terminal buds infested (PTI); (2) percent buds infested in the terminal whorl (PBI); (3) height growth increment for each of the three tip moth generations; and (4) annual height growth increments. Data were analyzed using analysis of variance, linear regression, and rank correlation techniques. Locations and years were analyzed separately, except for family rank correlations.

Results and discussion

Tip moth infestation levels were moderate to high across all locations and years, with a mean first generation infestation level of 58% (Table 1). The minimum and maximum family infestation levels for all locations were 17 and 98 for the first generation, 18 and 72 for the second generation, and 6 and 67 for the third generation (Table 1).

In general, resistance to tip moth was best expressed in the first tip moth generation on second year trees (Table 1). While some of the locations did not show significant differences ($p=0.05$) in the first insect generation, significance was usually greater for the first generation than for subsequent ones (Table 1). The largest percentage of annual height growth also occurred during the first generation cycle (unpublished observation). For these reasons, subsequent analysis of family differences caused by the insect were restricted to first generation infestation data.

Table 1. Analysis of variance F tests for family differences in: (1) percent buds infested in terminal whorl (PBI), or (2) percent terminals infested (PTI) by tip moth generation, and family minimum, maximum, and means for first generation PBI or PTI^a

family minimum, maximum, and means for first generation							
Location	Tree age	Generation			1st gen. PBI or PTI family means		
		1	2	3	Min	Mean	Max
		P Value ^b			Percent		
Beaufort	1	.45	—	.65	36	52	70
	2	.00	.01	.52	33	52	73
	3	.21	.59	.45	54	66	76
Jones	1	.27	—	.18	60	74	83
	3	.47	.71	.77	66	74	85
Jackson	1	.18	.93	.03	39	55	70
	2	.03	.83	.74	32	44	56
Abbott	1	.30	.00	.41	86	92	98
	2	.64	.25	.66	25	35	44
Washington	1	.04	.10	.51	17	33	52

^a All values are for PBI, except for age 1 values which are for PTI.

^b Probability level at which the F statistic for family is greater than the critical F value. Values of P equal to or less than .05 indicate significant differences among families exist for PBI or PTI at the P=.05 level for the respective location, age, and generation. Degrees of freedom for family = 11.

While it was evident that family differences in tip moth infestation occurred, it was necessary to determine if family rankings were consistent across years and sites. Family ranks for PBI were compared between selected pairs of locations and plantation ages using rank correlation techniques (Snedecor and Cochran 1967). Family rank correlations for first generation PBI between the Beaufort location at age 2 and other sites at age 2 or age 3 indicated a positive relationship in all comparisons except for the Abbott site (Table 2). The Abbott location was previously shown to have the poorest F-tests for family differences in PBI (Table 1). On the other hand, family rank correlations for first generation PBI (or PTI for age 1 sites) between data at age 1 and age 2 at the same location were near zero or negative (Table 2). The mean family rank correlation for first generation PBI for the four comparisons between age 2 and age 3 was 0.31, compared to a mean family rank correlation of -0.24 for the three comparisons between age 2 and age 1. These data suggest that first-year family ranks for first generation PBI were generally quite different than family rankings for the same variable for age 2 or age 3 sites. For this reason, first-year results were not included in this analysis.

Table 2. Family rank correlations for percent buds infested in terminal whorl (PBI) between selected pairs of locations and plantation ages

Location 1		Location 2		Rank correlation ^a
Site name	Plantation age (yrs)	Site name	Plantation age (yrs)	
Beaufort	2	Beaufort	3	.69
Beaufort	2	Jones	3	.49
Beaufort	2	Jackson	2	.28
Beaufort	2	Abbott	2	-.23
Beaufort	2	Beaufort	1	-.41
Jackson	2	Jackson	1	-.37
Abbott	2	Abbott	1	.05

^a Snedecor and Cochran (1967) page 193.

There are two possible reasons for the higher variability in newly planted tests: first, transplant shock results in delay of shoot growth, which might make the host less acceptable to the insect; second, tip moth populations often did not develop to high enough levels to cause significant differentiation in first generation PTI.

Family mean correlation coefficients for PBI with growth increment by respective insect generation revealed that there was a strong negative relationship between these variables for the first generation at all five locations (Table 3). The correlation was significant at the .05 level of significance at four of the five locations. Some significant correlations existed for the second and third generations, but they were not as consistent as those for the first generation. In fact, 9 of the 16 second and third generation correlations were positive instead of negative (Table 3).

The importance of the first generation tip moth infestation level was also evident by its relationship to annual growth increment. In the second year at Beaufort, the lowest ranking family for first generation PBI (Family A) had a mean annual growth increment that was 20 cm greater than Family K, the highest ranking family for PBI (Figure 1). For this particular example, 65% of the variation in annual height increment among families was attributable to family differences in PBI in the first generation. While the second-year Beaufort site data were the most significant of all eight combinations of locations and years tested, the relationship between first generation annual height increment and PBI was consistently strong, except for the Abbott location. The average correlation coefficient for these two variables for all eight combinations of locations and years was -0.56. A chi-square test to determine if the individual location-year correlations were from a common population (allowing calculation of an average r-value) revealed that they were ($p=0.81$) (Snedecor and Cochran 1967).

Table 3. Pearson correlation coefficients (CC) and significance levels (P) for relationship between mean family height increment and percent buds infested (PBI) or percent terminals infested (PTI) by tip moth generation^{a,b}

Location age	Tree —1— (yrs)	Generation					
		CC	P	CC	P	CC	P
Beaufort	2	-.82	.00	-.34	.28	-.35	.27
	3	-.49	.10	-.15	.63	.12	.70
Jones	3	-.72	.009	-.31	.32	-.51	.09
Jackson	1	-.58	.05	.56	.06	.35	.26
	2	-.52	.08	-.17	.60	-.62	.02
Abbott	1	-.43	.16	.52	.08	.02	.94
	2	-.34	.28	.07	.83	.51	.09
Washington	1	-.69	.009	.56	.04	.40	.18

^a Age 2 and age 3 values are for PBI; age 1 values are for PTI.

^b CC = Pearson's correlation coefficient; P = significance level.

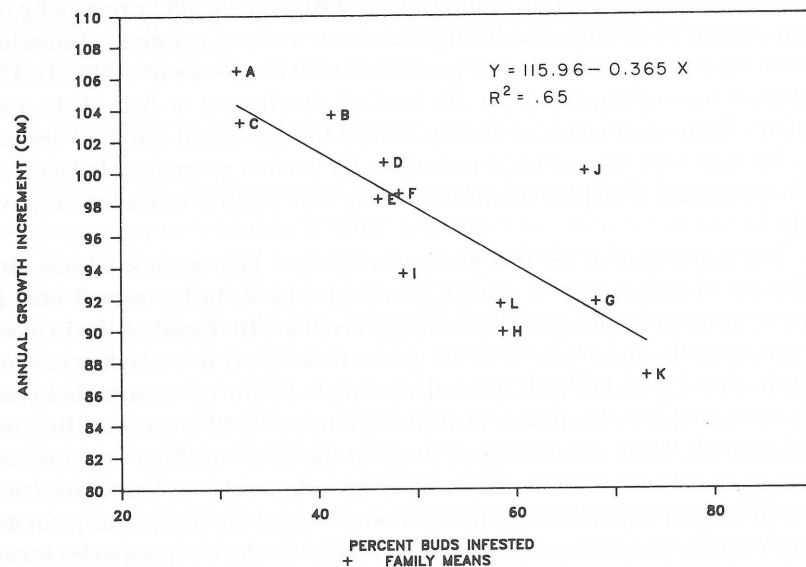


Figure 1. Relationship between annual height increment and percent buds infested (terminal whorl only) by first generation tip moth for twelve 2-year-old loblolly pine half-sib families, Beaufort, North Carolina.

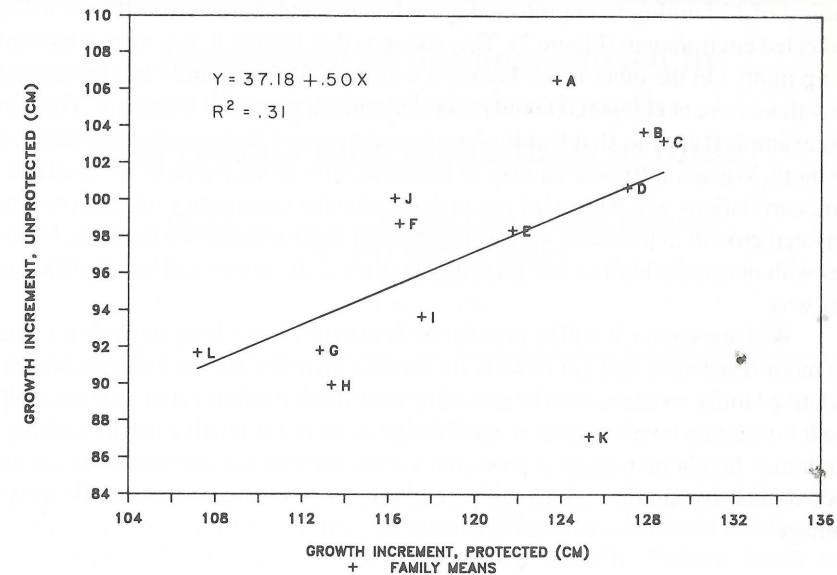


Figure 2. Relationship between annual height increment of 12 half-sib families, unprotected, and the same 2-year-old families protected from pine tip moth with insecticides, Beaufort, North Carolina.

Annual growth increment is so sensitive to first generation tip moth infestation because: (1) a high percentage of the annual growth increment occurs in synchrony with the first generation. For example, at the Beaufort location, 54% of the annual height increment occurred during the first insect generation; and, (2) first generation infestation level is often greater than that for later generations.

Data from the insecticide-treated (protected) portion of the family plots was used to compare growth in the absence of the insect with growth in the unprotected environment. In one example, family rankings for annual growth increment were similar in both the protected and unprotected treatments (Figure 2). However, we have already shown that the more resistant families (those with lower PBI) were also the higher ranking families for unprotected growth increment (Figure 1). This, in turn, means that the faster growing families were less susceptible to tip moth, and therefore exhibited less growth loss due to the insect than did the slower-growing, more susceptible families. Therefore, in an environment with high tip moth population levels, height differences between the faster growing families and the slower growing families will be larger when compared to similar differences in a low tip moth environment. This will cause genetic gain estimates to be upwardly biased.

The growth increment relationship between the protected and unprotected families can also be used to detect families which have large rank changes between the protected and unprotected environments. For example, Family K was the

poorest of 12 families in unprotected growth increment, but was fourth best in the protected environment (Figure 2). This suggests that Family K was very intolerant of tip moth. On the other hand, Family J was the fifth best family in unprotected growth increment compared to only ninth best in the protected treatment. Thus, in this example it appears that Family J possessed a greater-than-average tolerance to tip moth. When a sufficient number of locations with protected plots are available, rank correlations will be carried out to determine the consistency of relationships between growth in protected versus unprotected environments for families. Families with unusually high or low growth tolerance to the insect will be identified in this way.

With these data, it will be possible to develop: (1) screening methods for pine tip moth resistance; and (2) models for ranking families for tip moth resistance. Relative family resistance can be ranked by determining relative first generation tip moth infestation levels in tests at age 2 or age 3; then, the relative family rankings for annual height increment in protected versus unprotected environments can be used to identify families which are particularly tolerant or intolerant to the insect damage.

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Assessment of damage caused by European pine shoot moth in radiata pine plantations in Chile

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Abstract

This paper reports on the annual rate of increase in damage and the volume losses caused by the European pine shoot moth (*Rhyacionia buoliana* Schiff.) in one radiata pine (*Pinus radiata* D. Don.) plantation in Chile. Volume losses were calculated for individual trees and for the entire stand. The number of trees damaged rose from one season to the next by 9%, from 23.3 to 32% of the surveyed trees, although the total number of trees per hectare decreased by 1%. Volume losses increased from 9.0% to 14.7% from one season to the next.

Résumé

Les auteurs étudient l'accroissement annuel des dommages et des pertes en volume causés par le perce-pousse européen du pin (*Rhyacionia buoliana* Schiff.) dans une plantation de pin de Monterey (*Pinus radiata* D. Don.) au Chili. Ils ont calculé les pertes en volume au niveau des arbres et du peuplement entier. Le nombre d'arbres endommagés a augmenté de 9% entre deux années, passant de 23,3 à 32% des arbres examinés; toutefois, le nombre total d'arbres par hectare a diminué de 1%. Les pertes en volume sont passées de 9,0 à 14,7% entre les deux années.

Introduction

Chile currently has 1 242 315 ha of man-made forests (Instituto Forestal 1987). Of these, 1 081 551 ha correspond to radiata pine (*Pinus radiata* D. Don.), representing an estimated volume of 134.2 million m³ of timber. The remaining area is covered primarily by *Eucalyptus* and poplar. Geographically, these plantations stretch from the Metropolitan Region through to Region X, with the greatest concentration in Region VIII.

Since the European pine shoot moth (*Rhyacionia buoliana* Schiff) was first detected in Chile in 1985 (Cerdeña et al. 1985), the National Forestry Corporation has

been interested in conducting an economic assessment of the damage caused by this insect in radiata pine plantations, particularly in light of the fact that in neighboring countries (Argentina and Uruguay) it has become a serious constraining factor for timber and woodpulp output.

Furthermore, the information available indicates that no country where the European pine shoot moth occurs has been able to eradicate it, a fact which undoubtedly underlines the threat this insect poses to the considerable area of radiata pine plantations existing in Chile.

It was on these grounds that in 1987 the National Forestry Corporation undertook a study aimed at determining the annual rate of spread of the damage caused by shoot moth, in a region of the country where it is assumed to have been present from 8 to 9 years.

The objectives of this preliminary study were:

- To assess the annual spread rate of the damage caused by this insect in one radiata pine plantation.
- To determine the loss at the tree level and, subsequently to estimate the volume loss for an entire stand.

It must be pointed out that at this stage there is very little knowledge about this pest in this country and, therefore, the conclusions are based on a series of assumptions regarding its possible behavior in Chile.

Materials and methods

The study consisted of the following stages:

- Sampling determination and data gathering.
- Determination of volume loss at the tree level.
- Volume loss estimation for an entire stand.

Sampling, design and size

The property sampled was a 22.9 ha of 9-year-old pine at the Villa Vieja Forest Farm, located at Rio Bueno Junction, La Unión.

Considering that this pest adopts a negative binomial distribution, i.e., it is contagious aggregative, a systematic transect design was selected. Transects were 100 m apart, oriented in an east-west direction, and at right angles to the pest's main attack front. These transects corresponded to one plantation row and were subdivided into 10-m-long plots.

For the purposes of this study, only apical damage was considered. Lateral-type damage was considered negligible, and with no particular relevance in height or diameter gain. Apical damage was divided into recoverable (crook) and non-recoverable (bushy top, multileader, pruning, and leader kill) (Figure 1).

The plots were measured in order to conform to the pest distribution characteristics, measuring 100% of the damaged plots (with at least one tree damaged) and 20% of the undamaged plots (no trees showing apical damage). Undamaged plots

TYPES OF APICAL DAMAGE

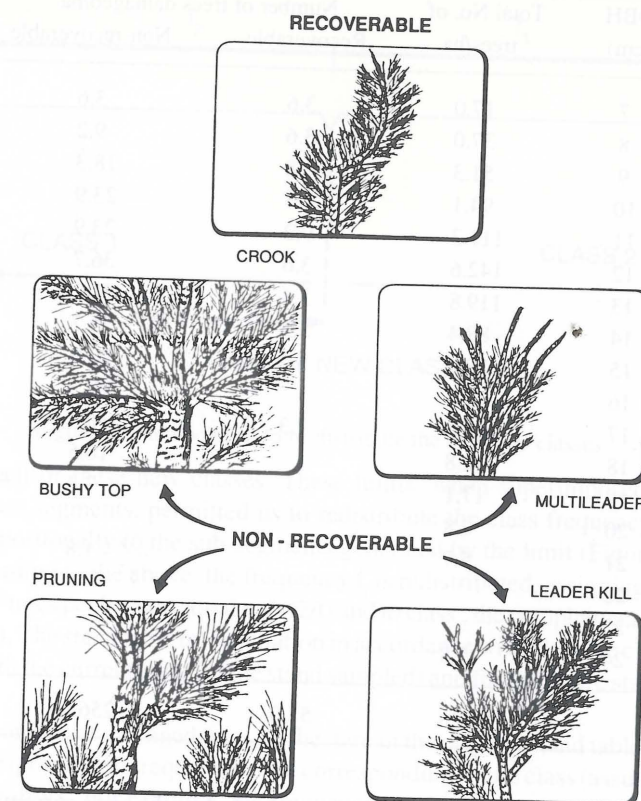


Figure 1. Types of apical damage caused by the European pine shoot moth to radiata pine.

were selected by taking one out of every five undamaged plots. The total number of plots measured was 218, of which 119 were damaged and 99 were undamaged.

Every tree in all plots was measured for diameter (cm) at breast height (DBH) and total height (m). For damaged trees the height at the base of the damage (damage height) and the age of the damage were recorded.

A total stand table was compiled, breaking it down into trees with recoverable and non-recoverable damage. DBH class intervals of 1 cm were used (Table 1). Next, a DBH/damage height function was determined.

Estimation of the stand volume losses at harvest

To calculate the volume loss at harvest it was necessary to estimate the stand

Table 1. Stand table for the Villa Vieja radiata pine stand

DBH (cm)	Total No. of trees/ha	Number of trees damaged/ha	
		Recoverable	Non-recoverable
7	17.0	3.6	3.6
8	37.0	3.6	9.2
9	51.3	1.8	18.3
10	94.1	7.3	23.9
11	111.3	9.2	23.9
12	142.6	3.6	36.7
13	119.8	3.6	31.2
14	88.4	5.5	25.7
15	88.4	5.5	22.0
16	71.3		20.2
17	68.4	7.3	16.5
18	42.8		16.5
19	17.1		7.3
20	2.8		
21	5.7		1.8
22			
23			
24	2.8		
960.8		51.0	256.8

table for the future stand (at 25 years of age), including the trees currently damaged. The estimation of the evolution of a stand in time is an extremely complex process, particularly when the projection period is long. This evolution entails tree growth and involves changes in the number of trees per hectare due to mortality and silvicultural interventions. The problem was therefore approached in a simplified manner by assuming that the future stand table for the stand under study would be similar to that for a 25-year-old plantation in a nearby area with a similar number of trees per hectare.

In order to reduce the number of computations necessary to estimate losses per tree and to simplify the simulation of the future stand, the number of diameter classes was reduced to three, each adopting the following values:

- Lower class: Mid-value for the lower third of the diameter range.
- Middle class: Mid-value for the central portion of the diameter range.
- Higher class: Mid-value for the upper third of the diameter range.

To redistribute the number of trees per hectare among these three classes, limits were established between the three classes, which corresponded to the mid-

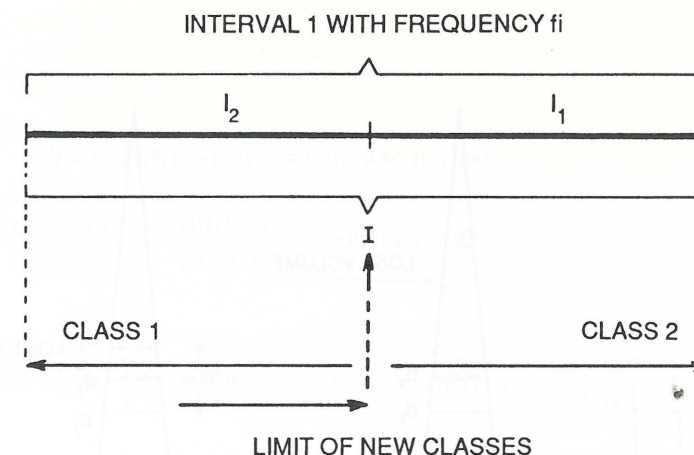


Figure 2. Method used to re-distribute the diameter classes

point of each of these new classes. These limits, when superimposed onto the original class segments, permitted us to redistribute the class frequency of these classes proportionally to the sub-segments generated by the limit (Figure 2).

According to the above, the frequency f_i is redistributed, assigning to class $_1$ a number of trees per hectare equal to $f_i(I_2/I)$ and to class $_2$ the complement, i.e., $f_i(I_1/I)$ (Figure 2). The stand table reformulation in accordance with the three classes was done for both the current table (of the stand sampled) and for the future stand (at age 25).

The number of damaged trees per hectare in the original stand table was kept constant, assigning their frequency to the corresponding future class (assuming zero natural mortality). For example, the frequency for the lowest class in the current stand table is the same as that of the lowest class in the future stand.

In a more detailed study, a conventionally structured stand table, with 2-cm class intervals, should be used. This prevents the distorting effect introduced by large intervals in cases where the interval's mid value is far from the mean square.

Determination of volume loss per tree at harvest time

Loss was estimated in a simplified manner assuming that:

- a. Shoot moth does not reduce diameter growth significantly, i.e. a tree with apical and/or lateral damage will continue to increase in diameter at the same rate as healthy trees.
- b. Volume loss occurs when the leading shoot is damaged, and it will be concentrated in the upper segment, i.e. it will extend from the point where the first apical damage occurred up to the top.
- c. There are both recoverable and non-recoverable damage.

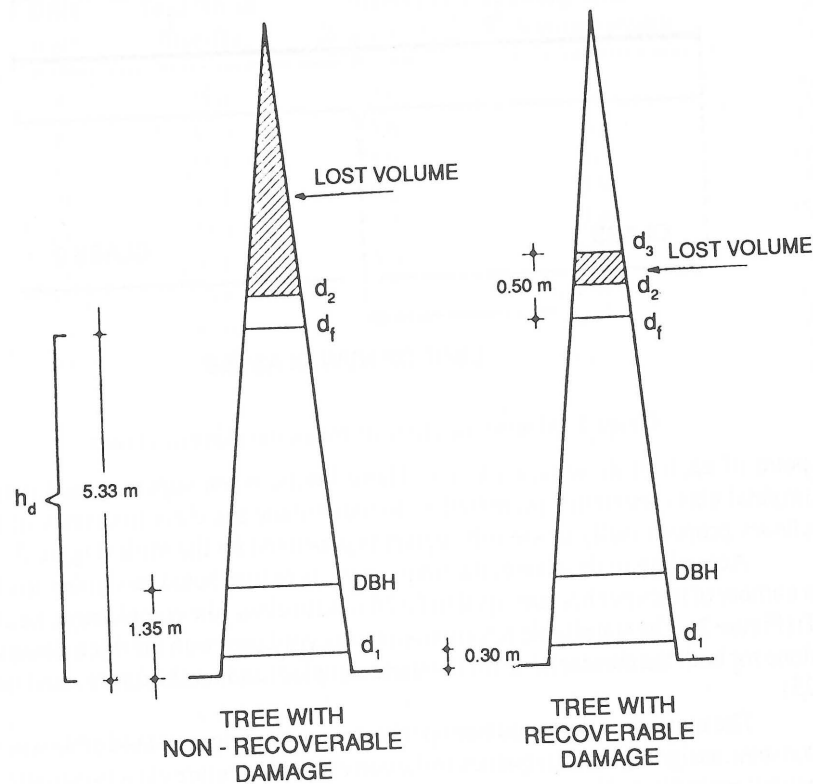


Figure 3. Schematic representation of losses caused by shoot moth

Loss was estimated differently depending on whether damage was recoverable or nonrecoverable. For nonrecoverable damage, loss was estimated by establishing the difference between the volume the tree would have attained if undamaged, obtained from volume tables, and the volume of the undamaged basal segment.

The volume of the undamaged basal segment (V_s) is estimated by the Smalian formula. This needs the diameters at stump height (d_1) and at the height where the apical damage occurred (damage height) (d_2); these were based upon DBH and the Girard form class. This alternative was chosen because no applicable taper function was available. The taper calculated by the Girard form class was projected linearly as a function of the distances between DBH and each of the diameters to be determined (Figure 3).

$df = F \cdot DBH$, where F = Girard form class.

$$\frac{DBH - df}{5.33 - 1.35} = \frac{DBH - d_2}{hd - 1.35} \quad \text{Solving for } d_2$$

$$d_2 = DBH \left| 1 - \frac{hd - 1.35}{5.33 - 1.35} (1-F) \right| = DBH \left| 1 - \frac{hd - 1.35}{3.98} (1-F) \right|$$

$$\text{and also: } \frac{d_1 - DBH}{1.35 - 0.30} = \frac{DBH - df}{5.33 - 1.35}, \text{ and solving for } d_1$$

$$d_1 = DBH \left| 1 + \frac{1.35 - 0.30}{5.33 - 1.35} (1-F) \right| = DBH \left| 1 + \frac{1.05}{3.98} (1-F) \right|$$

The values of F were taken from available tables (Instituto Forestal 1965). The value of hd was estimated using a hd vs. (DBH) curve, determined by the least squares method based on the sampling data and the Hendriksen model.

$$H = a + b \log DBH$$

The volume was computed by Smalian using d_1 , d_2 and length (length = $hd - 0.30$, where 0.30 is the stump height).

$$V_s = (d_1^2 + d_2^2) \pi (hd - 0.30) 8^{-1} \times 10^{-4}$$

and losses with:

$$VP = V_t - V_s, \text{ where } V_t = \text{volume from table.}$$

In the case of recoverable damage, losses were computed by determining the volume of the damaged segment. For this it was necessary to estimate the length of the segment and its extreme diameters. A length of 0.50 m was assumed, and the following formula was used for the diameters (d_2 and d_3 , as indicated in Figure 3):

$$d_2 = \text{DBH} \left| 1 - \frac{hd - 1.35}{5.33 - 1.35} (1 - F) \right| = \text{DBH} \left| 1 - \frac{hd - 1.35}{3.98} (1 - F) \right|$$

$$d_3 = \text{DBH} \left| 1 - \frac{hd + 0.50 - 1.35}{5.33 - 1.35} (1 - F) \right| = \text{DBH} \left| 1 - \frac{h - 0.85}{3.98} (1 - F) \right|$$

The volume loss was estimated by Smalian:

$$V_p = (d_2^2 + d_3^2) \pi 0.50 \times 8^{-1} \times 10^{-6}$$

The formulae for determining volume losses at harvest time, both for trees with recoverable damage and nonrecoverable damage, were applied considering the DBH and form classes which would be attained at harvest time (25 years); for the damage height (hd), the values taken at sampling and adjusted as per Hendriksen model were maintained.

Estimation of Volume Losses for a Stand (volume/ha)

The volume loss for the entire stand was based on the future stand table and on the volume loss per tree computed for the future DBH classes of trees with both recoverable and nonrecoverable damage (Tables 2 and 3).

Results

The analysis of the Villa Vieja stand table shows that, after two years of consecutive sampling the same trees in the same stand, the total number of trees per hectare decreased 1% from one season to the next. The diameter classes at the Villa Vieja stand ranged from 6 to 19 in the 1986 season, while in the 1987 season they ranged from 7 to 24 cm. In the same period, the number of trees damaged increased by 9% from one season to the next (Table 4) and volume losses in percentage varied from 9.0% to 14.7%, a change of 5.7% (Table 5).

Data for this study were taken at a forest farm showing the highest level of damage known to date, which gives a reasonable safety margin to the findings of this

Table 2. Simplified present stand table for the Villa Vieja stand

DBH	Total no. trees/ha	Total height	No. damaged trees		Damage height
			Recoverable	Non-recoverable	
9.0	310.7	6.3	16.0	67.8	5.5
14.0	510.5	8.4	18.9	135.8	6.7
19.0	139.6	9.9	16.1	53.2	7.2
	960.8		51.0	256.8	

Table 3. Simplified future stand table for the Villa Vieja stand

DBH	Total no. trees/ha	Total height	Form class	Damaged trees		Damage height
				Recoverable	non-recoverable	
10.5	310.7	21.0	61.5	16.0	67.8	5.5
30.5	510.5	24.0	76.0	18.9	135.8	6.7
50.5	139.6	27.0	77.0	16.1	53.2	7.2
	960.8			51.0	256.8	

Table 4. Change in the number of radiata pine trees infested by European pine shoot moth in one stand

	1986 season	1987 season
No. of trees/ha	970.5	960.8
Total No. of damaged trees	226.4	307.8
% damaged trees	23.3	32.0

Table 5. Volume loss per hectare at Villa Vieja stand

	Diameter class			Total
	10.5	30.5	50.5	
No. of trees damaged/ha				
Recoverable	16.0	18.9	16.1	51
Non-recoverable	67.8	135.8	53.2	256.8
Total	83.8	154.7	69.3	307.8
Volume lost per tree				
Recoverable m ³	0.002	0.020	0.050	
Non-recoverable m ³	0.055	0.294	0.864	
Volume loss per ha				
Recoverable	0.032	0.378	0.805	1.215
Non-recoverable	3.729	39.925	45.964	89.618
Total	3.761	40.303	46.769	90.833
Volume/ha, undamaged stand				
No. trees/ha	310.7	510.5	139.6	
Volume/tree	0.084	0.652	1.837	
Volume/ha	26.09	332.84	256.45	695.38

$$\% \text{ volume loss per ha} = (90.83 / 695.38) \times 100 = 14.76\%$$

Conclusions and recommendations

The following conclusions may be derived from this study

1. A clear increase in the percentage of volume losses was evident from one season to the next. In the case of Villa Vieja stand it amounted to 5.7%.
2. It is recommended that data collection be continued for at least another five years in order to obtain accurate knowledge on the damage caused by this insect.
3. The methodology in this study is useful to measure variables of this nature.

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Current situation of the European pine shoot moth (*Rhyacionia buoliana* (Schiff.)) Lepidoptera: Tortricidae) in Chile

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Abstract

The presence of the European pine shoot moth (*Rhyacionia buoliana* (Schiff.)) was detected for the first time at the beginning of 1985, affecting about 9000 ha of plantations of radiata pine (*P. radiata* D. Don.) and lodgepole pine (*P. contorta* Dougl.). This paper summarizes a number of programs started by different Chilean organizations in order to deal with this threat. These include a program of biological research to ascertain the basic biology and life cycle of this insect in this new habitat, and programs of surveys, chemical control, biological control, and basic research on the damage caused by this insect.

Résumé

Le perce-pousse européen du pin (*Rhyacionia buoliana* Schiff.) a été décelé pour la première fois au début de 1985; il avait alors attaqué environ 9000 ha de plantations de pins de Monterey (*Pinus radiata* D. Don.) et de pins tordus (*P. contorta* Dougl.). Les auteurs décrivent un certain nombre de programmes mis en place par différentes organisations chiliennes pour contrer la menace posée par le perce-pousse, notamment un programme de recherche biologique visant à établir les caractéristiques biologiques de base et le cycle biologique de cet insecte dans l'habitat chilien ainsi que des programmes d'inspections, de lutte chimique ou biologique et de recherche de base sur les dommages causés par cet insecte.

Introduction.

The forest sector plays an important part in the economy of Chile. This economic sector is based primarily on the cultivation of radiata pine (*Pinus radiata* D. Don.), which currently encompass over a million hectares of plantations. These plantations are distributed continuously between the country's V and Xth Regions (33°00' to 41°28' south latitude) (Figure 1) in a monoculture situation, and as such they are at risk from pests.

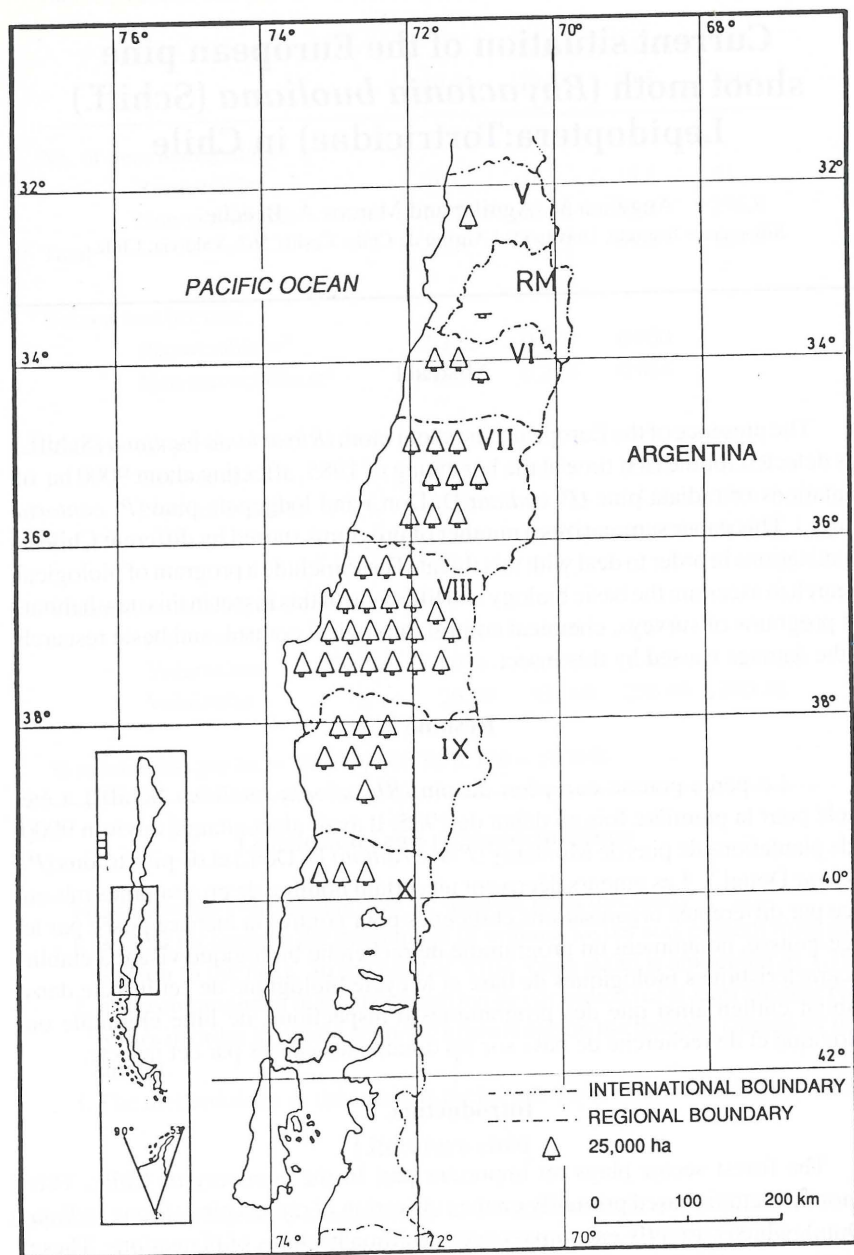


Figure 1. Location of radiata pine plantations in Chile, by region.

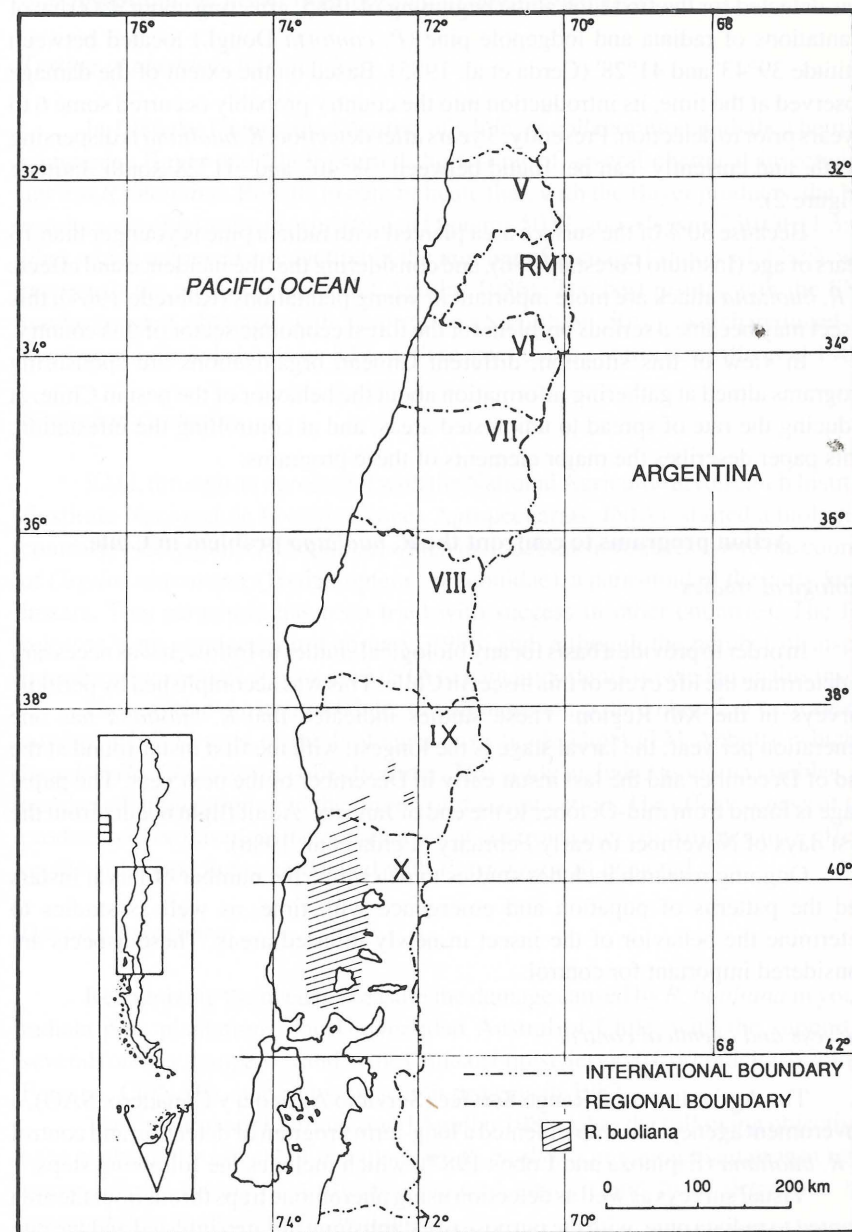


Figure 2. Present distribution of *Rhyacionia buoliana* (Schiff) in Chile.

The presence of the European pine shoot moth (*Rhyacionia buoliana* (Schiff.)) was detected for the first time at the beginning of 1985, affecting about 9000 ha of plantations of radiata and lodgepole pine (*P. contorta* Dougl.) located between latitude 39°43' and 41°28' (Cerde et al. 1985). Based on the extent of the damage observed at the time, its introduction into the country probably occurred some 6 to 8 years prior to detection. Presently, 3 years after detection, *R. buoliana* is dispersing North and currently can be found between 38°40' and 41°28' south latitude (Figure 2).

Because 80% of the surface area planted with radiata pine is younger than 15 years of age (Instituto Forestal 1986), and considering that the incidence and effects of *R. buoliana* attack are more important in young plantations (Robredo 1964), this insect may become a serious problem for the forest economic sector of this country.

In view of this situation, different Chilean organizations are sponsoring programs aimed at gathering information about the behavior of the pest in Chile, at reducing the rate of spread to uninfested areas, and at controlling the infestation. This paper describes the major elements of these programs.

Action programs to confront the *R. buoliana* problem in Chile

Biological studies

In order to provide a basis for any biological studies to follow, it was necessary to determine the life cycle of this insect in Chile. This was accomplished by periodic surveys in the Xth Region. These studies indicated that *R. buoliana* has one generation per year; the larval stage is the longest, with the first instar found at the end of December and the last instar early in December of the next year. The pupal stage is found from mid-October to the end of January. Adult flight occurs from the first days of November to early February (Cerde et al. 1986).

Ongoing research includes studies to determine the number of larval instars and the patterns of pupation and emergence with time, as well as studies to determine the behavior of the insect in newly infested areas. These aspects are considered important for control.

Surveys and chemical control

The Agriculture and Range Service (Servicio Agrícola y Ganadero, SAG), a government agency, has implemented a long-term program of detection and control of *R. buoliana* (Espinoza and Lobos 1987), which includes the following steps:

Visual surveys as well as detection using pheromone traps throughout the area planted to radiata pine, with the purpose of establishing the area infested and the rate of spread.

Localized chemical control with the purpose of retarding the spread of the pest. The pesticides used are Carbaryl and Diflubenzuron, which are applied by ground or air application to newly infested areas.

Quarantine regulations which control the movement of plant material capable of transporting the insect from infested to noninfested areas.

Testing of chemical insecticides

In 1986 the Universidad Austral de Chile, in collaboration with the chemical companies Bayer and Shell, started the testing of several chemical insecticides against *R. buoliana*. Results to date indicate that, with the Bayer products, the best results were obtained with a mixture of Dipterex 50 SL and Alsystin 250 OF (1.5:0.2 l/ha) which achieved a reduction in the number of damaged shoots of 42.2% with respect to the control (Cerde and Aguilar 1986). The best results with the Shell products were obtained with Fenitrothion (Sumithion 50%), which reduced the number of infested shoots by 83% with respect to the control (Carrillo et al 1986).

Biological control

SAG, through an agreement with the National Agricultural Research Institute (Instituto Nacional de Investigaciones Agropecuarias, INIA), started a biological control project against *R. buoliana*, which includes the introduction into the country of *Orgilus obscurator* (Hymenoptera: Braconidae), a parasitoid of the early larval instars. This parasitoid has been tried with success in other countries. The first releases were conducted in February, 1988, and, although the number of insects introduced was small, it permitted INIA to gain important knowledge on this insect.

Universidad Austral de Chile, in collaboration with Abbott Laboratories, is conducting field tests of the biological insecticide Dipel (TM Abbott), which is based on *Bacillus thuringiensis* Berliner. This study included as main variables, the number of applications and the timing of the application. The effectiveness of this product will be based on the percentages of control achieved. Any negative effects on the arthropod fauna associated with *P. radiata* will be noted.

Damage assessment

Recognizing the need to measure the damage caused by *R. buoliana* in young radiata pine plantations, the Universidad Austral de Chile, with the support of several forestry companies and of the Chilean Forest Service (Corporación Nacional Forestal, CONAF), started two research projects in 1987.

The first project (Lanfranco and Aguilar 1988a), has the following objectives: a) to evaluate the effects of the attack by *R. buoliana* in young plantations (1 to 3 years old) by means of artificially induced attacks; and b) to determine tree susceptibility to attack by *R. buoliana*.

The objectives of the second project (Lanfranco and Aguilar 1988b) are: a) to classify and quantify the damage caused by *R. buoliana* under natural conditions, on young plantations of radiata pine; b) to monitor the damage (particularly the apical damage) in individual trees; c) to relate the level of damage to site quality,

stand age, management system, chemical treatment and population level, and; d) to develop methodology for assessing and predicting the damage caused by *R. buoliana*.

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How *Lonchaea corticis* Taylor may impact broods of *Pissodes strobi* (Peck) in *Picea sitchensis* (Bong.) Carr.

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Abstract

Pupae but not prepupal larvae of *Pissodes strobi* (Peck) (Coleoptera: Curculionidae) were consumed by third instar larvae of *Lonchaea corticis* Taylor (Diptera: Lonchaeidae) in a 1-week laboratory test at 9°C. *Picea sitchensis* (Bong.) Carr. leaders attacked by *P. strobi* during a 2-year period were collected at nine locations on or near Vancouver Island, British Columbia, Canada and dissected. Results indicated that predation of *P. strobi* in pupal cells by *L. corticis* began as soon as the pupal cells were constructed in late summer and continued throughout the autumn and winter. Comparing the apparent impact of *L. corticis* in the 2 years, about half the *P. strobi* in pupal cells were consumed in the warmer year and about three-quarters were consumed in the cooler year. In one lightly infested *P. sitchensis* plantation all the attacked leaders were clipped during the spring. Eight leaders were obtained but only one had adult weevil emergence holes resulting from the previous year's attack and this leader had approximately half the *L. corticis* complement of the other seven leaders.

Résumé

Dans un essai en laboratoire effectué à 9°C et ayant duré une semaine, des larves au troisième stade de *Lonchaea corticis* Taylor (Diptera: Lonchaeidae) ont consommé les nymphes de *Pissodes strobi* (Peck) (Coleoptera: Curculionidae) mais pas les larves prénympheales. Des pousses apicales de *Picea sitchensis* (Bong.) Carr. attaquées par *P. strobi* durant une période de deux ans ont été prélevées à neuf endroits dans l'île de Vancouver, en Colombie-Britannique, ou à proximité. Les résultats ont indiqué que la prédation par *L. corticis* de *P. strobi* dans les loges nympheales a commencé dès que ces loges ont été construites à la fin de l'été et qu'elle s'est poursuivie pendant tout l'automne et l'hiver. En comparant les deux années, on a constaté qu'au cours de l'année plus chaude, environ la moitié des nymphes de *P. strobi* ont été dévorées par *L. corticis*, tandis que l'année plus froide, ce sont environ les trois quarts qui ont été consommées. Dans une plantation de *P.*

sitchensis infestée à un degré faible, toutes les pousses apicales attaquées ont été prélevées au cours du printemps. Sur les huit pousses obtenues, seulement une présentait des trous de sortie de charançons adultes résultant d'une attaque l'année précédente; cette pousse abritait à peu près la moitié des nombres de *L. corticis* comptés sur les sept autres pousses.

Introduction

Pissodes strobi (Peck) (Coleoptera: Curculionidae) is the most destructive insect pest of young Sitka spruce, *Picea sitchensis* (Bong.) Carr., in British Columbia, Washington and Oregon (Wright 1970). Larvae mining under the bark of the first internode kill the leader. When the larvae finish mining they excavate a shallow cell in the xylem, pupate, and the resultant adults chew a hole through the bark to emerge from the leader before the onset of winter. The death of the leader results in stem deformities that reduce the timber value of the tree (Silver 1968), in some cases making the tree worthless (Alfaro 1982). Planting of Sitka spruce has thus been curtailed in British Columbia.

Many insects are associated with broods of *P. strobi* in *P. sitchensis* (Alfaro *et al.* 1985). Larvae of *Lonchaea corticis* Taylor (Diptera: Lonchaeidae) are usually the most common associates but the precise nature of the association remains uncertain. *Lonchaea* larvae are variously considered to be coprophagous, entomophagous, myrmecophagous, necrophagous and even ornithophagous (Séguy 1950).

Kishi (1972) reviewed the literature and cited 13 examples where various species of *Lonchaea* were thought to be predators of various scolytids and curculionids found under bark. He questioned the experimental methods used and concluded that predation had not been conclusively demonstrated. Using *L. scutellaris* Rondani as a model, Kishi then failed to demonstrate predation when he confined the feeding dipteran larva in his experimental apparatus with immature stages of various scolytids and curculionids, mainly *P. obscurus* Roelofs. He thus concluded that "*L. scutellaris* has no ability to attack the living weevil larva" and "it is certain the fly is zoonecrophagous."

Alfaro and Borden (1980) concluded that *L. corticis* was an effective predator of *P. strobi* pupae in a laboratory test but was unable to kill healthy larvae. These experiments were conducted at ambient laboratory temperature which would simulate warm afternoon summer conditions of coastal British Columbia. Cooler conditions prevail most of the time. Furthermore, many immature *P. strobi* are unable to complete their development before cool autumn weather arrives and remain lodged in their pupal cells (Silver 1968). The potential therefore exists for *L. corticis* to prey on *P. strobi* during the summer and some of the winter. The objectives of the present work were thus to show in laboratory trials designed to satisfy Kishi's requirements whether *L. corticis* could prey on *P. strobi* in cool temperatures found in coastal British Columbia, and to survey *P. strobi* broods throughout the year for evidence of predation by *L. corticis*.

Materials and methods

The laboratory apparatus used to investigate predation comprised glass vials 13 mm in diameter and 44 mm long stuffed with cotton wool. Either a prepupal larva (a mature larva that had excavated its pupal cell) or young pupa of *P. strobi* was inserted into each vial. Third instar *L. corticis* larvae obtained from leaders collected in late summer were added to some of the vials so that the vials contained either 5, 2 or 0 dipteran larvae. Each test was replicated 10 times requiring 60 vials in total. The vials were stored in a refrigerator for one week at $9^{\circ}\pm 2^{\circ}\text{C}$. The numbers of live and dead insects were then counted.

Sitka spruce plantations about 15 years old located in nine areas of Vancouver Island, part of southwest coastal British Columbia, from Port McNeill (lat. $50^{\circ}35'\text{N}$, long. $127^{\circ}06'\text{W}$) south to Port Renfrew (lat. $48^{\circ}33'\text{N}$, long. $124^{\circ}25'\text{W}$), and at Kingcome Inlet (adjacent mainland, lat. $50^{\circ}53'\text{N}$, long. $126^{\circ}5'\text{W}$) were periodically sampled from 1983 to 1985. Every site was not included in every sample period. Leaders diagnosed as containing weevil brood were clipped to remove the entire brood and the clipped leaders taken to the laboratory for dissection and cataloguing of approximately 40 parameters. The measurements for each tree used here included the number of *L. corticis* larvae, the total number of pupal cells excavated by *P. strobi*, the number of pupal cells containing live *P. strobi*, the number of pupal cells with exit holes chewed by emerging *P. strobi* adults, and the number of empty pupal cells that had neither insect parts other than head capsules nor insect emergence holes and were situated below intact bark. A further group of pupal cells not reported here contained or had contained hymenopteran parasites.

One *P. sitchensis* plantation about 25 km east of Woss (lat. $50^{\circ}10'\text{N}$, long. $126^{\circ}38'\text{W}$) received special attention because the 15-year-old trees had supported only a small population of *P. strobi* for several years. All the attacked leaders were clipped, taken to the laboratory and dissected. Parameters were catalogued as described previously.

Results

The data in Table 1 clearly demonstrate that in cool temperatures *P. strobi* pupae are vulnerable prey for third instar *L. corticis* larvae collected in late summer. Prepupal larvae of *P. strobi* were not attacked by *L. corticis* during the 1-week test. These conclusions complement those of Alfaro and Borden (1980) drawn from experiments run above 20°C .

Data from the leaders periodically collected from 1983 to 1985 are summarized in Table 2. The mean number of *L. corticis* larvae per tree increased from zero in May to four in June. Mean numbers from July onwards were about 25 per tree although two collections averaged near 10. *Pissodes strobi* began constructing pupal cells in July and most construction was finished by September (data not shown). Emergence of *P. strobi* adults began in August and ended early in October. These observations agree with predictions from laboratory data of McMullen (1976).

Table 1. Predation by *Lonchaea corticis* larvae on *Pissodes strobi* for 1 week at 9°C

Number of <i>Lonchaea corticis</i> larvae per replicate	Percentage of <i>Pissodes strobi</i> dead after 1 week*	
	larvae	pupae
0	0	0
2	0	80
5	0	70

*10 replicates for each of the 6 tests.

that by early October the weather would no longer be warm enough to support emergence of adults. In 1983 a larger percentage of *P. strobi* that made pupal cells emerged as adults perhaps because the summer was warmer. For example, at Tofino (lat. 49°05'N, long. 125°46'W) the number of degree-days above 7.2°C, the threshold for any *P. strobi* development (McMullen 1976), was approximately 25% greater than in 1984 (Anon 1983, 1984). A larger percentage of *P. strobi* also remained in pupal cells in the autumn of 1984.

Many pupal cells were found to be virtually devoid of *P. strobi* body parts, apart from larval head capsules, yet had no insect emergence holes (into the pith or through the bark) nor signs of damage from bird predation. Occasionally the pupal cell contained several *L. corticis* larvae consuming *P. strobi* remains. Sometimes the dipteran larvae were found in the pupal cell without any obvious remains of *P. strobi*. We label all these cells as empty pupal cells in Table 2, meaning that the cell contained no live, parasitized, intact dead nor emerged *P. strobi*. By far the most common category of empty pupal cells contained no insects nor insect parts other than larval head capsules. We ascribe the presence of these empty pupal cells to the activity of *L. corticis* larvae whether it be necrophagy or predation. The percentage of pupal cells classified as empty increased throughout the late summer, autumn, winter, and following spring (the high percentage shown for July 1983 is based on only 6 pupal cells since construction by *P. strobi* was just beginning). About half the empty pupal cells were generated during late autumn and winter. The marked increase in the percentage of empty pupal cells in 1984 compared with 1983 may again be due to the cooler summer of 1984 lengthening the period that *P. strobi* remained in pupal cells and increasing their susceptibility to activity by *L. corticis*. The laboratory test reported earlier indicates that *L. corticis* may be predacious in cool temperatures. Thus, the results in Table 2 suggest that in 1983 the contents of approximately half the pupal cells were removed by *L. corticis* during the late summer, autumn and winter, whereas in the cooler year of 1984 when *P. strobi*

Table 2. Temporal data collected during 2 years on *Picea sitchensis* leaders attacked by *Pissodes strobi*

Collection Month	Number of leaders	Percentage of <i>Pissodes strobi</i> pupal cells showing			Mean leader number of <i>Lonchaea</i> <i>corticis</i>
		<i>P. strobi</i> exit holes	<i>P. strobi</i> occupant	Empty	
1983 weevil attack					
May	10	-*	-	-	0
June	9	-	-	-	4
July	23	0	67	33	31
August	49	5	50	20	23
September	40	20	40	25	10
February	54	30	8	54	8
April	20	30	7	57	35
1984 weevil attack					
August	16	4	50	32	19
October	103	9	43	37	23
May	9	9	6	76	26
June	95	7	6	82	27

*no pupal cells constructed

development would be retarded during the summer, the contents of approximately three-quarters of the pupal cells were removed by *L. corticis*. In both years about half the empty pupal cells were generated after the temperature dropped below the threshold for emergence of *P. strobi* adults.

Data from a *P. sitchensis* plantation east of Woss, where tree morphology indicated that a small population of *P. strobi* had not expanded for several years, showed that of the total of eight leaders attacked, only one had *P. strobi* emergence holes by the following spring. In the seven leaders without emergence holes the *P. strobi* brood had failed: approximately 90% of the pupal cells were empty, and most of the remainder contained either dead *P. strobi* or showed evidence of parasitic Hymenoptera. The number of *L. corticis* found in each leader exceeded one per *P. strobi* pupal cell. In the eighth leader, which had six emergence holes, only 0.6 *L. corticis* were found per pupal cell. These limited data suggest that predation by *L. corticis* may have been largely responsible for regulating the *P. strobi* population in this plantation in the year we collected the attacked leaders.

Acknowledgment

We thank Al Dawson for invaluable technical help.

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Effect of red alder overstory on the occurrence of *Pissodes strobi* (Peck) during the establishment of a Sitka spruce plot

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Abstract

Two planting stocks, 2+1 and 1/0 Sitka spruce, *Picea sitchensis* (Bong.) Carr., seedlings, were planted in 1980 under a red alder, *Alnus rubra* Bong., canopy and in an adjacent cleared area, at the University of British Columbia Malcolm Knapp Research Forest in Maple Ridge, British Columbia, Canada. This is a report on the growth of these trees and the incidence of spruce weevil, *Pissodes strobi* Peck, attack on them throughout the first 8 years. The overstory shade hypothesis is evaluated and a side shading regime proposed.

Résumé

Des semis d'épinette de Sitka (*Picea sitchensis* [Bong.] Carr.) de 2+1 et de 1/0 ont été plantés en 1980 sous le couvert d'aulnes rouges (*Alnus rubra* Bong.) et dans un terrain déboisé adjacent de la forêt expérimentale Malcolm Knapp de l'UBC à Maple Ridge (Colombie-Britannique) Canada. Le présent rapport fait état du déroulement de la croissance de ces arbres et des répercussions des ravages causés par le charançon du pin blanc (*Pissodes strobi* Peck) pendant les huit premières années. L'hypothèse de l'effet d'ombrage de l'étage dominant est évalué et un régime d'ombrage latéral est proposé.

Introduction

The transcontinental species *Pissodes strobi* (Peck), the white pine weevil, inflicts serious damage on its host trees by feeding and ovipositing on the previous year's leaders. If sufficient eggs are laid so that a feeding ring of larvae becomes established, the new terminal growth withers and the previous year's height growth is also lost. In extreme cases, damage may also occur to the 2-year-old growth as

well. The lateral branches respond to the lack of terminal bud dominance by turning up and competing for dominance. If one should succeed then a crook forms where the lateral joins the main stem. In older trees, two laterals may compete equally and a fork is formed. These growth responses result in lower quality stem form and the dead leaders also act as an infection court for fungi.

In western North America, the white pine weevil attacks many species of spruces, *Picea* spp. The recognized common name results from synonymy studies by Smith and Sugden (1969) where they demonstrated by karyotype studies that two other species collected on spruces, *Pissodes sitchensis* Hopkins collected from Sitka spruce, *Picea sitchensis* (Bong.) Carr., and the Engelmann spruce weevil, *Pissodes engelmannii* Hopkins, from Engelmann spruce, *Picea engelmannii* Parry, were the same species. To prevent confusion in this presentation, I will describe the weevil feeding on spruces as the spruce weevil.

The impact of the spruce weevil in British Columbia is very serious. Sitka spruce planting in the Vancouver Region has been severely curtailed and even in the low-hazard fog belt on western Vancouver Island (McMullen 1976a) Sitka spruce may be a maximum of 20% of the seedlings planted (Carlson et al. 1984). The increasing incidence of spruce weevil in young white spruce, *Picea glauca* (Moench) Voss, stands in the interior of British Columbia is of concern where large areas are being regenerated after extensive bark beetle salvage programs of the last decade. Intensive silvicultural practices, including conifer release programs, have resulted in pure open-grown spruce stands which become highly susceptible to spruce weevil attack.

Several authors have supported the concept of growing *P. strobi* hosts under an overstory. Graham (1918) noted that eastern white pine, *Pinus strobus* L., growing at high densities or growing in the shade, were less attacked by the white pine weevil than similar-aged trees growing in full sunlight. Graham (1926) recommended silvicultural systems that provided shade for the young pines. Several studies have sought to define the role of shade and its effect on temperature and humidity as they affect the white pine weevil (Sullivan 1959, 1960, 1961) and the spruce weevil (McMullen 1976b). The reduced vigor of the white pine seedlings and the effects of competing understorey vegetation have been described by Logan (1962) and Steill and Berry (1985). Overstory effects have been linked to reduced overwintering success of the weevil (Harman and Kulman 1969), insufficient heat accumulation to complete brood development (McMullen 1976b), reduced temperatures resulting in less aggregated feeding (Sullivan 1961), and confusion of leader silhouette response (VanderSar and Borden 1975) by stems of the overstory species.

The objective of this experiment was to compare the height and diameter growth of the Sitka spruce growing under a red alder overstory with an adjacent plantation of the same stocks growing in an open site and to record the impact of the spruce weevil under these two regimes.

Methods

In the spring of 1980, a 0.14-ha area of 3-year-old natural red alder regeneration was marked out on Road G at the University of British Columbia Malcolm Knapp Research Forest, Maple Ridge, British Columbia. Half the site was completely cleared (the *open* regime) and the other half was strip cleared to leave rows of young alder in north-south running rows (the *under* regime). Two stock types were planted out in each regime: 1/0 plugs (S10) and 2+1 transplants (S21). The planting was carried out at standard 2 m x 2 m spacing. A total of 341 seedlings were planted. Trees were enumerated within rows with plastic tags on stakes beside the trees and in 1987 these were replaced with metal tags attached to a branch at breast height on each tree.

The overstory was thinned in 1984 to 3-m spacing and brashed to a height of 3 m. The site has been hand weeded and cleaned each summer. The major competing ground species in the open regime have been bracken fern, *Pteridium aquilinum* (L.) Kuhn, trailing blackberry, *Rubus ursinus* Cham and Schlecht, assorted grass species, thistle, *Cirsium* spp., hardback, *Spirea douglasii* Hook, and pearl everlasting, *Anaphalis margaritacea* (L.). In the *under* regime the main competing species have been trailing thimbleberry, *Rubus parviflorus*, Nutt., salmonberry, *Rubus spectabilis* Pursh, bracken fern, and elderberry, *Sambucus racemosa* Michx.

Height and leader length measurements have been made each year. Root collar diameters were measured in 1984, 1986, and 1987. Careful note was taken of which trees were attacked. All infested leaders were collected in January 1988 and dissected to determine the numbers of weevils which emerged successfully, the numbers of chip cocoons, parasites, and predatory *Lonchaea corticis* Taylor larvae.

Results and discussion

The S10 stock was about 27 cm tall at the time of planting while the S21 stock was 66 to 70 cm tall. This height differential has been sustained throughout the first eight growing seasons (Figure 1). The S21 stock is maintaining similar height growth under the red alder and in the open although the high density of weevil attack has depressed the growth of the S21 open stock. The trees damaged in 1987 averaged 2.43 m in height, not significantly different from the unattacked trees which averaged 2.32 m. In 1986, the trees that were damaged were significantly taller, at 2.33 m, than the unattacked trees, at 2.09 m (t-test, $P < 0.05$). The S10 stock in the open received its first heavy infestation by *P. strobi* in 1987 and the attacked trees were significantly taller, 2.16 m, than the unattacked trees, 1.59 m (t-test $P < 0.001$).

While the S21 stock growing under the red alder was able to maintain comparable height growth with the S21 in the open, the S10 stock planted under the red alder has been growing at a significantly slower rate than the S10 stock growing in the open (Figure 1). By 1984, both stocks growing in the open had significantly greater root collar diameters than the same stock growing under the red alder

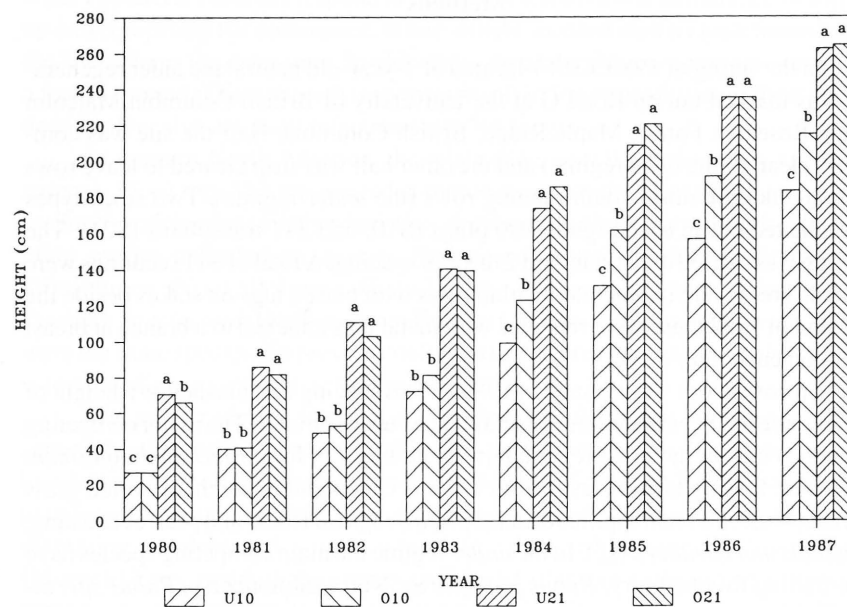


Figure 1. Heights of the S10 and S21 stock planted under the red alder overstory (U10, U21) and in an adjacent open area (O10, O21) on Road G at the University of British Columbia Research Forest in Maple Ridge. Letters on top of bars indicate significant differences in height within years, Scheffe's test, $P < 0.05$.

overstory (Scheffe's test $P < 0.05$) (Figure 2). By 1987, after eight seasons of growth, the S10 stock growing in the open had an average root collar diameter similar to that of the S21 stock growing under the red alder (Figure 2). Thus, while height growth might not be affected so much by the overstory, radial growth is certainly suppressed.

The first spruce weevil-infested leader was recorded on an S21 tree in the open regime in 1982. The following year, five trees were attacked in the same stock and one of the S21 stock growing under the red alder was attacked. The 1984 attack frequencies were similar to those of 1983 (Table 1). In 1985, as the S21 stock in the open regime was about 2 m in height (Figure 1) the incidence of damage increased to 14 of the 88 trees (16%) and in the two succeeding years it was 44%. As the S10 stock in the open regime approached 2 m in height, the spruce weevil successfully attacked seven trees and in 1987 the high weevil population resulted in 49 of the trees (55%) being successfully attacked. Twenty-three of the S21 trees growing in the open have been attacked for a second time. The spatial development of these attacks is shown in Figure 3. In 1987, 22 of 81 trees (27%) of the S21 stock growing under the red alder were also attacked (Table 1).

Successful weevil attacks have been recorded on the tallest trees (Figure 4).

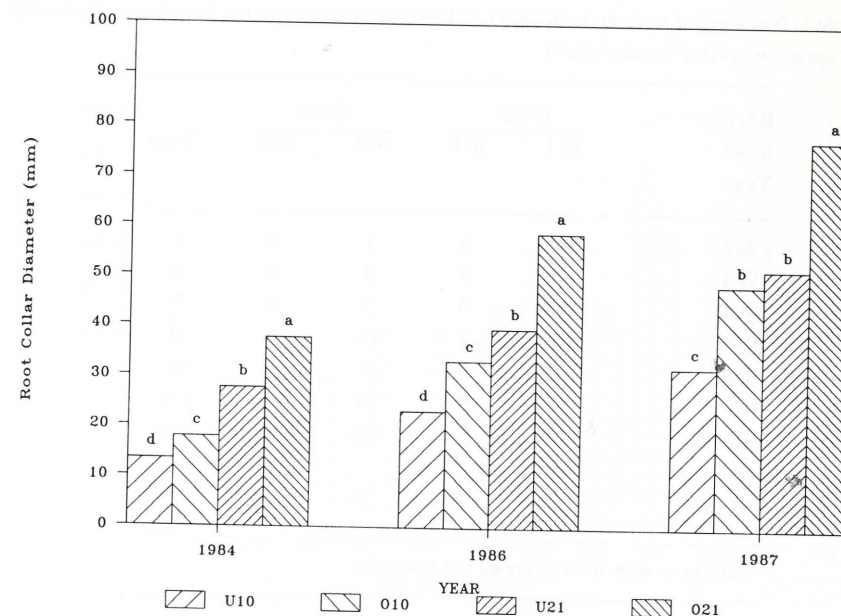


Figure 2. Root collar diameters of the S10 and S21 stock planted under a red alder overstory (U10, U21) and in an adjacent open area (O10, O21) on Road G at the University of British Columbia Research Forest in Maple Ridge. Letters on top of bars indicate significant differences in root collar diameters within years, Scheffe's test $P < 0.05$.

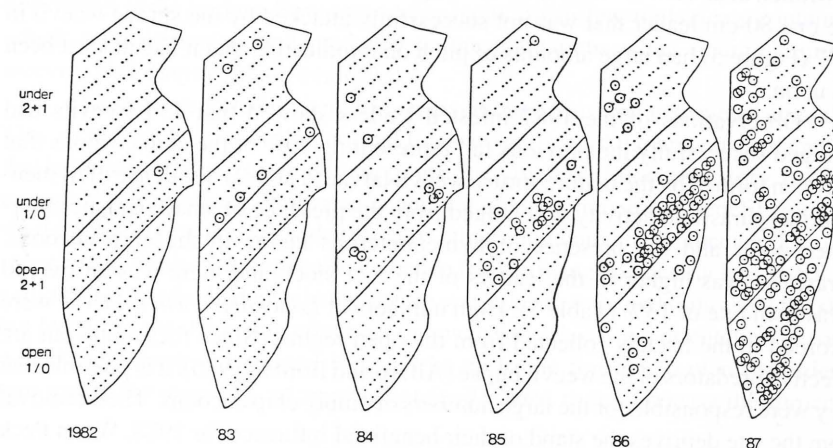


Figure 3. Spatial distribution of spruce trees in the G Road plantation at the University of British Columbia Research Forest showing the trees successfully attacked by *Pissodes strobi* 1982-1987.

Table 1. Numbers of trees in the Road G Sitka spruce plantation that have been attacked by the spruce weevil, *Pissodes strobi*

Regime Stock Year	Under		Open		Total
	S21	S10	S21	S10	
1982	0	0	1	0	1
1983	1	0	5	0	6
1984	2	0	5	0	7
1985	0	1	14	0	15
1986	7	2	38	7	54
1987	22	9	39	49	119
Total	32	12	102	56	202
More than one attack	1 ^a	1 ^a	23	0	25

^a Attacks on edge trees receiving full insolation.

However, what is more striking is that in 1987 the attacks were spread over many height classes: 1.0-m and 1.3-m trees recorded rates between 0.28 and 0.30 (Figure 4). The longest leaders were also attacked in 1986 and 1987 but again there is a wide distribution of attacks across leader length classes, especially in 1987 (Figure 5). The 1987 data were very similar to the attack probability function used by McMullen et al. (1987) which was developed from data gathered by Silver (1968). The one 80-cm leader that was not successfully attacked by the spruce weevil in 1987 (Figure 5) had large amounts of pitch on it indicating that it had at least been fed upon.

Observations of the 1987 infested leaders showed that 434 weevils had emerged successfully the previous fall representing 26% of the chip cocoons that had been formed by the mature spruce weevil larvae (Table 2). Evidence of hymenopterous parasitoid activity was judged from the presence of small parasite emergence holes and the presence of hymenopterous larvae in the chip cocoons. Parasitism was higher in the leaders of the S21 stock and there was an overall parasitism rate of 13% (Table 2). High numbers of *Lonchaea corticis* larvae were recorded in the leaders collected from the open regime. Since these dipteran are effective predators of the weevil pupae (Alfaro and Borden 1980), it is possible that they were responsible for the large numbers of empty chip cocoons. Their removal from the site deprives the stand of their beneficial influence for 1988. When Peck first described the white pine weevil in 1817, he suggested that infested leaders should be "committed to the fire" (Wallace and Sullivan 1985) and leader clipping and burning have been widely applied in British Columbia. It is clear from this dissection record that removal of leaders also removes the beneficial insects which

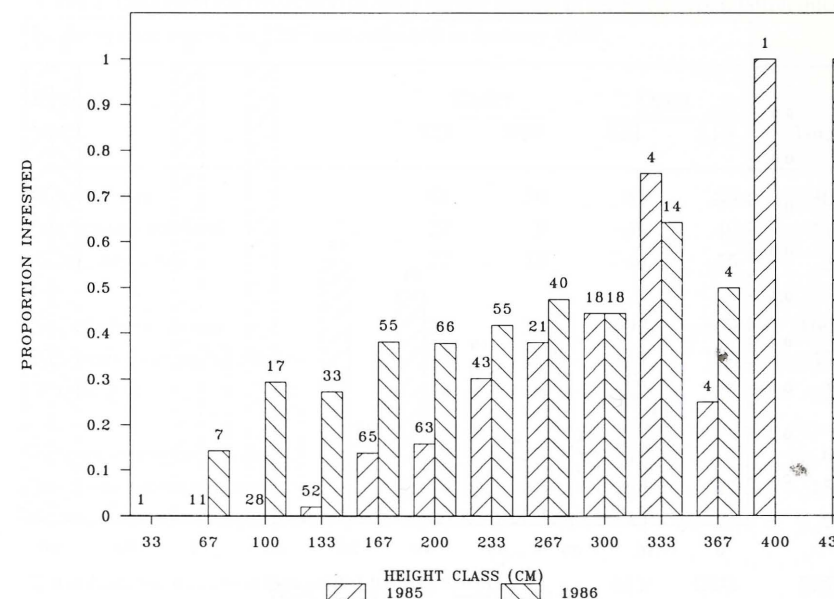


Figure 4. Proportions of spruce trees in the Road G plantation at the University of British Columbia Research Forest successfully attacked by the spruce weevil in 1986 and 1987. All heights were measured in September of the year previous to attack. Trees grouped by height classes and the numbers appearing over the bars represent the numbers of trees in that height class.

overwinter in the leaders. New approaches including differential release containers which return parasites and predators to the plantations while retaining spruce weevils are currently being evaluated.

The stand reported on here has received hand brushing treatments annually. This would not be practical in normal forestry, nor would the brushing treatments that have been applied to reduce whipping effects of the red alder overstory. In order to meet these practical requirements and yet obtain a maximum benefit from the shading effects of the red alder, or any other candidate shade species, I would recommend a side-shading regime where a fast-growing species such as red alder could provide side shade while the spruce was open to reflected light from the sky, but free from the damaging effects of the overstory. East-west orientation of rows would meet these criteria and it would be up to the forester to plan for orderly removal of the overstory, at approximately 40 years, to fully release the spruce.

Acknowledgements

I thank P. Sanders and E. Jeklin for encouraging this research on the University of British Columbia Research Forest and for helping set up the original

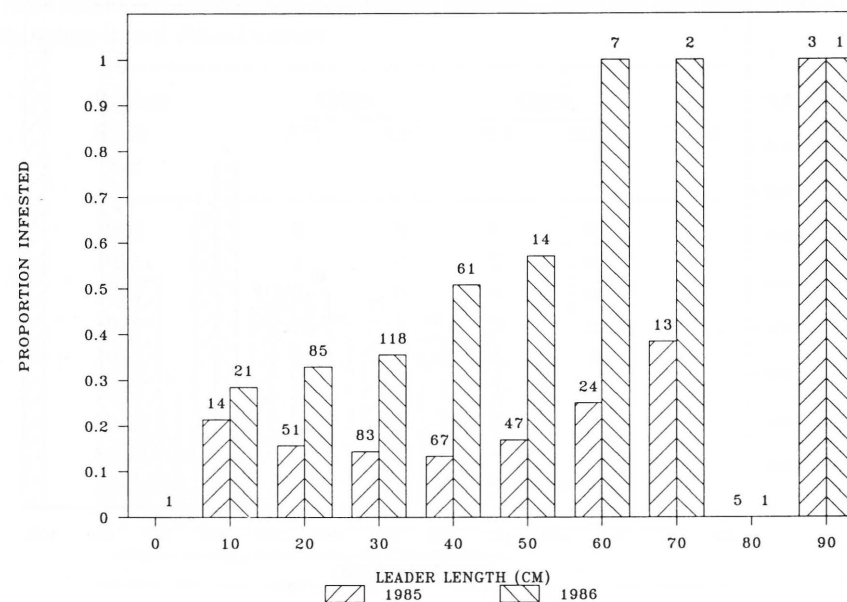


Figure 5. Proportions of leaders attacked by the spruce weevil in the G Road plantation at the University of British Columbia Research Forest in 1986 and 1987. Leaders are grouped by 10-cm length classes. Numbers appearing over each bar indicate the total number of leaders in this length class.

plantation; G. Sommers, G. Hamma, N. Kunzli and M. Baptie for measuring this stand as part of the data collecting phase for their graduating essays; the fourth year forest entomology class of 1988 who helped with the leader collection and dissection; and L. Friskie for helping keep the plantation in order and for maintaining the data set.

Table 2. Data from the dissection of Sitka spruce leaders in the Road G plantation infested by the spruce weevil in 1987 and collected in January 1987

Regime Stock	Under		Open		Total
	S21	S10	S21	S10	
No. of Trees	81	50	88	89	308
No. leaders infested	22	9	39	49	119
% infested 1987	27	18	44	55	39
No. of chip cocoons	276	59	692	669	1696
No. weevil emergence holes	95	10	149	180	434
% emerged	34	17	22	27	26
Parasite emergence holes	17	2	45	4	68
No. hymenopterous larvae	17	2	95	42	156
% chip cocoons with parasites	12	7	20	7	13
Total <i>Lonchaea corticis</i> larvae	221	93	641	1003	1958
No. larvae/leader	10.0	10.3	16.4	20.5	16.5
Range (/leader)	0-44	7-28	0-130	0-87	0-130

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Stem defects in Sitka spruce induced by Sitka spruce weevil, *Pissodes strobi* (Peck.)

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Abstract

The effects of attack by the Sitka spruce weevil (=white pine weevil), *Pissodes strobi* (Peck.), on Sitka spruce trees, *Picea sitchensis* (Bong.) Carr. are described. The study was based on records of attack collected for 10 years (between 1959 and 1968), in a stand located near Nitinat Lake, British Columbia. The stand was revisited in 1984 and tree quality was rated based on stem form. Also, the consequences of each attack in the period 1959-1968 for the quality of the stem in 1984 was determined. Twenty-six percent of the trees in this severely attacked area were rated as having good form; 51% had a medium form and 23% were so deformed that their condition was rated as poor (no good for lumber). The trees sustained an average of 2.4 attacks per tree in the 1959-1968 period. These attacks resulted in an average 1.6 defects per tree. In 36% of the attacks studied the tree was able to develop one single stem and appeared normal, without external symptoms of attack. The remainder of the attacks developed into various defects as follows: scar 9%, minor crook 45%, major crook 7.3% and fork 2.7%. It was concluded that the Sitka spruce weevil caused a severe productivity depletion of the stand surveyed.

Résumé

L'auteur examine les dommages causés par le charançon du pin blanc (*Pissodes strobi* [Peck.]) sur des épinettes de Sitka (*Picea sitchensis* [Bong.] Carr.) Il utilise les données recueillies pendant 10 ans (entre 1959 et 1968) dans un peuplement fortement attaqué, situé près du lac Nitinat, en Colombie-Britannique, ainsi que les données d'évaluation de la qualité des arbres d'après la forme de la tige qui ont été obtenues en 1984 lors d'une réinspection du même peuplement. Il analyse les conséquences de chaque attaque ayant eu lieu entre 1959 et 1968 pour la qualité de la tige en 1984. La forme de la tige a été jugée bonne pour 26 % des arbres, moyenne pour 51 % et médiocre (c'est-à-dire inacceptable pour la production de sciages) pour 23 %. Les arbres ont subi en moyenne 2,4 attaques au cours

de la période de 1959 à 1968, et ces attaques ont causé en moyenne 1,6 défaut par arbre. À la suite de 36 % des attaques étudiées, les arbres ont réussi à conserver une tige unique et un aspect normal, sans symptômes externes d'une attaque. Les attaques étudiées ont résulté en divers défauts: cicatrices, 9 %; courbures mineures, 45 %; courbures importantes, 7,3 %; et développements en fourche, 2,7 %. L'auteur conclut que le charançon du pin blanc a causé une grave perte de productivité dans le peuplement étudié.

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, the adult weevils crawl or fly to the tree leader (apical shoot) grown in the previous season where females lay eggs in niches excavated under the bark. The larvae kill the leader by mining and consuming its phloem. Following an attack, the lateral branches from the stem whorl immediately below the damaged leader assume a vertical position and compete for dominance. This process usually results in the formation of stem defects, such as crooks and forks, at the point of injury. Repeatedly attacked trees are stunted and overtopped by competing vegetation (often volunteer deciduous species), to the point where a severely attacked plantation may be worthless (Alfaro 1982).

The intensity of weevil attack on young plantations (percentage of trees attacked per year) is routinely reported in weevil surveys (Harris et al. 1968; McMullen 1976; Alfaro 1982; Heppner and Wood 1984; Cozens 1987; Humphreys and Ferris 1987). However, the exact nature of the damage has not been described, neither have there been any reports on the consequences of the attack for the ensuing development of the tree. Of particular importance in determining the economic damage caused by this weevil is the proportion of the attacks that result in the formation of a stem defect. This paper describes the condition of the tree stem in Sitka spruce trees several years after attack by the Sitka spruce weevil. This study was based on detailed records of attack obtained between 1959 and 1968 on southern Vancouver Island, by the Canadian Forestry Service, as part of investigations of the biology of this weevil and the possibilities of chemical control (Silver 1968). In 1984 the plots were revisited and the type and severity of the stem defects encountered was noted.

Materials and methods

The 1960's study

In 1960, Dr. G.T. Silver (formerly with the Canadian Forestry Service, Pacific Forestry Centre, Victoria, B.C.) established four research plots near Nitinat Lake on Vancouver Island, British Columbia in an area of natural Sitka spruce regeneration

which originated after logging. The plots were rectangular in shape, had a combined surface area of 1 ha, and initially included 692 trees which were marked with metal tags (Silver 1968). 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 1959 until 1968, every plot tree was examined and tree height, length of all leaders (including multiple leaders) and attack condition (attacked or not attacked) were recorded. Since the examinations were conducted in early spring, before growth started, they represented tree condition at the end of the previous growing season.

The 1984 study

The studies reported in this paper were conducted in Silver's check plot which was never treated, and it therefore represents uncontrolled damage levels. This plot occupied 0.32 ha and initially contained 231 trees; by 1984 only 160 trees survived. Average height and diameter at breast height by 1984 were 24 cm and 14.2 m, respectively. In the fall of 1984 every surviving tree with an intact tag was located and examined as follows. First, the entire length of the stem was observed, and the number and type of stem defects and stem quality (as explained below) was recorded. Then, using the available height records, the section of the stem grown between 1959 and 1968 (the period covered by the records) was located with the help of a height measuring pole. If past attacks had been recorded for this period, the precise location at which the attacks had been reported was examined and any stem defects noted. The frequency of stem defects in the 1959-1968 period was tabulated by the number of attack-years (years in the 1959-1968 period that a tree was attacked in one or more of its leaders).

Based on a preliminary inspection of the stand, stem defects caused by Sitka spruce weevil were classified (Figure 1) according to the following scheme:

(1) Scar: This is a minor defect characterized by a minor loss of cylindricity of the stem at the point where the original leader (now dead and usually broken off) departed from the stem. This defect is usually accompanied by abnormal bark growth at the point of injury. Scars are classified as minor defects.

(2) Crook: This consists of a deflection of the stem longitudinal axis at the point of injury, such that the vertical axis of the stem sections above and below the defect are not in line with each other. For the examination of the section grown between 1959 and 1968, crooks were further classified as minor or major. In minor crooks the deflection was minor in nature and lumber recovery was expected from the section containing the crook. This was the case when the deflection was less than 50% of the tree diameter at the point of injury (Figure 1). Major crooks consisted of a major deflection of the stem which was expected to prevent any lumber recovery from a section containing the crook. This usually occurred when the stem deflection was greater than 50% of the stem diameter.

(3) Fork: This consists of a bifurcation of the main stem into two or more stems above the point of injury.

STEM DEFECTS ASSOCIATED WITH S. SPRUCE WEEVIL

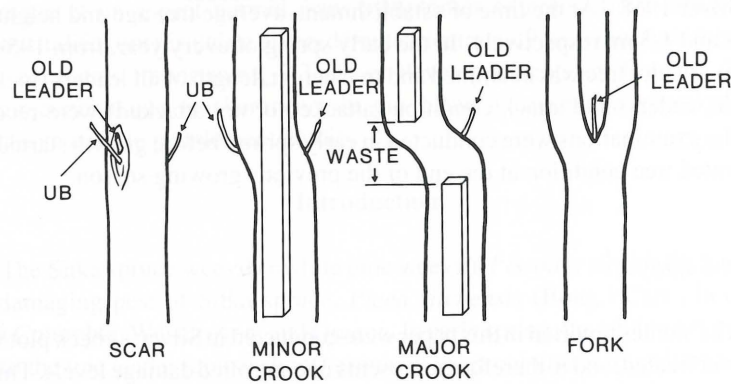


Figure 1. Stem defects in Sitka spruce associated with Sitka spruce weevil attack. Once a leader is killed, the lateral branches from the highest whorl curve up and compete for dominance. In the most common case only one branch dominates and a crook is formed. The unsuccessful branches (UB) can often be identified by their acute angles.

classes (Figure 2):

Good: Stem fairly straight, up to three minor defects (scars or minor crooks). No major defects (major crooks or forks). Full or nearly full lumber recovery expected.

Medium: Stem fairly straight, several minor defects, up to one major defect. Some lumber recovery is expected.

Poor: Stem not straight, many minor defects, two or more major defects. This type of tree will yield no lumber.

Results

Tree form

Examination of the entire tree stem indicated that, of the 160 trees surveyed, 42 (26%) were rated as having a good stem form, 82 (51%) had a medium form, and 36 (23%) were classified as poor (not good for lumber). The trees had an average of 2.8 defects/tree (range 0-11), and 10% of the trees had no visible stem defects. Of all defects observed ($n=429$), 14% were scars, 77% were crooks, and 9% were forks.

Quality the stem section grown between 1959 and 1968

Mean tree heights at the end of the 1959 and 1968 growing seasons were 1.3 and 4.6 m, respectively; the trees grew an average 3.3 m in this period. An examination of the attack records for the trees in this study (those that survived to

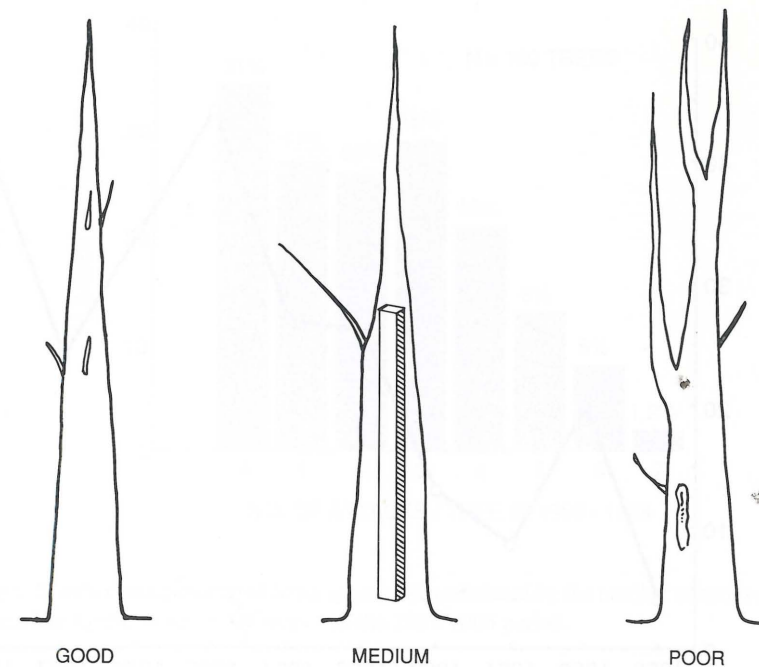


Figure 2. Schematic representation of the tree types used to classify the form of Sitka spruce trees attacked by Sitka spruce weevil.

The quality of the tree stem was classified into the following subjective form (1984), indicated that the percentage of trees attacked increased from 4% in 1959 to a maximum of 44% in 1965; after 1965, the attack rate oscillated around 30% per year (Figure 3). These attack rates were similar to the rates for the entire stand. The number of attack-years in the period from 1959-1968 varied from 0 (never attacked) to 7. The distribution of the number of trees versus the number of attack-years was highly skewed: 21% of the trees were never attacked, and 1.2% were attacked in 7 of the 10 years of observation. The mean number of attack-years per tree was 2.4 (Figure 4). These attacks resulted in an average of 1.6 defects per tree in the stem section grown between 1959 and 1968. There was a distinct trend toward a higher number of defects in this stem section with increasing number of attacks in the period (Figure 5).

A total of 411 attacks in the stem section grown between 1959 and 1968 were inspected. Of these, 265 (64%) resulted in some form of defect; in the remainder (36%) the tree had completely overgrown the injury and no visible sign of injury was present. Of the 411 attacks studied, 9% became scars, 45% minor crooks, 7.3% major crooks, and 2.7% were forks (Figure 6). These results show that the majority of the attacks resulted in defects, and that the most common defect was



Figure 3. Percentage of Sitka spruce trees attacked by the Sitka spruce weevil in the 1959-1968 period, near Nitinat Lake, British Columbia.

a minor crook. Ten percent of the attacks resulted in major defects (major crooks and forks).

Discussion

In addition to quality losses, trees with major crooks or forks sustain volume losses because the section of the stem where the defect is located is usually wasted (Figure 1). Further waste occurs if the remaining stem sections, after the defects are removed, are of odd lengths that are not currently utilized by industry. Attacked trees also suffer height growth loss regardless of whether a defect is formed. This is because a destroyed leader is replaced by lateral branches which are shorter than the leader. Hence, the total loss caused by this weevil consists of volume loss due to reduced growth and waste, quality losses, and, indirectly, tree mortality as attacked trees are stunted and overtopped by other vegetation.

The study reported here provided a "snap shot" of the stem quality at this particular time, 25 years after the first records were obtained. In the future, as trees continue to grow, it is likely that some of these defects may be partially overgrown,

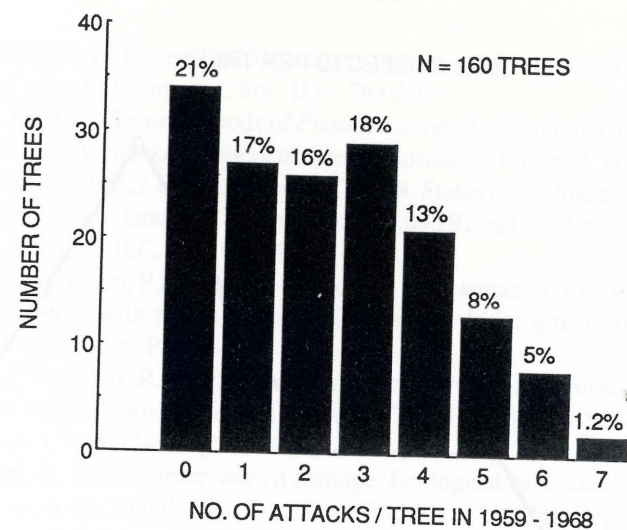


Figure 4. Number (and percent) of Sitka spruce trees tabulated by the number of times a tree was attacked by the Sitka spruce weevil in the 1959-1968 period.

with some changing in severity and others disappearing. The quantification of the economic loss due to reduced quality will be possible only at harvest when the final tally of utilization and wastage will be obtained. However, judging by the large number of defects per tree and the relatively high proportion of severe defects, it is anticipated that the economic losses of severe weevil attack in this stand will be very important.

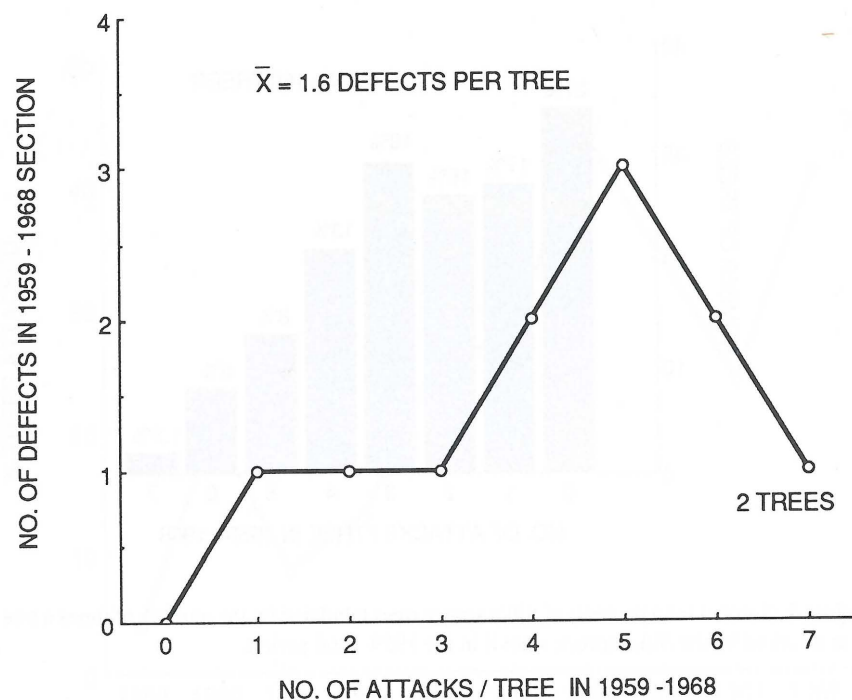


Figure 5. Number of defects in Sitka spruce stem sections grown in the 1959-1968 period, tabulated by the number of attacks per tree in the same period.

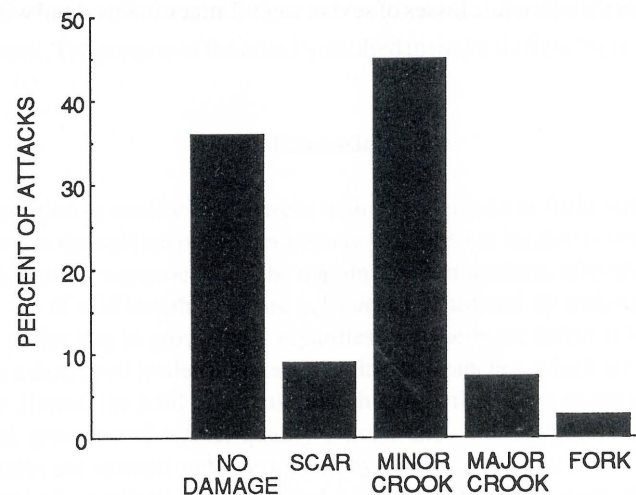


Figure 6. Percentage of attacks in the 1959-1968 period that resulted in various stem defects.

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***Pissodes nitidus* Roelofs, the yellow-spotted pine weevil (Coleoptera: Curculionidae): a serious pest of Korean pine plantations in northeast China**

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Abstract

The yellow-spotted pine weevil, *Pissodes nitidus* Roelofs, is a serious pest of terminals of young Korean pine, *Pinus koraiensis* Sieb. and Zucc., in Northeast China. Up to 20% of stand volumes can be lost after two to four repeated attacks with 0.25 to 0.33 m of height loss resulting for each attack. Heat sum requirements for each life stage have been computed. More than 50 species of parasitoids have been reared from infested leaders of Korean pine. Most are members of the Chalcidoidea and the Ichneumonoidea. The major parasites have three generations per year and hibernate as mature larvae. Strategies for management of *P. nitidus* infestations including leader clipping and parasite enhancement are discussed.

Résumé

Le charançon *Pissodes nitidus* Roelofs est un ravageur important des pousses terminales des jeunes pins de Corée (*Pinus koraiensis* Sieb. and Zucc.) dans le nord-est de la Chine. À la suite de deux à quatre attaques répétées, la perte en volume peut atteindre 20% au niveau des peuplements, chaque attaque causant une perte en hauteur de 0.25 à 0.33 m. Les sommes calorimétriques requises pour chaque stade biologique ont été calculées. Plus de 50 espèces de parasitoïdes ont été obtenues à partir d'échantillons de pousses apicales infestées de ces pins. La plupart appartiennent aux Chalcidoidea et aux Ichneumonoidea. Les principaux parasites produisent trois générations par année et hibernent sous forme de larves matures. Diverses stratégies sont examinées pour la lutte contre les infestations de *P. nitidus*, y compris la coupe de la pousse apicale et la facilitation de parasites.

Introduction

Pissodes nitidus (Roelofs), the yellow-spotted pine weevil, is an important insect pest attacking 1-year-old leaders of Korean pine, *Pinus koraiensis* Sieb. and Zucc. in northeast China. The insect is distributed in the China subregion, northeast of the paleo-north region including northeast China, the far east of the Soviet Union, Japan, and Korea. It attacks mainly *P. koraiensis* in the lesser Xingan Mountain Forest area of Heilongjiang Province, as well as *P. tabulaeformis* Carr in Jilin and Laoning Provinces. Several other *Pinus* species have been recorded as occasional hosts for the yellow-spotted pine weevil.

Damaged trees lose height growth from 2 years with each attack and this can amount to 60 to 100 cm annual height loss (Jin 1982). Volume losses in a stand where trees have been damaged two to four times is estimated at 20%. The probability of forking of the main stem after the first attack is 0.25, 0.7 after the second attack, 0.82 for trees attacked three times, 0.9 after four attacks, and 1.0 for the fifth attack. Sustained attacks over several years rapidly produce a stem with multiple crooks and forks that is no longer of use as saw timber.

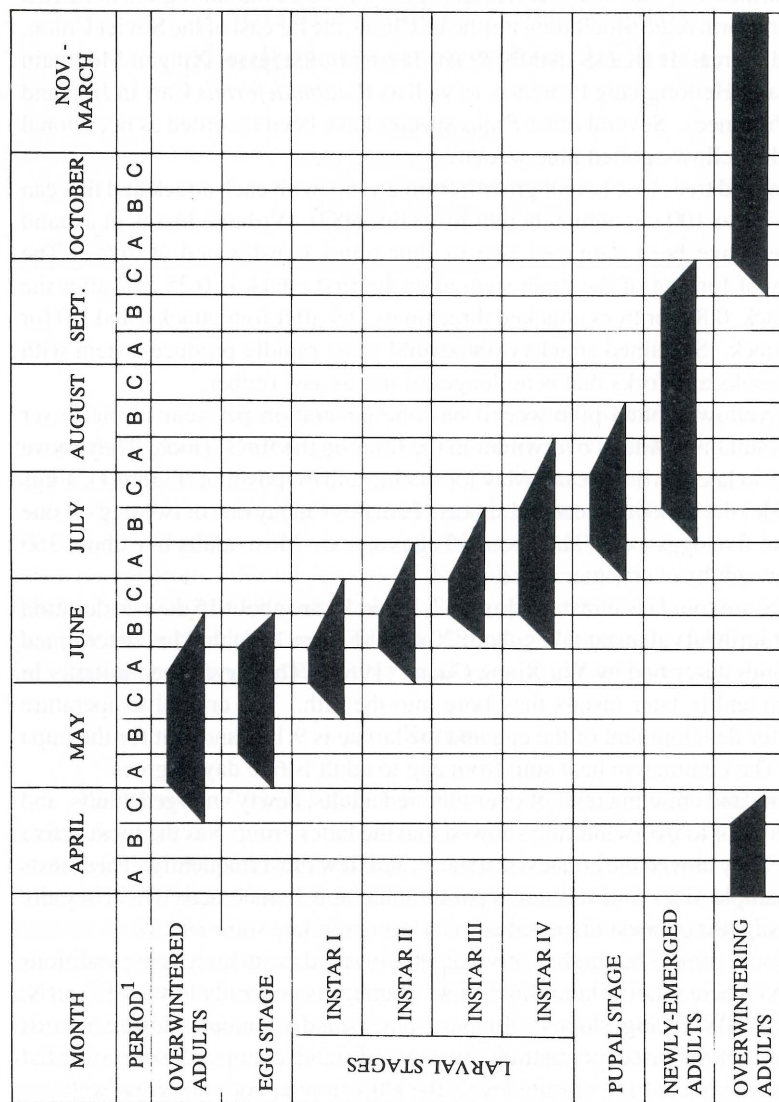
The yellow-spotted pine weevil has one generation per year in the lesser Xingan Mountains. Adults overwinter in the litter on the forest floor. They move up the trees in late April and early May for mating and oviposition (Figure 1). Eggs are laid under the bark of 1-year-old shoots. Females can lay one or two eggs at one time, one to five eggs a day, and about 30 eggs a year. Most adults live about 360 days. A few adults overwinter twice.

There are four larval instars. Instars I, II and III are about 15 days in duration while the fourth larval instar takes about 20 days (Figure 1, Table 1) as determined by techniques described by Wu Xiang Guang (1962). The larvae feed initially in the phloem and in later instars they bore into the pith. The critical temperature threshold for development of the egg and the larvae is 9.1°C and that for the pupa is 9.6°C. The cumulative heat sum from egg to adult is 620 day-degrees.

Flying and crawling tests of overwintered adults, newly emerged adults, and new adults prior to overwintering showed that the latter group was the most active (Table 2). They moved the greatest distances, and flew most frequently. These tests had low sample sizes and did not separate male and female activity. They do, however, suggest greatest dispersal activity occurs in late summer.

Pissodes nitidus has higher survival rates in stands with high light conditions (>50%) and where relative humidity is low. Damage is generally low (<5%) on N, NNE and NNW facing slopes. In pure pine stands, canopy closure retards development of the insect population. In a mixed stand, canopy closures over 0.4 reduce damage but at high closure levels the Korean pine does not grow well.

Damage was also low (<5%) in stands where the parasite index (parasite population/insect population) was 0.8 or better (Table 3). A comparative analysis showed that the following characteristics could be related to weevil population levels (partial correlation coefficients in parentheses): parasite factors (0.662), stand tending measures (0.525), closure of broadleaf overstory on top of Korean pine



¹Months are divided into three successive 10-day periods (A, B and C)

Figure 1: Life cycle of the yellow-spotted pine weevil, *Pissodes nitidus* Roelofs, showing occurrence of life stages throughout the year.

Table 1: Development periods for different life stages of *Pissodes nitidus* Roelofs

Life stage		Days	Ave. Temperature (°C)	Average relative humidity (%)
Egg	Laboratory	12	17.0	74
	Field	13	11.5	68
Larvae	Laboratory	31	21	63
	Field - Instar I	7	15.9	78
	- Instar II	8	15.6	87
	- Instar III	13	15.6	81
	- Instar IV	15	19.9	72
Pupae	Laboratory	12	23.2	72
	Field	12	22.4	83

Table 2. Measurements of *Pissodes nitidus* activity. Two robust beetles from each category tested and the higher value was recorded

	Age group of adult beetle		
	Over-wintered	Newly emerged	Current Year before over-wintering
Total distance flying and crawling (m)	472	860	1660
Flight frequency (number of occasions)	10	18	91
Flying distance as % of total distance moved	4.2	4.2	11.0

Table 3. Survival index of *P. nitidus*, parasite index, and percentage of trees damaged in different stands

	Stand Number							
	I	II	III	IV	V	VI	VII	VIII
Year examined	1980	1981	1981	1981	1981	1980	1981	1980
Survival rate of insect	32	<5	6.2	22.7	74.9	25.9	29.5	44
Survival coefficient of insect	0.32	<0.05	0.06	0.23	0.75	0.26	0.30	0.44
Parasite index in stand	0.06	3.0	1.2	0.1	0.1	0.04	0.1	0.04
% trees damaged	40	<1	4	27	24	49	38	74
								78

(0.386), canopy closure of Korean pine itself (0.216) and stand aspect (0.179). A multiple regression with all factors included (Zhu Bo-Cheng 1975) gave a multiple r of 0.839. These results suggest that management activities, such as release thinning, adversely affect stands already infested with *P. nitidus* as they enhance the survival of the weevil.

More than 70 species of parasitoids have been associated with *P. nitidus*. They belong mainly to the families Ichneumonidae (36), Braconidae (20), and Chalcidoidea (7). In numerical terms, species of Chalcidoidea accounted for 87.7% of 19 260 reared parasitoids. Braconid parasites accounted for an additional 10% of those reared. *Eurytoma* spp. and *Bracon* spp. had three generations per year. The third generation overwinters in the leaders killed by *P. nitidus*.

In May and June 1981, 120 damaged leaders were collected from nine different stands (10-20/stand). The leaders were dissected and 6 795 eggs and larvae were counted (57 eggs/leader). In the fall, 10 000 infested leaders were collected (from 14 stands) and 650 of these were checked for emergence holes. A total of 11 543 emergence holes (18/leader) were found. About 9% of the population were judged to have emerged through a common exit hole; thus production of adults per leader is estimated at 19.62/leader. This represents a mortality of 65.5%.

The main cause for damage from *P. nitidus* in the Korean pine forest is the change in stand environment caused by release thinning. A more complete picture of all major factors included in forecasting *P. nitidus* populations in Korean pine stands is given in Table 4.

When planning new plantations, existing plantations within 2 km should be checked and infested leaders should be clipped in June or July and treated in the year before planting or within 3 years of plantation establishment. It is the author's unquantified opinion that a varied habitat should be encouraged to improve community succession and strengthen the ecological diversity. A mixed forest has the advantage of providing food plants (flowers) for adult parasites and closed canopies provide a protected habitat in strong winds, prolonged rains, or extensive dry periods.

When leader clipping is carried out, it is recommended that leaders should be placed in protective boxes covered with a screen which allows the parasites to emerge to continue their useful work while retaining the *P. nitidus* so as to prevent them from attacking new leaders. Dead weevils are removed from the protective cages in September and the leaders (with parasites) are placed in branches of trees throughout the plantation. Additional measures to enhance parasite populations include "closing" the forest to cattle and people in order to maintain a diverse ecology as a favorable habitat for parasites.

Acknowledgements

I thank He Jun-Hua and Zhao Yang-Chang for identifying the parasite material; Bi Zi Liang, Wang Wen Man, Gao Ziu Feng, Li Fu Xue, Jin Zhen Hao, Guo Ting Ju, Li Dian Hua, Zhang Xin Chun, Lu Wei Hua and Wang Yin Yan for their

Table 4. Factors which affect success of *P. nitidus* infestations in Korean pine stands

Factor	Hierarchial classification (Low, Medium, or High hazard)	
Aspect	L.	Stands on NNE, N, NNW facing slopes, >5 degrees slope
	M.	Stands on E, NE, NW, W facing slopes
	H.	Stands on SE, S, SW facing slopes and on flat plains
Canopy closure of broadleaf trees over Korean pine	L.	Stand with closure density >0.40
	M.	Stands with closure between 0.31 and 0.39
	H.	Stand closure <0.30
Canopy status of Korean pine	L.	Stand with good Korean pine closure up to 0.80
	M.	Stand with poor Korean pine closure: with open areas, and Korean pine distributed in big pockets
	H.	Stand without Korean pine closure, low Korean pine density and not well stocked
Release cutting	L.	Without release cutting
	M.	Stand which had release cutting once, keeping some canopy broadleaf trees without removing leader growth or brush
	H.	Stand with release cutting, once or more, in combination with removing broadleaf trees, under growth and brush
Parasite index	L.	Stands with parasite index >0.80
	M.	Stands with parasite index between 0.40 and 0.79
	H.	Stands with parasite index lower than 0.40

assistance in fieldwork; and L. Friskie for preparation of the figure. This paper was condensed from a more detailed manuscript which is available on request from J.A. McLean, Department of Forest Sciences, University of British Columbia, Vancouver, British Columbia, V6T 1W5.

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Gall and Pitch Midges

Growth loss in sapling ponderosa pine associated with injury caused by gouty pitch midge

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Abstract

In a case history using paired-comparison tests of annual height growth and shoot injury, growth loss in sapling ponderosa pines in northern California was associated with injury caused by the gouty pitch midge. Trees with resinous surfaces on their elongating spring shoots were repeatedly injured by the midge. Of three different expressions used to compare height growth of midge-injured and uninjured trees, internode length was judged most appropriate because its results were simplest to interpret.

Résumé

Dans une étude de cas utilisant des tests de comparaison par paires de l'accroissement annuel de la hauteur et des blessures aux pousses, on a constaté que la perte de croissance de jeunes pins ponderosa (gaules) dans le nord de la Californie était associée à des blessures causées par des cécidomyies résineuses. Les arbres ayant une couche de résine à la surface des pousses printanières en croissance étaient attaqués de façon répétée par les cécidomyies. Trois critères différents ont été utilisés pour comparer l'accroissement de la hauteur des arbres attaqués et non attaqués par les cécidomyies, et celui de la longueur de l'entre-nœud a été jugé le meilleur car il donnait des résultats plus faciles à interpréter.

Introduction

The Gouty pitch midge (GPM), *Cecidomyia piniinopis* Osten Sacken, is considered a pest of ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws.) and to

some extent of Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) plantations where it causes shoot mortality, deformities of limbs and stems, stunting and occasionally death of small trees (Eaton and Yuill 1971). In spring, GPM eggs are laid on the current year's expanding shoots (Eaton and Yuill 1978). Newly hatched larvae bore into the shoot but grow very little until the shoot has expanded and set its bud for the next year (Bedard; unpublished data). The following fall and winter, the growing larvae expand the lumen of the cavity where they live and feed. By March, larvae have opened the cavity to the outside and the tree responds with a visible flow of resin from the opening and by the formation of a swelling (gall) over the cavity. Frequently, cavities coalesce and the cambium is killed. During the second growing season, as new wood is formed on the affected shoot, callous tissue forms swellings around the margins of the galls, by now necrotic tissue, which shrinks as it dies and dries. When necrotic areas are large, shoots frequently bend. The callous tissue surrounding or mixed with sunken areas (goutiness) and the sinuous limbs remain on yearly internodes as a sign of past attacks.

Growth loss could be caused by GPM activity by any or all of the following host responses. On the affected shoot, goutiness could interrupt translocation and kill the terminal portion of the shoot, or cause reduced numbers of stem units (internodes) to be formed, or prevent full expansion of the units. On affected shoots as well as the entire tree, nutrient reserves normally available for growth would not be produced in killed shoots and, in surviving shoots, would be lost in the production of midges and in wound response, i.e., resin and callous production. The delay of larval development until the year's shoot elongation is completed on the attacked shoot should result in a delay of 1 year between initial attack (in year x) and reduced elongation of the subsequent year's shoot (in year $x + 1$).

Recent attempts to quantify growth loss attributable to the GPM in a variety of growing conditions and injury levels, however, have been unsuccessful (Ferrell et al. 1987; Bedard and Ferrell, published data). In these studies, heights and diameters of GPM-injured versus uninjured trees growing side by side were compared. Uncontrolled variation, low injury levels, and possibly an insensitive measure of growth loss that averaged the results of too many factors may have obscured detection of loss. Bedard and Ferrell (unpublished data) concluded, however, that for the slower growing trees of the southern Cascade Range, injury caused by GPM was not a cause of reduced growth even in severely injured trees.

This paper reports a study demonstrating that growth loss associated with GPM injury can occur, and describes a sensitive method to quantify such loss.

Methods

Snowman's Hill progeny test plantation of the California Cooperative Forest Tree Improvement Program was selected as a study area because it met the following conditions: no apparent competition between trees and grass or brush; protection from pocket gophers, deer and cattle; improved seed sources to represent current and future plantations; and very high GPM-caused injury levels in some

trees. It is located in the southern Cascade Range 5 km southeast of Mt. Shasta City, Siskiyou Co., in northern California on a southwest-facing slope at 1320 m above sea level. Its 186 half-sib families of ponderosa pine were planted in 1977 with each individual of a family randomly planted adjacent to individuals of different families.

In August 1985, internode lengths and the amount of GPM-caused goutingness were determined for 58 pairs (one with goutingness and one without) of 9-year-old ponderosa pine saplings. Trees were paired for the purpose of minimizing growth differences related to microsite and thereby increasing the likelihood of detecting growth loss due to GPM. We assumed that growth of midge-susceptible trees does not differ from that of midge-resistant trees. This assumption is supported by the fact that trees selected for superior growth in the California Cooperative Tree Improvement Program have as high a proportion of midge-susceptible trees as do trees in natural stands, and by our results with 1800 saplings in the southern Cascade Mountains of California (Bedard and Ferrell unpublished data) where differences in shoot surface coating (highly correlated with midge susceptibility) were not associated with stem growth. The first member of the pair, the tree with goutingness, was found by randomly selecting trees and looking at the surface of limbs and stems. The degree of goutingness was estimated visually to the nearest 10% for each year in two ways: 1) as the percentage of the surface area of the internode with goutingness; and 2) the maximum percentage of the circumference of the internode with goutingness. Estimates of goutingness were made for 1982 through 1984 only, since goutingness due to 1985 attack was not yet visible in August 1985 and pre-1982 goutingness was too slight to be considered significant. Area and circumference goutingness were estimated on the basis of 10 internodes (stem and limb combined) randomly selected from the upper half of the crown. Henceforth these two categories, percentage of shoot surface area and percentage of circumference estimated to have goutingness, will be referred to as area and circumference goutingness, respectively. Annual area and circumference goutingness are collectively referred to as annual goutingness categories. Since the purpose of this study was to detect growth loss, a tree was not selected unless it had at least 30% area or circumferential goutingness for 1 year.

The second member of the pair, the tree without goutingness, was the nearest neighbor which met the following criteria: 1) little or no evidence of GMP-caused goutingness; and 2) within 30% of the height of the tree with goutingness in 1983. Trees with growth irregularities in the stem were not used in the study. Lengths of the 1979 to 1985 stem internodes were measured to the nearest 0.5 cm on all trees.

Analysis

Three different methods were used to express the annual height growth rate in trees with and without goutingness: 1) internode length; 2) internode length expressed as a percentage of the previous year's internode length; and 3) internode length as a percentage of the tree's growth rate over the last 7 years (1979 - 1985). The two methods that express the tree's annual growth as a proportion of its growth

rate in previous years were chosen to reduce the variability introduced by comparing pairs of trees with different growth rates. Each of these three expressions of annual growth was used in a paired comparisons t-test to determine if the differences between any 1 year's internode lengths or trees with and without goutingness were significant. This same analysis was performed again when the tree pairs for any given year had been divided into two groups based on amount of goutingness — more or less than the mean. Correlation coefficients were calculated for all possible combinations of annual goutingness categories and the three annual growth expressions. In addition, simple and multiple regression analyses were performed to identify sources of variation in the annual growth expressions of trees with goutingness. A third injury category, the product of area and circumference goutingness, was created and used in the paired comparison t-tests where tree pairs were divided on the basis of amount of goutingness (more or less than the mean), and also in the correlation and regression analyses to explore associations with tree growth.

Results

Goutingness was lower in 1982 than in 1983 and 1984 (Table 1). When all trees with goutingness were divided into high or low on the basis of 1983 goutingness levels, the low group also had lower goutingness in 1982 and 1984 (Table 1).

Trees with goutingness grew significantly shorter internodes than those without in 1984 and 1985 (Table 2). Internodes with goutingness grew less than those without by 23.0% in 1984 and 9.4% in 1985. When pairs of trees with and without goutingness were divided into two groups based on amount of goutingness in 1983 or 1984, the group with the most goutingness consistently had the most growth loss (Table 3).

Table 1. Mean goutingness on ponderosa pine caused by gouty pitch midge, by year, category of goutingness, and amount of goutingness (Siskiyou Co., CA, August 1985)

Year internode elongated	Shoot Surface area with goutingness			Shoot surface circumference with goutingness		
	All ^a (S.D.) n = 58	High 26	Low 32	All (S.D.) 58	High 27	Low 31
		Percent				
1982	12.3 (6.5)	16.1	9.2	16.4 (9.0)	21.8	11.7
1983	41.4 (9.2)	49.6	34.8	47.0 (10.8)	56.8	38.4
1984	55.6 (10.6)	61.7	50.6	49.1(11.2)	52.0	46.5

^a The 58 trees with goutingness caused by the gouty pitch midge were divided in two by the amount of area or circumference goutingness they had in 1983, high = higher than the mean, low = lower than the mean.

Table 2. Mean internode lengths of ponderosa pine pairs with and without goutiness caused by the gouty pitch midge (n = 58 pairs; Siskiyou Co., CA, August 1985)

Year internode elongated	Internode length (cm)				Prob. ^a
	With goutiness	Without goutiness	Difference	SE	
1979	19.94	19.58	0.36	0.81	0.6585
1980	26.15	26.29	-0.14	1.02	0.8924
1981	31.50	31.48	0.02	1.17	0.9883
1982	35.27	34.91	0.36	1.26	0.7742
1983	36.91	37.34	-0.43	1.15	0.7090
1984	29.46	38.27	-8.81	1.39	0.0001
1985	40.55	44.77	-4.22	1.93	0.0330

^a Student's t-test

Similar results were obtained when the groupings were based on goutiness in 1983 and 1984 combined.

There was a delay of 1 year between the onset of goutiness in excess of 30% and the occurrence of growth loss. In 1983, goutiness exceeded 30% (Table 1), yet there was no difference between internode lengths in trees with and without goutiness (Table 2). The first growth loss occurred in 1984, the year following goutiness in excess of 30%.

Correlation coefficients between combinations involving annual goutiness categories (e.g., area goutiness in 1984 with circumference goutiness in 1984, or area goutiness in 1983 with area goutiness in 1984) for 1982 through 1984 were all positive and significant at $P \leq 0.004$. The highest coefficients, 0.7 to 0.9, were for area with circumference within the same year. Next highest were those for area or circumference with area or circumference for an adjacent year, *ca.* 0.4 to 0.7. Lowest were those between 1982 and 1984, 0.3 to 0.4.

There were few (10%) significant ($P \leq 0.05$) correlation coefficients between combinations of annual goutiness categories with annual growth expressions.

When simple regressions of infested internode length (dependent variables) were run with annual goutiness categories (independent variables), significant models with low R-squared values, 0.09 to 0.18 ($P \leq 0.02$ - 0.001; and wide, 95% prediction intervals, ± 19.4 - 25.0 cm) resulted in one-fourth (5 of 18) of the cases. In all cases, the relation between growth and goutiness was negative.

All three of the multiple regression models of infested internode length (dependent variable) with annual goutiness categories (independent variables) were significant with low R-squared values, 0.28 to 0.41 ($P \leq 0.001$ - 0.008, 95% prediction intervals, ± 16.0 - 21.1 cm). In these models, there were no patterns

Table 3. Differences^a between yearly stem internode length of ponderosa pine saplings with and without goutiness caused by the gouty pitch midge grouped by goutiness category, amount, and year (Siskiyou Co., CA, August 1985)

Stem	Percentage of shoot surface area with goutiness for year ^b	Stem internode lengths (cm)		Percentage of shoot circumference with goutiness for year	Internode lengths (cm)	
		1984	1985		1984	1985
1983 high ^c (n = 26)		-11.6(2.4)**	-7.0(3.1)*	1983 high n = 27	-10.6(2.5)**	-4.3(2.9)
1983 low (n = 32)		-6.5(1.5)**	-2.0(2.4)	1983 low n = 31	-7.2(1.5)**	-4.2(2.6)
1984 high (n = 29)		-10.6(2.2)**	-7.2(3.0)*	1984 high n = 26	-13.4(1.7)**	-10.6(3.0)**
1984 low (n = 29)		-7.0(1.7)**	-1.2(2.3)	1984 low n = 32	-5.1(1.9)*	0.1(2.1)

^a Paired-comparison t-test. * $P \leq 0.05$, ** $P \leq 0.01$. Standard error of the mean in parentheses. There were no significant differences in 1983; 1985 goutiness data were not collected.

^b Based on 10 shoots for each tree/year.

^c Fifty-eight pairs of sapling ponderosa pine, a tree with goutiness caused by the gouty pitch midge and its control without goutiness, were divided into two groups; high goutiness—greater than mean, and low goutiness—less than the mean. Unique divisions were made for each year and each category of goutiness, e.g., 1983 surface area goutiness.

suggesting strong cumulative effects of annual goutingness on growth. There was, however, a tendency for annual goutingness to be significantly associated with growth loss the following year. For example, 1985 internode length in infested trees was significantly ($P \leq 0.001$) associated with 1984 circumference goutingness although the R-squared was low (0.18).

Discussion

Our results demonstrate an association between high levels of GPM-caused goutingness and growth loss. Also, there is a clear tendency for trees with goutingness to be reattacked in subsequent years. This tendency is apparent in Table 1 where division of trees into high and low on the basis of 1983 goutingness resulted in division into high and low goutingness in 1982 and 1984. It is also apparent in the results of correlation analyses. Correlation coefficients between all combinations of area and circumference goutingness were 0.4 to 0.7 for adjacent years. This tendency has been reported previously (Austin et al. 1945) and is related to the high susceptibility to attack in trees with resinous shoot surfaces during elongation in the spring — corresponding to the ovipositional period of the midge — and to the fact that shoot surface coatings are heritable traits (Duffield 1985) likely stable in expression from year to year.

The 1-year lag between goutingness in excess of 30% and growth loss could be due to the delay in larval development during shoot elongation. Most shoots that are killed by GPM appear to have fully elongated needles and a developed bud for the subsequent year, indicating that even at extreme attack densities, infested shoots elongate before shoot mortality occurs.

An apparent inconsistency in our results is that the goutingness in 1984 was as high or higher than in 1983, yet the 1985 growth loss was less than that in 1984. If goutingness were directly related to growth loss, 1985 growth loss would be expected to equal or exceed that of 1984. We examined plantation records after finding this apparent anomaly and found a possible explanation. Brush, competing with pine for resources required in growth, may have interacted with goutingness to enhance growth loss. Competing brush (principally *Prunus* species) was cut in the plantation in the spring of 1984 and resprouted to compete with trees in the 1984 growing season. Brush was ground sprayed with the herbicide glyphosate in August 1984 and was mostly dead in August 1985; thus, there was apparently no brush competition during the 1985 growing season. Additionally, both 1984 and 1985 were years of deficient precipitation during January to May. Lack of adequate soil moisture for growth would exacerbate the effects of brush competition and might have effected the goutingness/shoot growth relationship directly. McDonald (1981) and McDonald and Oliver (1984) have demonstrated that GPM-caused injury (primarily shoot mortality) and growth loss is greatest when brush competition is greatest and Schultz has speculated that growth loss associated with midge-caused injury (including goutingness, shoot mortality, and deformities) is enhanced by brush competition and dry spring weather (Smith 1986).

The negative relation between internode length and goutingness categories along with the consistently higher growth loss in pairs of trees with more goutingness (Table 3) suggests that higher levels of goutingness produce higher levels of growth loss. However, the only tests of significance of this relationship rest on the 5 out of 18 regression models with significant P values, low R-squared's, and wide confidence intervals. Although our results are suggestive of a direct relationship between increased goutingness and increased growth loss, they are inadequate to support it unequivocally.

Significantly, goutingness explains only a small proportion of growth in regression models. Part of this poor showing could be attributed to artifacts of the experiment and analysis. We exclude trees that had lost apical dominance or that had forked tops (in many cases as a result of severe GPM attack) and we excluded trees with less than 30% goutingness. Also we introduced more variability by associating stem internode growth with the mean goutingness of 10 internodes than we would have had if we used the goutingness of the previous year's stem internode. We have observed that, within a single limb or stem, the amount of previous year's goutingness appears to be closely related to the next year's growth, especially for extreme goutingness. However, even if these artifacts were corrected so that more of the variability in growth was associated with goutingness, we believe that goutingness would still explain only a small proportion of the variability.

The method of comparing growth of trees with and without goutingness using differences in internode length yields results which are simpler to interpret than those of the other methods. With several types of interactions between yearly goutingness and yearly height growth possible (e.g., additive, synergistic, compensatory), we feel the more straightforward method is most appropriate for general use. The two methods that standardize growth to an internal standard, i.e., growth expressed as a proportion of last year's growth and as a proportion of 7 year's growth, yield results that are difficult to interpret. The great variability in growth rates normally found in plantations provides a strong reason to attempt to standardize growth prior to comparison. If standardization is done, however, the years when growth difference under study occurred should not be included in the standard (Thomson and Van Sickle 1980).

Although we have demonstrated that high levels of GPM injury causes growth loss of individual trees in the Snowman's Hill plantation, the significance of GPM injury to growth of trees growing elsewhere is moot because the representativeness of these results is unknown. We found that with slower growing trees on the nearby Lassen National Forest (mean yearly height = 16.5 cm vs 32.3 cm for study trees at Snowman's Hill) injury did not cause growth loss in any of the nine plantations studied (Bedard and Ferrell, unpublished data). Although the different methods used preclude direct comparison of the results of the two studies, we believe we would have detected a relationship between GPM injury and reduced growth in the Lassen study if such a relationship was present. Also we failed to find growth loss associated with GPM-caused injury in medium to lightly injured trees growing on the Eldorado National Forest (Ferrell et al. 1987) and in medium to

heavily injured trees on the Stanislaus National Forest (Ferrell and Bedard unpublished data). Thus we speculate that the midge-caused growth loss at Snowman's Hill is a special case resulting from a combination of several conditions, e.g., moderate growth rate, high to extreme goutiness, and drought or brush competition present.

Acknowledgments

We wish to thank James A. Baldwin for statistical help; David Schultz, Philip M. McDonald, and Russell Mitchell for their manuscript reviews; and Wendy Johnston of Santa Fe Pacific Timber Co. for providing the study site.

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Geographic variation in *Pinus ponderosa* susceptibility to the gouty pitch midge, *Cecidomyia piniinopsis*, in the Sierra Nevada and southern Cascade Mountains of California

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Abstract

Geographic variation in susceptibility to the gouty pitch midge, *Cecidomyia piniinopsis* O.S. (Diptera: Cecidomyiidae), was analyzed in 3-year-old ponderosa pine, *Pinus ponderosa* Doug. ex Laws., seedlings in an outdoor nursery in the central Sierra Nevada. In this study, 472 families of phenotypically superior, wind-pollinated seed trees from the species range in the Sierra Nevada and southern Cascade Mountains of California were represented. Trees with viscid (resinous) spring shoot surfaces were more often injured by gouty pitch midge than those with nonviscid (smooth or waxy) surfaces. Susceptibility was based on mean family scores for shoot surface and gouty pitch midge injury. Analysis of these families in relation to latitude, longitude, and elevation of the seed source revealed a complex geographic pattern. Susceptibility of families from the northern Sierra Nevada and southern Cascades was relatively low and increased only moderately at the northern, eastern, and southern margins of the region. In the southern Sierra Nevada, susceptibility was higher, and increased with decreasing latitude. Longitudinal trends in susceptibility to gouty pitch midge were not evident in this region. Watered seedlings had more gouty pitch midge injuries than unwatered, but there was no evidence this difference affected gouty pitch midge susceptibility of families.

Résumé

La variabilité géographique de la vulnérabilité du pin ponderosa (*Pinus ponderosa* Doug. ex Laws.) à la cécidomyie du pin gris (*Cecidomyia piniinopsis* O.S. [Diptères: cécidomyidés]) a été analysée chez des semis de 3 ans d'une pépinière extérieure du centre de la Sierra Nevada. Cette étude regroupait 472 familles de semenciers génotypiquement supérieurs et librement pollinisés (vent) provenant de l'aire d'extension de cette essence dans la Sierra Nevada et le sud des monts Cascade

en Californie. Les arbres dont la surface des bourgeons du printemps était visqueuse (résineuse) étaient plus souvent blessés par la cécidomyie du pin gris que ceux à surface non visqueuse (lisse ou cireuse). La vulnérabilité était établie à partir des notes moyennes attribuées aux familles pour la surface des bourgeons et les blessures infligées par la cécidomyie du pin gris. Une analyse de ces familles en fonction de la longitude, de la latitude et de l'élévation de l'origine des graines a révélé l'existence d'une configuration géographique complexe. La vulnérabilité des familles provenant du nord de la Sierra Nevada et du sud des monts Cascade était relativement faible et n'augmentait que modérément aux extrémités nord, sud et est de la région. Dans le sud de la Sierra Nevada, la vulnérabilité était plus grande, augmentant de façon inversement proportionnelle à la latitude. Dans cette région, aucune tendance ne s'est dessinée en fonction de la longitude. Les semis irrigués portaient un plus grand nombre de blessures causées par la cécidomyie du pin gris que ceux qui ne l'étaient pas, mais rien ne prouve que cette différence influait sur la vulnérabilité des familles à cet insecte.

Introduction

The gouty pitch midge, *Cecidomyia piniinopsis* O.S. (Diptera: Cecidomyiidae), infests elongating shoots of ponderosa pine, *Pinus ponderosa* Doug. ex Laws, throughout much of the range of this tree species in California and elsewhere (Eaton and Yuill 1971). The mining larvae cause gall-like swellings and scars, resulting in dead needles and twigs, and eventually in deformed (gouty and sinuous) branches. Saplings and poles are most heavily infested, but trees under 3 years old ordinarily escape injury. Protracted, severe infestations can stunt, deform, and occasionally kill small trees. Gouty pitch midge is not considered a serious pest in natural stands, but its economic significance is a cause of concern in plantations where damage has been prevalent (Eaton and Yuill 1971).

A previous study of a 12-year-old ponderosa pine plantation at the USDA Forest Service's Institute of Forest Genetics near Placerville, Eldorado County, California reported trees with viscid (resinous) spring shoot surfaces were much more susceptible to gouty pitch midge than trees with nonviscid shoot surfaces (Austin et al. 1945). This plantation consisted of ponderosa pines from much of the range in western North America. However, this study did not address the question of whether the susceptibility of trees varied according to their geographic origin or provenance.

This paper reports a study to determine if ponderosa pine susceptibility to gouty pitch midge (1) could be assessed in 3-year-old seedlings growing in outdoor nursery beds, (2) varied with watering regime, and (3) varied according to geographic seed source in the Sierra Nevada and southern Cascade Mountains in California.

Materials and methods

Outdoor nursery beds at the Institute of Forest Genetics were sown in 1981 with seeds collected from phenotypically superior, wind-pollinated trees from much of the species range in the Sierra Nevada and Southern Cascade Mountains in California. The seeds represented 590 families, the geographic origins of which were recorded by latitude, longitude, and elevation. Families were sown in six-seed plots, replicated in each of four randomized blocks, and thinned to three seedlings after the first growing season. All blocks were watered once or twice a week from late May through August, except in 1983 when two blocks, hereafter referred to as the "unwatered treatment," were watered only once in mid-July to test whether availability of water affected family phenotypes. In spring 1983, morphological traits of the seedlings were assessed. Shoot surface on the elongating terminals (laterals were ignored to standardize observations) was scored as (1) glaucous or waxy, (2) glabrous or smooth, (3) slightly viscid or resinous, (4) moderately viscid, or (5) very viscid. In spring 1984, gouty pitch midge injuries (gall-like swellings) on naturally infested 1983 terminals were scored as 0 (none), 1 (one), or 2 (2 or more).

Family plot means for shoot surface and gouty pitch midge injury scores were subjected to analysis of variance for significant ($p \leq .05$) effects of family, treatment (water regime), family \times treatment, and blocks within treatment (SAS Institute 1985). The error terms were family \times treatment for family effects, and family \times blocks within treatments for family \times treatment effects.

Family means for shoot surface and gouty pitch midge injury scores were analyzed simultaneously by canonical correlation (SAS Institute 1985) for relationships with the geographic variables, with the expectation that this multivariate analysis would more clearly reveal geographic patterns than would univariate techniques. After a normal probability plot of canonical scores indicated that deviations from multivariate normality were small, an adequate model was searched for by analyzing all combinations of latitude, longitude, elevation, and their interactions, in both linear and quadratic form, and selecting the model which maximized the canonical R^2 without diminishing statistical precision. The model chosen from the canonical correlation analysis contained latitude (LAT), longitude (LON), elevation (ELEV), LAT \times LON, ELEV², LAT \times ELEV, and (LAT \times ELEV)² as geographic variables (canonical $R^2 = .268$). Predicted values of the canonical vector representing shoot surface and gouty pitch midge injury were obtained by regressing the geographic model used in the canonical correlation analysis against scores for the vector (SAS Institute 1985). These predicted values were plotted by geographic location to delineate geographic patterns.

Results

Of a total of 7080 seedlings intended by the experimental design, 5493 were scored for shoot surface and gouty pitch midge injury (Table 1), with the rest

Table 1. Ponderosa pine seedlings categorized by number of gouty pitch midge injuries, shoot surface type, and watering treatment

Number of injuries	Nonviscid shoot			Viscid shoot			Total	% of grand total
	Water	No water ^a	Total percent ^b	Water	No water	Total		
0	92.5	96.5	94.5	82.4	89.3	86.0	5109	93.0
1	2.1	1.4	1.8	3.7	3.5	3.6	115	2.1
> 1	5.4	2.1	3.7	13.9	7.2	10.4	269	4.9
Total	2262	2283	4545	460	488	948	5493	
Percent of grand total	41.1	41.6	82.7	8.4	8.9	17.3		

a. Except for once in mid-July.

b. Based on column totals.

missing because seeds failed to germinate. Of the 590 families originally present, 472 families were still represented in all blocks, permitting their analysis according to the experimental design. Of the total seedlings assessed, 4545 (82.7%) had shoots scored as nonviscid (glaucous or glabrous); the remaining 948 (17.3%) had shoots scored as viscid to some degree. Of seedlings with nonviscid shoots, 5.5% had one or more gouty pitch midge injuries (1.8% had one and 3.7% had more than one), whereas 14.0% of those with viscid shoots had at least one gouty pitch midge injury. Comparable figures for two or more injuries were 3.7% and 10.4%, respectively.

Results of analysis of variance in family plot means for shoot surface and gouty pitch midge injury scores differed. Family and watering treatment were significant as main effects for gouty pitch midge injury, but only family was significant for shoot surface. Family x treatment was not significant for either variable.

Evidently, the watering treatment had little or no effect on shoot surface type but had a pronounced effect on gouty pitch midge injury. In watered blocks (Table 1), percentages of seedlings with viscid and nonviscid shoots (8.4% and 41.4%) were similar to those in unwatered blocks (8.9% and 41.6%). But there was about a two-fold difference between watered and unwatered blocks in the percentage of seedlings with one or more gouty pitch midge injuries (25.1% versus 14.0%) or with two or more injuries (19.3% and 9.3%).

Contour mapping of predicted gouty pitch midge susceptibility values indicated two patterns, closely paralleling those of shoot surface, in the region studied (Figure 1). gouty pitch midge susceptibility in families from the zone north of 38° latitude was lower than that in the zone south of this latitude and increased only moderately at the northern, eastern, and southern margins of the northern region.

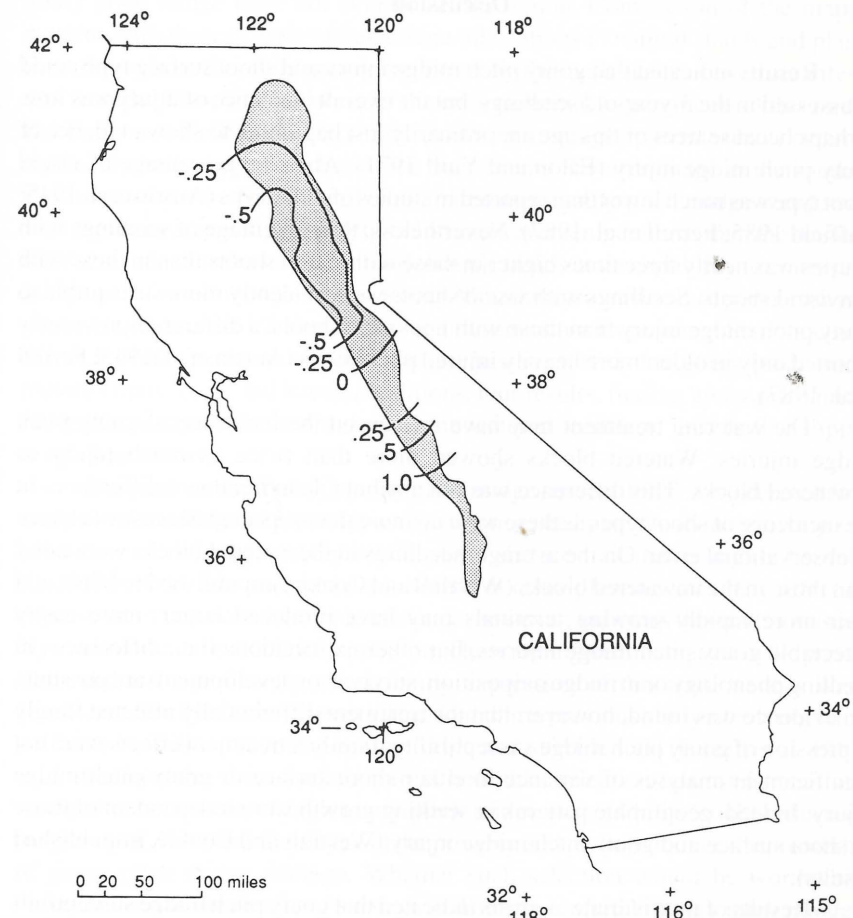


Figure 1. Geographic variation in ponderosa pine susceptibility to gouty pitch midge in the Sierra Nevada and southern Cascade Mountains is shown by contour lines that connect points of about equal values of susceptibility as indicated by values of the standardized canonical variable predicted by latitude, longitude, and elevation. Shaded area indicates approximate range of ponderosa pine studied.

South of 38°, susceptibility was higher and increased still further with decreasing latitude. Little longitudinal variation was evident in this zone. Susceptibility generally decreased with elevation with the trend steepening towards the south.

Discussion

Results indicated that gouty pitch midge injury and shoot surface type could be assessed in the 3-year-old seedlings, but the overall incidence of injury was low, perhaps because trees of this age are ordinarily just beginning to show evidence of gouty pitch midge injury (Eaton and Yuill 1971). Also, the percentage of viscid shoot type was much lower than reported in studies of older trees (Austin et al. 1945; Duffield 1985; Ferrell et al. 1987). Nevertheless, the percentage of seedlings with injuries was nearly three times higher in those with viscid shoots than in those with nonviscid shoots. Seedlings with viscid shoots were evidently more susceptible to gouty pitch midge injury than those with nonviscid shoots, a difference previously reported only in older, more heavily injured plantations (Austin et al. 1945; Ferrell et al. 1987).

The watering treatment may have influenced the incidence of gouty pitch midge injuries. Watered blocks showed more than twice as much injury as unwatered blocks. This difference was not attributable to treatment differences in the incidence of shoot types as these were no more than expected because of chance or observational error. On the average, seedlings in the watered blocks were taller than those in the unwatered blocks (Westfall and Conkle, unpublished results), and their more rapidly growing terminals may have produced larger, more easily detectable gouty pitch midge injuries, but other explanations (i.e., differences in seedling phenology or in midge oviposition, survival, or development) are possible. No evidence was found, however, that the treatment differentially affected family expression of gouty pitch midge susceptibility; family \times treatment effects were not significant in analyses of variance in either shoot surface or gouty pitch midge injury. Indeed, geographic patterns in seedling growth were independent of those in shoot surface and gouty pitch midge injury (Westfall and Conkle, unpublished results).

Results of multivariate analysis indicated that gouty pitch midge susceptibility of families, as expressed by mean scores for gouty pitch midge injury and shoot surface, varied by latitude, longitude, and elevation of their seed source. About 73% of the variation in susceptibility remained unexplained by these relationships, however. This variation was at least partly attributable to sampling error arising from the limited family size, given the observed within-family polymorphism for shoot surface and low overall incidence of gouty pitch midge injury. Nevertheless, the association between gouty pitch midge injury and shoot surface, together with the large number of geographic seed sources analyzed, permitted the mapping of geographic variation in susceptibility.

The pattern of susceptibility delineated for families from the southern Cascades and northern Sierra Nevada differed from that of families from the

southern Sierra Nevada. Compared to the broad geographic range of ponderosa pine in the southern Cascades and northern Sierra Nevada, the range in the southern Sierra Nevada is, at any given latitude, narrower and more physiographically complex, perhaps explaining in part why longitudinal trends in susceptibility to gouty pitch midge were not evident in this region. Comparison of the mapped patterns with those of gouty pitch midge infestations in natural stands and plantations throughout the study area is hampered by the inadequacy of existing infestation records. Also, little is known of the environmental requirements of this midge. But Eaton and Yuill (1971) report the gouty pitch midge epidemics have occurred repeatedly in the upper reaches of the Sacramento River drainage in the southern Cascades where we found family susceptibility to gouty pitch midge was lowest. This region averages higher precipitation and lower temperatures than the southern Sierra Nevada. Similar latitudinal and climatic trends in susceptibility to gouty pitch midge were found among northern Rocky Mountain provenances of ponderosa pine planted in Idaho, and US Forest Service Intermountain Experiment Station, Ogden UT., R.J. Hoff (personal communication) has suggested that gouty pitch midge requires rainy, cool, and humid conditions. Our results, finding gouty pitch midge caused more injuries in watered than in unwatered seedlings, lend further support to this hypothesis.

The patterns we found in gouty pitch midge susceptibility were derived from analysis of seedlings of phenotypically superior seed parents at one growing site, but they were based primarily on the shoot surface trait that is highly heritable (Duffield 1985). Environmental conditions at other planting sites may affect the expression of this trait. Available evidence, however, indicates this trait is reasonably environmentally stable in expression. The watering treatment used in the present study did not significantly affect family expression of this trait. Neither was a significant family \times environment effect found in a previous study involving wind-pollinated families planted on nearby fertile and infertile soils (Ferrell et al. 1987).

Because the shoot surface trait is heritable, selection against parents with viscid shoots in areas of high gouty pitch midge susceptibility could reduce the frequency of the viscid shoot type in the progeny and perhaps reduce the possibility of gouty pitch midge damage. Whether such selection would be worthwhile, however, awaits the results of surveys to determine whether gouty pitch midge is a serious pest of young ponderosa pine plantations.

Acknowledgments

We thank the staff of the Institute of Forest Genetics for providing access to the plantation and shoot surface data; William Critchfield of the Pacific Southwest Forest and Range Experiment Station, David Schultz and Jennings Kitamiller of the Pacific Southwest Region, USDA Forest Service, for review of the manuscript; and Lori Nelson and Julie Duffin for providing field assistance.

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The biology, damage and within-tree distribution of the spruce bud midge, *Rhabdophaga swainei* Felt (Diptera: Cecidomyiidae), on black spruce in Newfoundland

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Abstract

Rhabdophaga swainei has one generation a year on black spruce in Newfoundland. Newly hatched larvae enter bud primordia of flushing shoots in late June and early July and larvae mature by fall to overwinter within buds. Pupation occurs within buds the following spring and adults emerge in June. The number of eggs dissected from virgin females averaged 86. *Platygaster rhabdophagae* MacGown (Platygasteridae), *Mesopolobus* sp. (Pteromalidae), *Torymus* sp. (Torymidae) and *Tetrastichus* sp. (Eulophidae) were responsible for high parasitism levels.

Terminal buds were attacked significantly more than lateral or uppermost lateral buds, and more infested buds were in the top third of the crown than at lower crown levels, but displayed no directional pattern according to crown aspect.

An apical meristem never developed in infested buds which never flushed. The *R. swainei* larva redirects the growth of bud primordial cells to produce gall tissues that provide nutrients and an overwintering shelter. If a terminal leader bud is attacked, a subordinate bud assumes dominance and becomes the new leader shoot. During this transition there is a slight loss in height growth. Normal leader growth resumes the following year.

Résumé

La cécidomyie de l'épinette (*Rhabdophaga swainei*) n'a qu'une seule génération par année sur l'épinette noire, à Terre-Neuve. Les larves nouvellement écloses pénètrent dans les ébauches de bourgeons des nouvelles pousses à la fin de juin et au début de juillet; les larves, qui arrivent à maturité à l'automne, passeront l'hiver dans les bourgeons. Elles s'y transformeront en pupes au printemps suivant et des adultes en émergeront en juin. Le nombre moyen d'oeufs trouvés dans des femelles

vierges disséquées était de 86. Les parasites *Platygaster rhabdophagae* MacGown (Platygastridés), *Mesopolobus* sp. (Pteromalidés), *Torymus* sp. (Torymidés) et *Tetrastichus* sp. (Eulophidés) ont été trouvés en grand nombre.

Les bourgeons terminaux étaient beaucoup plus ravagés que les bourgeons latéraux ou latéraux supérieurs; le tiers supérieur du houppier contenait également un plus grand nombre de bourgeons infestés, infestation ne semblant pas se propager de façon particulière, à en juger par l'aspect du houppier.

Les bourgeons infestés n'ont jamais débouffés et leur méristème apical ne s'est jamais développé. Les larves de *R. swaini* désorganisent l'allongement des cellules de l'ébauche de bourgeon qui produisent des galls, sources d'éléments nutritifs et de protection pendant l'hiver. Si le bourgeon d'une pousse apicale est attaqué, un bourgeon accessoire deviendra dominant et formera la nouvelle pousse apicale. Cette période de transition ralentit légèrement l'accroissement en hauteur. La pousse apicale poursuivra normalement sa croissance au cours de l'année suivante.

Introduction

The spruce bud midge, *Rhabdophaga swaini* Felt (Diptera: Cecidomyiidae), attacks all species of spruce throughout the boreal region of Canada (Cerezke 1972; Rose and Lindquist 1977). Trees may form multiple leaders when terminal buds of leaders are infested (Clark 1952; Ruth et al. 1982).

The life history of *R. swaini* has been described by Clark (1952) and Cerezke (1972). Females oviposit in flushing shoots in late spring and newly hatched larvae bore into shoot tips. Larvae feed within developing buds throughout the summer and mature larvae overwinter in buds. Adults emerge in late April to early May.

In Newfoundland extensive multiple leadering has been observed in fire-regenerated stands of black spruce, *Picea mariana* (Mill.) B.S.P., infested by the midge (Carter 1984). The economic importance of this tree species dictated the initiation of studies to examine the biology of the midge and its damage. In this report, the life history, fecundity, parasites, and within-tree distribution of the midge are described, and its effect on bud development and leader growth are discussed.

Methods

Study site

Black spruce stands that regenerated naturally after a major forest fire in 1961 near Glenwood and Carmanville, Newfoundland were sampled. Trees in stands ranged from 1 to 4 m in height and from 10 to 25 years in age.

Midge biology

Infested buds were periodically collected at Gander from May to October 1984 and dissected to determine midge development and parasitism levels. To

estimate fecundity, 30 virgin females collected from the field as pupae were dissected upon emergence and their eggs counted.

Within-tree distribution

The distribution of infested buds within the tree was defined according to crown level (top, middle, and bottom crown thirds), crown aspect (north, east, south, and west quadrants), and bud position on the twig (terminal, uppermost lateral, and lateral). A bud was considered as an uppermost lateral if it was one of a group of distally located "nodal" buds subtending the terminal and as a lateral if it was clearly internodal. Buds intermediate between uppermost laterals and laterals were placed in the same category as the nearest identified bud.

Sampling was completed prior to bud flush in May and early June at Glenwood in 1985 and Carmanville in 1986. Equal numbers of entire year-old shoots ($n = 20$ in 1985, $n = 10$ in 1986) were removed from each of twelve tree sampling zones defined by the intersection of the four crown quadrants and three crown thirds. Twenty-five trees in each of three height classes (1-2 m, 2-3 m, and 3-4 m) were examined. All current-year buds on the sampled shoots were dissected for midges or parasites. Numbers of buds examined, infested buds, and infested buds with parasites were pooled according to category on a per tree basis and transformed by $\log(x + 1)$ (Zar 1974) to obtain normally distributed data sets. Category means were compared by an ANOVA and Duncan's multiple range test (SAS Institute 1985). The maximum probability of a type-1 error was set at 0.05.

Morphology of infested buds

The effect of the midge on bud development was determined by examining histologically processed infested and uninfested terminal buds collected periodically from branches of black spruce at Gander in 1984-85. Buds were bisected longitudinally, fixed in 6% glutaraldehyde in 0.2 M phosphate buffer, dehydrated in a tertiary butyl alcohol series and embedded in Paraplast®. Serial 8-mm sections were stained with hematoxylin and safranin (Johansen 1940).

Effect of midge infestation on leader growth

When the terminal leader bud is damaged, subordinate buds compete for dominance and eventually one becomes the new leader or dominant shoot. During this transition multiple leadering is present and some of the annual gain in leader growth may be at risk. Leader growth over 3 years was compared between two groups of 30 trees of similar size at the Gander site which differed by having either a midge-infested or uninfested leader bud in 1984. Mean tree heights (\pm S.E.) in 1984 were 281.7 ± 5.5 cm and 287.3 ± 5.2 cm for the infested and uninfested groups, respectively. Respective mean diameters at breast height for both groups were 2.7

± 0.1 cm. Annual growth was measured after mid-August which is when the seasonal period of vertical growth of black spruce concludes in the Gander area (Khalil 1973).

Results and discussion

Midge biology

Pupation began in early May and all adults had emerged by the end of July with the majority emerging by the end of June. Immature midge larvae were present in primordial (1985) buds in July. Larvae entered their third instar (overwintering stage) by October. Parasitism of mature larvae in the spring of 1984 ranged from 31 to 44% depending on the date of collection, but did not prevent bud damage. Species included two *Mesopolobus* spp. (Pteromalidae), *Torymus* sp. (Torymidae), *Platygaster rhabdophagae* MacGown (Platygastridae) and *Tetrastichus* sp. (Eulophidae). Although *P. rhabdophagae* has been described (MacGown 1979), taxonomic studies are needed to identify the species of *Torymus*, *Mesopolobus*, and *Tetrastichus* can be identified.

The number of eggs in the ovaries of 1-day-old virgin female midges averaged 86 ± 6 (S.E.) and ranged from 16 to 139, indicating that the species has the potential to increase rapidly in favorable circumstances. Clark (1952) reported nine "fully formed" eggs in the oviduct of one adult female, but made no reference to its age, mated state, and ovipositional history.

Within-tree distribution

Terminal buds were infested significantly more than other bud types in trees at both sites and in all height classes (Table 1). Uppermost lateral buds were infested more than lateral buds but only significantly so at the Carmanville site.

More buds were attacked in the upper crown third of infested trees and significantly so at the Glenwood site. There was a greater number of attacks in the middle crown third than the bottom third; however, this was not always significant (Table 2).

Analysis of bud distribution and damage disclosed that the number of attacks generally increased with height although differences between height classes were seldom significant.

There was no significant difference in the amount of infestation between the four crown aspects; however, there were always more infested buds sampled on the south side than the north side.

These results substantiate those of Cerezke (1972) who found that the amount of infestation was highest on terminal buds, increased with tree height, and was greater on the south rather than the north side. Similar within-tree distribution was also described for the pine needle gall midge, *Thecodiplosis japonensis* Uchida and Inouye (Soné 1985). Perhaps buds in terminal and upper crown positions are higher in nutritive value to midge larvae.

Table 1. Comparison by bud position on twig between the counts of buds (BDS), buds infested by the spruce bud midge (GB) and infested buds with parasites (GBP) on twigs sampled from black spruce in three height classes at Glenwood and Carmanville, Newfoundland in 1985 and 1986, respectively.

Year and bud parameter	Height class	Mean transformed counts per tree*		
		Bud position on twig		
		Terminal	Uppermost lateral	Lateral
1985 BDS	1-2 m	2.38 a,A	2.31 b,A	1.86 c,A
	2-3 m	2.38 a,A	2.40 a,B	2.12 b,B
	3-4 m	2.38 a,A	2.43 a,B	2.23 b,C
	GB	1-2 m	0.45 a,A	0.08 b,A
		2-3 m	0.75 a,B	0.15 b,A
		3-4 m	0.67 a,B	0.10 b,A
	GBP	1-2 m	0.25 a,A	0.00 b,A
		2-3 m	0.29 a,A	0.02 b,A
		3-4 m	0.36 a,A	0.02 b,A
1986 BDS	1-2 m	2.08 b,A	2.35 a,A	2.14 b,A
	2-3 m	2.08 b,A	2.36 a,A	2.07 b,AB
	3-4 m	2.08 b,A	2.31 a,A	1.96 c,B
	GB	1-2 m	0.57 a,A	0.40 b,A
		2-3 m	0.71 a,A	0.45 b,A
		3-4 m	0.71 a,A	0.35 b,A
	GBP	1-2 m	0.35 a,A	0.28 ab,A
		2-3 m	0.48 a,A	0.27 b,A
		3-4 m	0.47 a,A	0.24 b,A

* Counts transformed by $\log(x + 1)$ (Zar 1974). Means not significantly different ($P \leq 0.05$) if followed by the same letter within the same year and bud parameter. Mean groupings within height classes but between bud position on twig are indicated by lowercase letters. Uppercase letters indicate groupings within bud position but between height classes. Means were compared by an ANOVA and Duncan's multiple range test (SAS Institute 1985).

Table 2. Comparison by crown level between the counts of buds (BDS), buds infested by the spruce bud midge (GB) and infested buds with parasites (GBP) sampled from black spruce in three height classes at Glenwood and Carmanville, Newfoundland in 1985 and 1986, respectively.

Year and bud parameter	Height class	Mean transformed counts per tree*		
		Crown level (third)		
		Top	Middle	Bottom
1985	BDS	1-2 m	2.32 a,A	2.21 b,A
		2-3 m	2.47 a,B	2.20 c,AB
		3-4 m	2.52 a,C	2.22 b,B
	GB	1-2 m	0.38 a,A	0.15 b,A
		2-3 m	0.67 a,B	0.11 c,A
		3-4 m	0.59 a,A	0.15 b,A
	GBP	1-2 m	0.21 a,A	0.06 b,A
		2-3 m	0.24 a,A	0.01 b,A
		3-4 m	0.27 a,A	0.05 c,A
1986	BDS	1-2 m	2.29 a,A	2.20 b,A
		2-3 m	2.27 a,A	2.11 c,A
		3-4 m	2.25 a,A	2.11 b,A
	GB	1-2 m	0.53 a,A	0.46 a,A
		2-3 m	0.56 a,A	0.52 a,A
		3-4 m	0.58 a,A	0.46 a,A
	GBP	1-2 m	0.33 a,A	0.33 a,A
		2-3 m	0.34 ab,A	0.37 a,A
		3-4 m	0.40 a,A	0.29 a,A

*Counts transformed by $\log(x + 1)$ (Zar 1974). Means not significantly different ($P \leq 0.05$) if followed by the same letter within the same year and bud parameter. Mean groupings within height classes but between crown levels are indicated by lowercase letters. Uppercase letters indicate groupings within a crown level but between height classes. Means were compared by an ANOVA and Duncan's multiple range test (SAS Institute 1985).

The distribution of midge parasites within the tree generally followed that of their hosts. Infested buds with parasites were more plentiful in terminal bud positions and in the upper third of the crown.

Morphology of infested buds

By late July the terminal vegetative apex of uninfested primordial buds differentiates into an apical zone, peripheral zone, and rib meristem containing densely staining substances (Figure 1) as described for Engelmann spruce, *Picea engelmannii* Parry, by Harrison and Owens (1983). In midge-infested primordial buds, the terminal apex lacks distinct zonation but cells are mitotically active, cytoplasmically dense, and exhibit cytoplasmic stranding (Figure 2). These cells give rise to a distinct and densely staining "nutritive zone" (Rohfritsch and Shorthouse 1982) which sustains the growing larva throughout the summer (Figure 3). True primordial leaves and a normal rib meristem (Figure 4) never develop in infested buds; however, leaf primordia develop into swollen inner bud scales which envelop the midge in a larval chamber (Figure 3).

By late fall the midge larva is mature and presumably ceases to feed. Infested buds collected during the winter had a reduced nutritive zone with collapsed cells nearest the larval chamber (Figure 5). A hard layer of tissue, probably containing phenolic substances, forms next to the receding nutritive zone and may help to protect the larva during the winter (Figure 5).

There is little change in the morphology of infested buds prior to the emergence of the adult midge in late spring although inner bud scales may swell to a certain extent and assume the appearance of a pink-edged rosette. Infested buds do not flush and there is no shoot elongation because an apical meristem never develops.

Under the criteria of Rohfritsch and Shorthouse (1982), buds infested by *R. swainei* can be considered as galled because an insect has redirected normal patterns of plant growth to the formation of new tissues that it uses to its own advantage.

Effect of midge infestation on leader growth

The trees with infested 1984 terminal leader buds had multiple leaders and significantly less dominant shoot growth than uninfested trees in 1984 (Table 3). Cerezke (1972) simulated midge damage by removing the terminal leader buds of white spruce trees, 1.5 to 2.6 m in height, prior to spring bud growth. This resulted in a loss in dominant shoot growth of about 25%, less than the 16% loss observed in the present study. Aside from possible species differences in the growth of black and white spruce, the smaller growth loss might be explained by an earlier assumption of dominance by the bud destined to be the subsequent leader. In Cerezke's (1972) study, bud damage occurred in the spring whereas midge-infested buds are damaged as primordia the previous summer.

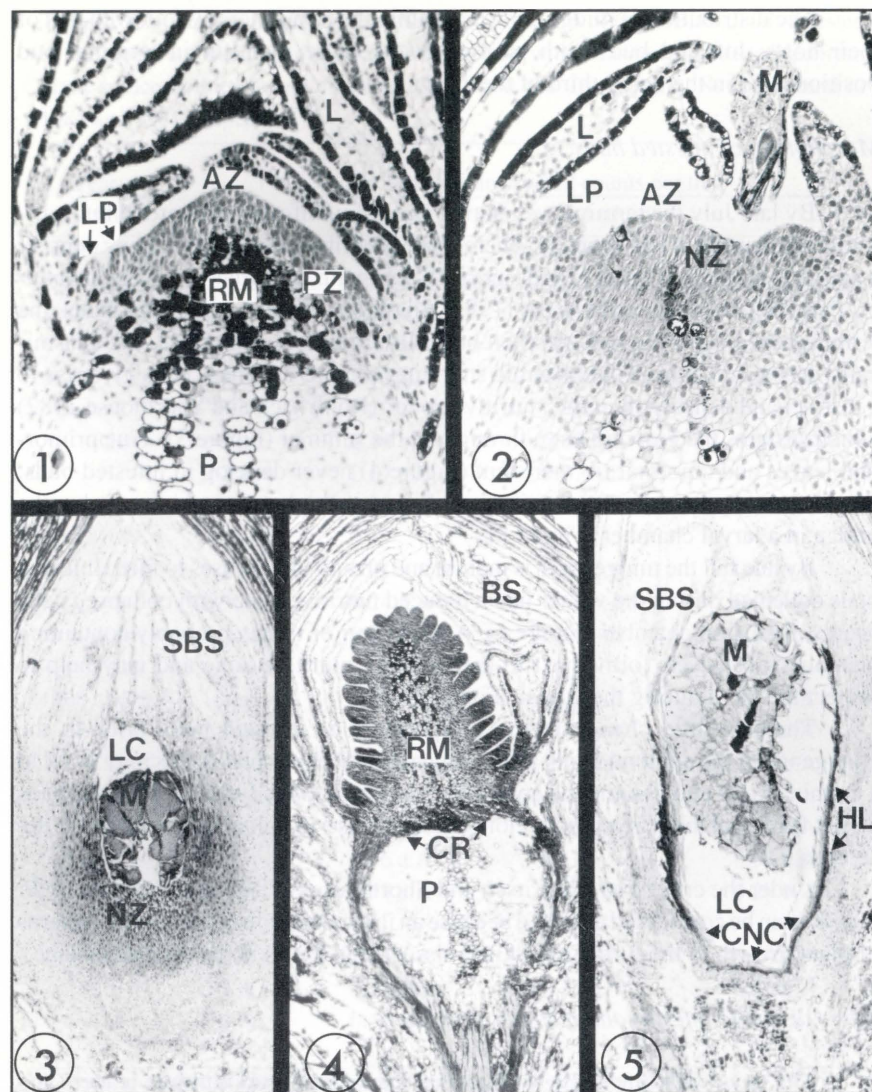


Figure 1. Median longitudinal section of a recently differentiated terminal vegetative apex of an uninfested primordial bud collected in late July. Note apical zone (AZ), peripheral zone (PZ), rib meristem (RM) containing densely staining substances, leaf primordia (LP), basal leaves (L), and pith (P) x 125.

Figure 2. Median longitudinal section of a terminal vegetative apex of a primordial bud infested by *Rhabdophaga swainei* collected in late July. Note densely staining and stranded cells of the young nutritive zone (NZ), relatively undifferentiated apex and the midge larva (M) x 125.

Figure 3. Median longitudinal section of an infested bud collected in late September. Note prominent nutritive zone (NZ), swollen inner bud scales (SBS), larva (M), and larval chamber (LC) x 27.

Figure 4. Median longitudinal section of an uninfested bud collected in late October showing well developed leaf primordia, rib meristem, crown region (CR), pith (P), and thin bud scales (BS) x 27.

Figure 5. Median longitudinal section of an infested bud collected in February showing a mature larva (M), collapsed nutritive cells (CNC), and a hard layer of tissue (HL) x 27.

Leader growth was not significantly different between the groups in 1985 or 1986 (Table 3). Cumulative leader growth from 1984 was significantly higher for the uninfested group in 1985 but not in 1986, indicating that the effect of midge infestation was significant for only 2 years. This conclusion is not considered to be affected by the level of leader bud infestation in 1985 and 1986 which was low and approximately equal for both groups (Table 3). Growth effects of a similar duration also were observed by Cerezke (1972) for artificially damaged white spruce. In summary, host damage by the spruce bud midge appears to be confined to a temporary loss of form due to multiple leadering and a small reduction in height growth when terminal leader buds are attacked.

Acknowledgements

I thank L. Durrouchel, L. Masner, C.M. Yoshimoto, and A. Borkent of the Biosystematics Research Institute for identifying specimens of the spruce bud midge and its parasites. Helpful comments on the manuscript were made by H. Cerezke of the Northern Forestry Centre and W. Bowers of the Newfoundland Forestry Centre. D. Durling (NeFC) provided assistance in the field.

Table 3. A comparison of dominant shoot (leader) growth over three years between two groups of 30 black spruce trees with either midge-infested or undamaged leader buds in 1984*

Status of leader bud in 1984	% of trees with midge-infested leader buds			Dominant shoot growth (cm) (x \pm S.E.)			Cumulative dominant shoot growth (cm) from 1984 (x \pm S.E.)	
	1984	1985	1986	1984	1985	1986	1985	1986
Midge-infested	100	13	10	20.7 \pm 0.9*	16.6 \pm 0.9	18.7 \pm 1.3	37.3 \pm 1.4*	56.0 \pm 2.3
Uninfested	0	13	8	24.7 \pm 1.1*	18.6 \pm 0.9	19.1 \pm 1.6	42.7 \pm 1.7*	61.8 \pm 2.9

Means followed by (*) indicate a significant difference (t-test, $P \leq 0.05$).

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The pine-gall midges and their economic significance in northern Germany

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Abstract

From 1981 till 1984 there were outbreaks of the gall midges *Thecodiplosis brachyntera* and *Contarinia baeri* in Lower Saxony, especially in the eastern parts.

1. In two research areas the attack was low to medium in 1983 and low in 1984.

2. In galls of *T. brachyntera* only one larva per gall was found, while up to 17 larvae of *C. baeri* lived in one pair of needles.

3. Until August mortality of both species reached 90%.

4. Needles attacked by *T. brachyntera* grew to only 30 to 40% of the length of healthy needles. Needle shortening by *C. baeri* amounted up to 88%.

5. *Contarinia baeri* preferred the terminal parts of trees, whereas *T. brachyntera* showed no preference.

6. Especially the highest trees of the research area were attacked by *C. baeri*.

7. Depending on the intensity of attack in 1983 the sprouts from 1984 were shortened.

8. Replies to a questionnaire sent to the state forest districts in Lower Saxony indicated that

- the centres of attack lay in the eastern part of Lower Saxony,
- Contarinia baeri* was more frequent than *T. brachyntera* (80% to 12%),
- the attack declined from 1983 to 1984,
- 10- to 20-year-old stands were mostly attacked,
- stands with a better supply of water and nutrients were preferred.

Résumé

De 1981 à 1984, des infestations des cécidomyies *Thecodiplosis brachyntera* et *Contarinia baeri* ont été enregistrées en Basse-Saxe (Allemagne fédérale) surtout dans l'Est.

1. Dans deux zones d'étude, l'infestation a été classée de faible à moyenne en 1983 et faible en 1984.

2. Alors que dans des galles de *T. brachyntera* on n'a trouvé qu'une larve par galle, on a compté jusqu'à 17 larves de *C. baeri* vivant dans une paire d'aiguilles.

3. Jusqu'en août, la mortalité pour les 2 espèces a atteint 90%.

4. Des aiguilles attaquées par *T. brachyntera* n'ont atteint que 30 à 40% de la longueur des aiguilles saines. Dans le cas des aiguilles attaquées par *C. baeri*, la perte de longueur pouvait atteindre 88%.

5. *C. baeri* préférait les parties terminales des arbres, tandis que *T. brachyntera* n'a pas fait voir de préférence à cet égard.

6. Les plus hauts arbres de la zone de recherche ont été particulièrement touchés par *C. baeri*.

7. Selon l'intensité de l'attaque en 1983, les rejets de 1984 étaient plus courts.

8. Un questionnaire envoyé aux districts forestiers de la Basse-Saxe a indiqué que:

- les foyers d'infestation se trouvaient dans la partie est de la Basse-Saxe;
- *C. baeri* était plus fréquent que *T. brachyntera* (80% par rapport à 12%);
- les attaques ont diminué de 1983 à 1984;
- les peuplements de 10 à 20 ans étaient attaqués en prédominance;
- les peuplements disposant de meilleures ressources en eau et en éléments nutritifs étaient préférés.

Introduction

In the years from 1981 to 1984 large areas in Northern Germany were attacked by the pine-gall midges *Thecodiplosis brachyntera* and *Contarinia baeri*, especially in the dry year 1983. Because they had caused little damage up to this time, these species were nearly unknown to foresters. We therefore started some investigations about their biology, phenology and economic importance.

The pine-gall midges

In Europe two species of gall midges feeding on pine are known, which are able to cause needle losses by sucking needles:

1. The needle-shortening or early flying pine-gall midge *T. brachyntera* and
2. The needle-kinking or late flying pine-gall midge *C. baeri*.

Thecodiplosis brachyntera

The flies of *T. brachyntera* swarm from late April until the middle of May. At this time the females lay their eggs singly or in heaps of two to six eggs under the bud scales of young needles. With the larvae sucking between two needles, the needle pair is stimulated to produce a gall. These needles grow together at their base. The development of most of the larvae is finished by the beginning of November. The grown-up, healthy larvae leave the galls during the winter and produce a cocoon between the needles and the needle sheath. Here they pupate in April and hatch after two weeks.

During the development of the gall the place deformed after egg laying swells and winds around the longitudinal axis. The growth of the needles is strongly

reduced, and the pairs of needles stay more or less reduced, according to the time of attack. The damaged needles change color in autumn and most of them fall during autumn or winter. Total defoliation of the youngest sprouts by gall midge attack is possible.

Contarinia baeri

The midges of *C. baeri* fly from the beginning of June to the middle of July. During this time the females lay one or more eggs at the bases of young needles. After 23-30 days the larvae hatch. From late June on, the adult larvae migrate out of the needle pair in order to overwinter in the soil. As a result of the sucking of the larvae at the base of the needles, the tissue around the sucked place is destroyed and changes color. The attacked needles bend more or less inside the sucked scales, often looking like a walking stick. The damaged needles turn brown by the end of July and begin to fall.

Methods

In two young pine stands (A & B) in Lower Saxony we investigated the attack and its effects on needles and plants. Methods are described elsewhere (Friederichs and Winter 1987).

Results

Study of the occurrence of the larvae in the needles indicated that 84% of the galls surveyed had only one larva of *T. brachyntera* per gall, 8% were attacked by two larvae, 1% by three, and 7% were empty. Fankhaenel (1962), on the other hand, found up to six larvae per gall in Eastern Germany. With *C. baeri* we counted up to 17 larvae (average 4.8) per pair of needles at the beginning of July. In no case did we find the larvae of both species living together in one pair of needles.

The mortality of the larvae was found to be 69% (*T. brachyntera*) and 10% (*C. baeri*) at the end of July. It increased up to 95% and 90% one month later. The larvae seemed to be putrefied either by virosis or bacteriosis. We did not investigate the cause of this high mortality.

The economic importance was estimated by

- the reduction of needle length,
- the needle losses and
- the height of infestation.

In all sampled needles attacked by *T. brachyntera* we found a reduction of needle length up to 70% in intact needles. That resulted in a relatively high loss of assimilation area during the growing season. The needles attacked by *C. baeri* showed significant reductions too. But this damage was not important because the midges did not attack the needles before the end of needle growth (Table 1).

Table 1. Mean needle length (cm) in undamaged trees and in trees damaged by *T. brachyntera* (T.b.) and *C. baeri* (n = number of samples; * and ** indicate significance; n.s. = not significant)

Date	Undamaged	Damaged	
		T. b.	C. b.
08.07.	4.62	2.72**	4.51 ^{n.s.}
n	50	50	50
21.07.	4.88	1.90**	4.29*
n	50	231	92
27.08.	7.00	2.11**	6.13*
n	50	223	297

Table 2. Needle losses in areas A & B (%) by Gall midges 1983 and 1984 in vertical layers

Plot Year	A		B	
	1983	1984	1983	1984
Terminal shoot	17.7	5.8	20.6	6.1
1. whorl	12.1	2.4	13.3	2.4
2. whorl	-	2.4	-	2.6

In spite of considerable needle losses in single trees, the total infestation in the researched areas (both species) was low to medium (Table 2) and declined from 1983 to 1984.

In all cases the terminal shoots were most infested. It is *C. baeri* which prefers the terminal shoots for oviposition. Also, we found 78% of the needle losses in the upper part of the shoots, whereas the lower part was not infested. *Thecodiplosis brachyntera* did not prefer any particular height of the tree for oviposition.

Distribution of attack in stands

In infested stands, the tallest trees showed higher needle losses than the shorter trees. We found this to be so in plantations and young trees as well as in old

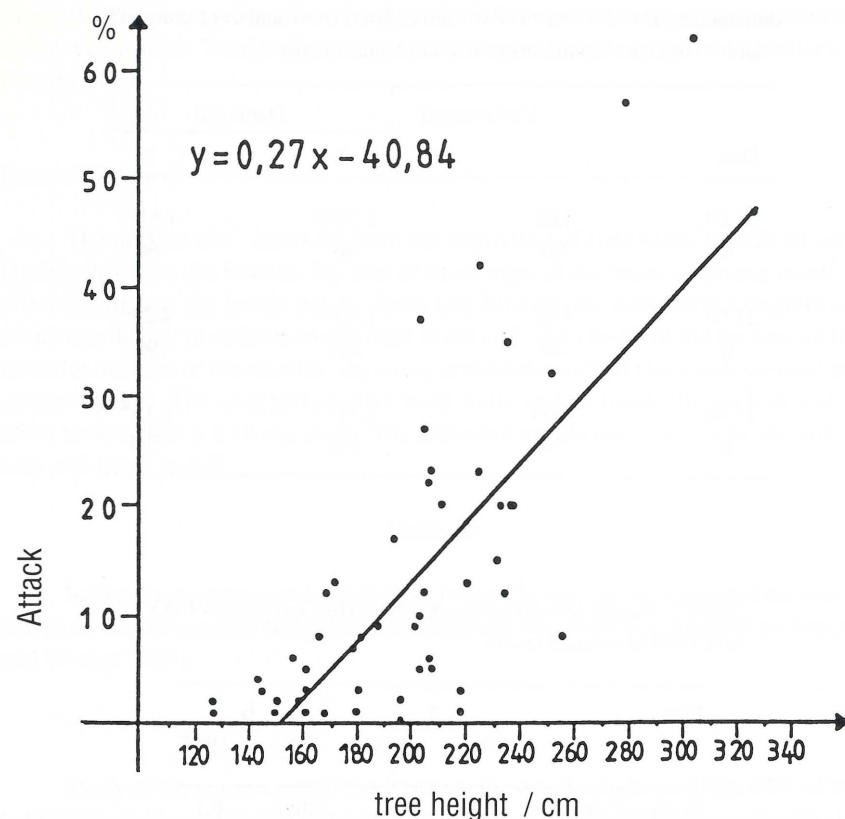


Figure 1. Correlation between tree height and attack, Plot A (1983)

stands. We tested the correlation between tree height and attack in the research plots. In plot A we found a correlation of 0.76, but no correlation in plot B. Probably the adjacent old stands had an influence (Figure 1). Measuring the needle losses in the top shoots in area B, we found that the trees at the edge were more infested than trees inside the area (Table 3).

Effects of the attack

In the summer of 1984 we noticed significant reductions of the new shoots in stands of all ages which suffered heavy needle losses. In area A a weak correlation ($r = 0.29$) was found between the needle losses on last year's shoots and the increment in 1984, but no correlation in area B (Figure 2). The losses of increment were determined by correlating the lengths of the terminal shoots of 1984 to those

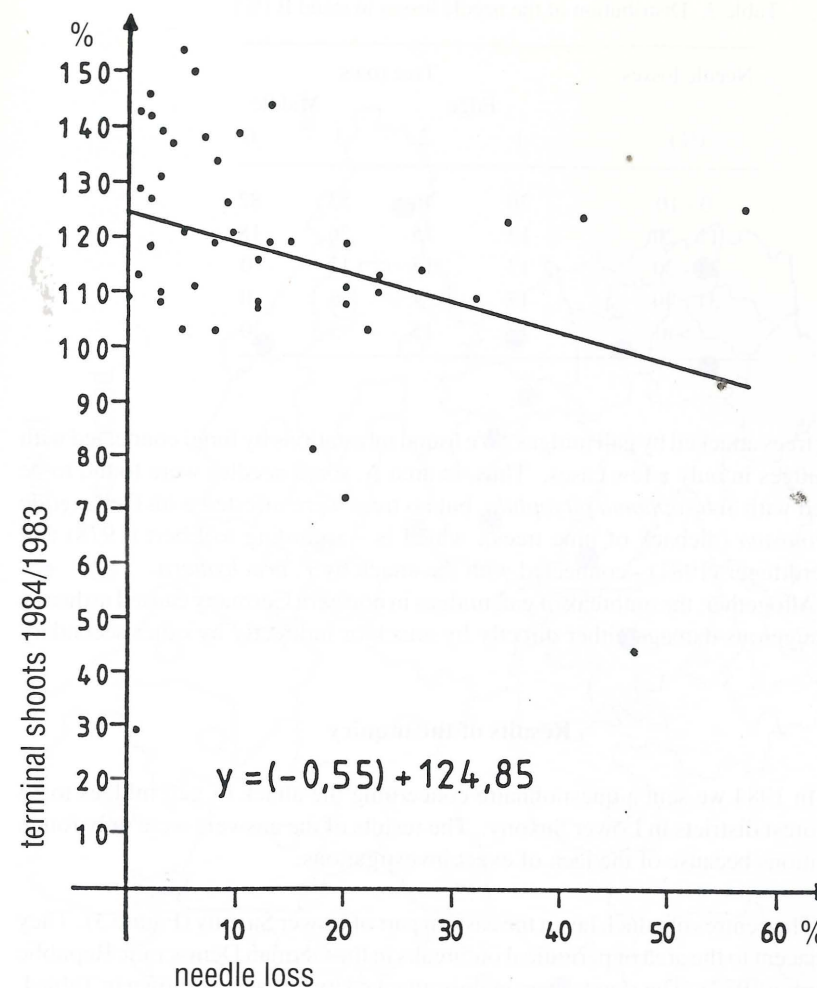


Figure 2. Correlation between the needle losses in 1983 and the length of terminal shoots, Plot B

of 1983. With increasing needle losses in 1983 the height growth decreased proportionally.

The trees selected in the pole stands, which were heavily infested because of their advanced growth, showed the largest reduction of shoots. It is possible that those trees may change their sociological position. This brings silvicultural and economic problems because it prevents the selection of the crop.

The infested trees are generally weakened by the needle losses and predisposed to attacks by other pests. Nevertheless we did not find dying branches or

Table 3. Distribution of the needle losses in stand B (%)

Needle losses (%)	Tree rows			
	Edge	Middle		
	1	2	3	6
0 - 10	36	46	53	82
11 - 20	13	15	26	18
21 - 30	17	15	12	0
31 - 40	17	8	6	0
>40	17	15	3	0

young trees attacked by gall midges. We found infestations by fungi connected with gall midges in only a few cases. Thus, in area A, some needles were found to be infested with *Sclerophoma pityophila*, but no trees were infested with *Cenangium ferruginosum* (dieback of pine trees), which is - according to Ebert (1978) and Schwerdtfeger (1981) - connected with the attack by *T. brachyntera*.

Altogether, the outbreak of gall midges in northern Germany caused no heavy and dangerous damage either directly by attack or indirectly by other secondary pests.

Results of the inquiry

In 1984 we sent a questionnaire concerning the attack of gall midges to 33 state forest districts in Lower Saxony. The results of the answers were only rough estimations because of the lack of exact investigations.

The centres of attack lay in the eastern part of Lower Saxony (Figure 3). They are adjacent to the area of periodical outbreaks in the German Democratic Republic (Skuhravy 1972). The stands were mainly attacked by *C. baeri* as shown in Table 4.

The intensity of attack decreased from 1983 to 1984 in the whole region.

Young stands, especially thickets and small pole stands, were attacked preferentially, but stands up to 50 years old were also attacked. The gall midges preferred stands in relatively good site classes, mainly 6 to 8 (Figures 4 and 5).

According to the soil moisture most infested stands grow on sites with very good to sufficient and constant water supply correlating to the results of site quality. Their nutrient supply is poor to low (Table 5).

However, pines are normally cultivated on sites with very poor to low nutrient supply (compulsory sites). This means, that comparatively better sites are preferred.

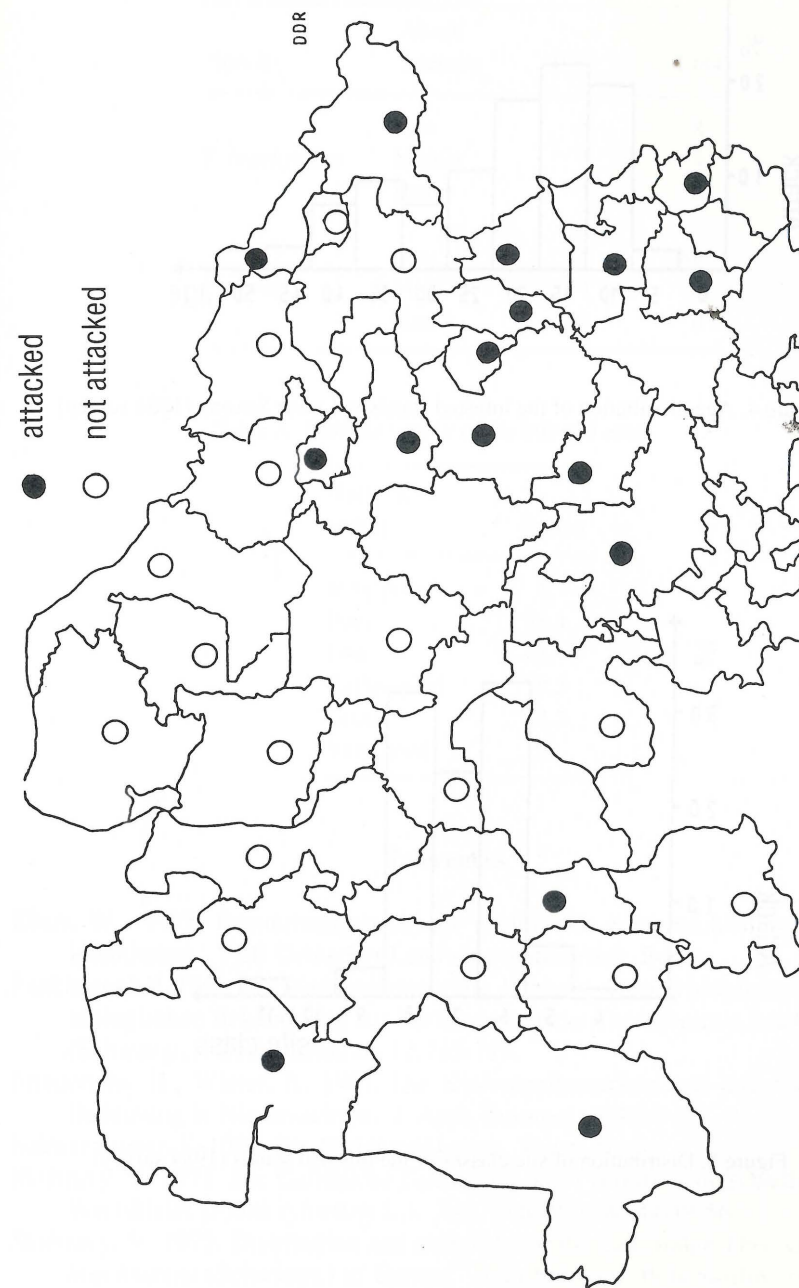


Figure 3. State forest districts in Lower Saxony attacked by gall midges in 1984 (results of survey)

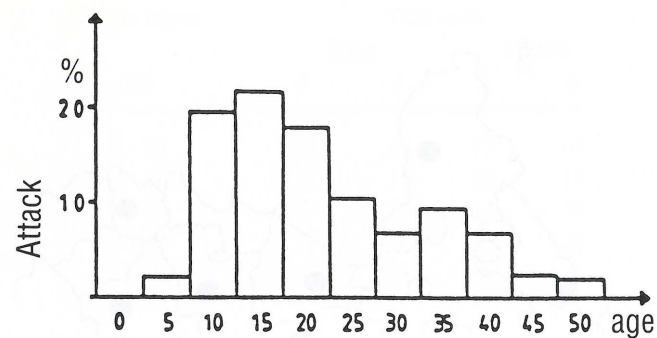


Figure 4. Age distribution of the infested stands in Lower Saxony (1984 survey)

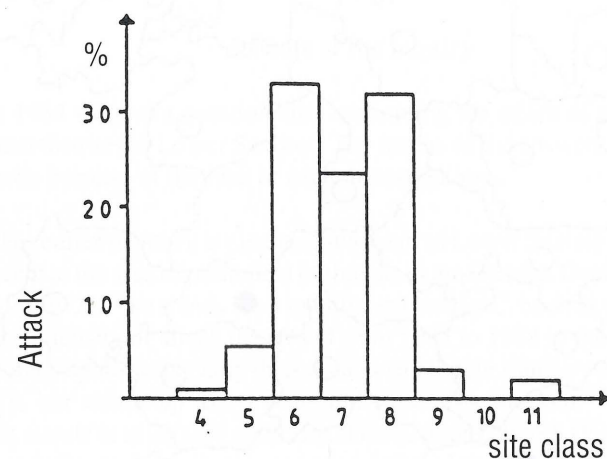


Figure 5. Distribution of site classes of the infested stands (1984 survey)

Table 4. Intensity (%) of Gall midge attack in Lower Saxony in 1983 and 1984

Species	Attack Intensity	1983	1984
<i>T. brachyntera</i>	Low	5	8
	Middle	5	4
	Heavy	1	0
<i>C. baeri</i>	Low	25	88
	Middle	34	0
	Heavy	30	0

Table 5. Nutrient supply of the infested areas

Nutrient supply	% area
Very poor	1.7
Poor	45.4
Low	31.1
Rather good	19.3
Good	2.5
Very good	0

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Defoliators

Control of the Texas leaf-cutting ant
 with a thermal fog application
 of rotenone

The Texas leaf-cutting ant, *Acronyctus mexicanus*, is a pest of citrus and other trees. It is a social insect that lives in colonies and feeds on plant material. The ant is known for its ability to cut leaves into small pieces, which it then carries back to its nest. This can cause significant damage to the foliage of the trees it infests. The Texas leaf-cutting ant is a major pest of citrus trees in Texas, and its control is a major concern for citrus growers. One method of control is the use of thermal fogging, which involves the application of a rotenone solution to the foliage of the trees. This solution is carried back to the nest by the ants, where it kills them. Thermal fogging is a highly effective method of control, and it is the only method that can reach the ants in their nests. The use of thermal fogging for the control of the Texas leaf-cutting ant is a well-established practice, and it has been shown to be highly effective in reducing the damage caused by the ant to citrus trees. The Texas leaf-cutting ant is a pest of citrus and other trees, and its control is a major concern for citrus growers. One method of control is the use of thermal fogging, which involves the application of a rotenone solution to the foliage of the trees. This solution is carried back to the nest by the ants, where it kills them. Thermal fogging is a highly effective method of control, and it is the only method that can reach the ants in their nests. The use of thermal fogging for the control of the Texas leaf-cutting ant is a well-established practice, and it has been shown to be highly effective in reducing the damage caused by the ant to citrus trees.

Control of the Texas leaf-cutting ant, *Atta texana* (Hymenoptera: Formicidae), with a thermal fog application of resmethrin

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Abstract

The Texas leaf-cutting ant, *Atta texana* (Hymenoptera: Formicidae), causes serious damage to pine plantations in Texas and Louisiana. Control methods currently available in the U.S.A. are either ineffective or dangerous to use. Thermal fogs containing aldrin or heptachlor have been used operationally to control leaf-cutting ants in South America, particularly in Brazil. A unique technique for applying a thermal fog containing resmethrin was tested for efficacy on *Atta texana* colonies in Texas. Effective control was attained with resmethrin (1% ai) applied as a fog at a rate of 10.2 ml/m² in 90-ml portions in entrance holes distributed evenly over the central nest area. Each injection treated ca. 8.5 m² of nest area.

Résumé

La fourmi champignoniste (coupeuse de feuilles) du Texas *Atta texana* (Hymenoptera: Formicidae) cause de graves dommages aux plantations de pins du Texas et de la Louisiane. Les méthodes de répression actuellement disponibles aux États-Unis sont souvent inefficaces ou dangereuses à utiliser. Des pulvérisations thermiques de brouillards contenant de l'aldrin ou de l'heptachlore ont été utilisées de façon opérationnelle pour lutter contre des fourmis champignonistes en Amérique du Sud, plus particulièrement au Brésil. Une technique spéciale de pulvérisation thermique d'un brouillard contenant de la resmethrine a été essayée contre des colonies d'*Atta texana* au Texas. Une répression efficace a été obtenue par injection de la resmethrine (1% d'ingrédient actif) à la dose de 10.2 ml/m² en portions de 90 ml dans les trous d'entrée distribués uniformément dans la zone centrale du nid. Environ 8.5 m² de la zone du nid était traitée par une injection.

Introduction

Leaf-cutting ants of the genus *Atta* (Hymenoptera: Formicidae) typically construct large subterranean nests, where the ants cultivate a fungus which serves as their primary source of food. These generalist herbivores cause millions of dollars worth of damage each year to a large variety of crops, particularly in tropical and subtropical America. Crops considered especially vulnerable to leaf-cutting ant damage include citrus, cocoa, coffee, maize, cotton, eucalyptus, and pines (Cherrett 1986b). The Texas leaf-cutting ant, *Atta texana* (Buckley), is the northernmost representative of the genus and is a serious pest in young pine plantations in western Louisiana and eastern Texas, particularly on well drained soils (Moser 1984; Cameron and Riggs 1985).

Mariconi (1970), Cherrett (1986a), Jaffe (1986), and Vilela (1986) have given comprehensive accounts of the many tactics which have been used against leaf-cutting ants. These include the use of explosives to blow up nests; persistent organochlorine insecticides applied to nests either as liquids, dusts, or thermal fogs; fumigants such as carbon disulfide, hydrogen cyanide, and methyl bromide; and baits containing slow acting toxicants such as aldrin, heptachlor, or mirex which are retrieved and carried by the ants into their underground nests.

The application of toxic baits, usually containing mirex, is the control technique most widely used to control leaf-cutting ants in Central and South America. However, thermal fogs containing aldrin or heptachlor applied with a Swing-Fog^{®1} machine have received considerable attention and wide use in recent years, especially in Brazil (Kennard 1965; Nogueira et al. 1981; Nogueira et al. 1982a,b; Nogueira et al. 1985; Vilela 1986).

Aldrin, heptachlor, and mirex are highly effective against ants, but have been banned in the United States and some other countries due to environmental concerns. Methyl bromide, a highly toxic fumigant, has been the only practical and effective product available for leaf-cutting ant control in the United States since the banning of mirex in 1978. Clearly, alternative control methods are needed.

Beginning in 1981, the Texas Forest Service began a program to develop alternative control techniques against the Texas leaf-cutting ant. Numerous toxic bait formulations containing hydramethylnon, abamectin, fenoxycarb, or sulfluramid have been tested for acceptance and efficacy against *A. texana* (Texas Forest Service 1984). Results of these tests will be reported elsewhere.

A unique technique has been developed for control of the red imported fire ant, *Solenopsis invicta* Buren, by Southern Avionics Company Research Center and Ant Fire, Inc., a privately owned corporation from Beaumont, Texas. This technique utilizes a device designed to deliver Earthfire^{®1} (resmethrin 1% ai) in the form of a thermal fog into subterranean ant nests. Trials conducted in Texas to develop this technique for the control of *Atta texana* are reported here.

¹ Mention of specific insecticides and trademarks in this document does not constitute recommendations for their use or imply that uses discussed here are registered.

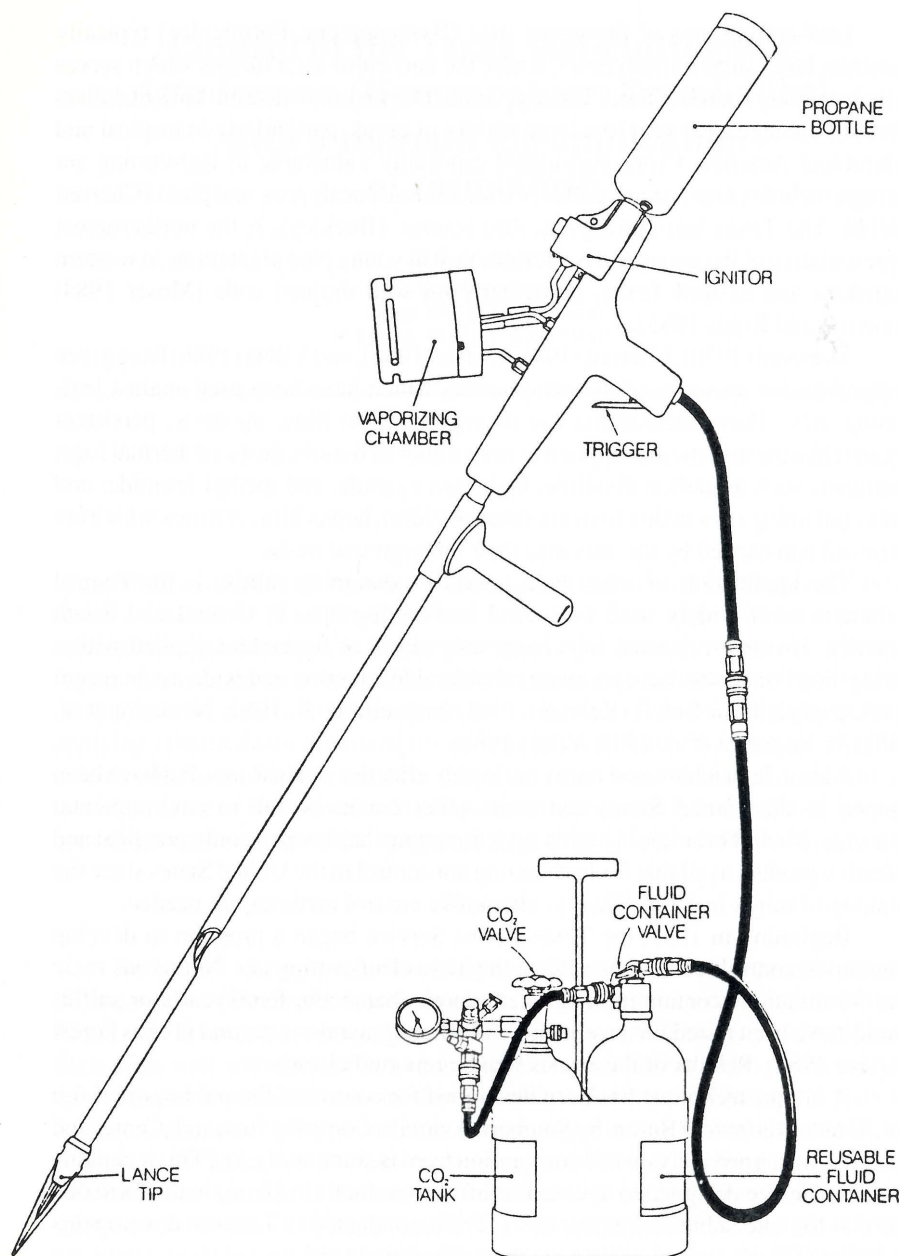


Figure 1. Subsurface thermal fogging device (Earthfire Injection System®).

Materials and methods

The subsurface thermal fogging device (Earthfire Injection System®) used in this study consisted of a propane-fueled burner that heated a CO₂-pressurized solution containing 1% (ai) resmethrin in a petroleum solvent to ca. 480°C resulting in a thermal fog (Figure 1). The thermal fog was delivered through a 1-m-long probe into entrance/exit holes in the central nest area of *A. texana* colonies.

Following preliminary trials, the pressurized holding tank was outfitted with a regulator valve to allow for constant pressure and flow rate of the material through the vaporizing coil resulting in a steady flow of thermal fog. This also allowed application rates to be accurately determined based on duration of flow instead of measuring the amount of material used from the tank after each injection.

The thermal fog which is heavier than air was drawn into the subterranean galleries and chambers of the nest by simply placing the tip of the probe in the opening of an entrance/exit hole; the material was not otherwise forced into the nests. Occasionally the fog was immediately ejected from an injection hole, in which case another adjacent hole was utilized. The thermal fog sometimes exited through adjacent holes which were then closed off to prevent loss of the toxicant. Otherwise the remaining holes in the colony were not sealed.

Following preliminary applications, the decision was made to treat numerous holes evenly spaced over the apparent central nest of the colony rather than continue applying the fog into one central hole. It often seemed impossible to fill up the colony from one hole as fog continued to be drawn in without exiting through other holes after several minutes of application.

Four replicated tests were then conducted on *A. texana* colonies in east Texas. Dates of application, rates, mean nest areas, and numbers of replicates for each of these tests are listed in Table 1. At each site a series of suitable test colonies was first selected to exclude extremely large (larger than 30 x 30 m), small (less than 3 x 3 m), and complicated nests (two or more adjacent colonies, or colonies without a distinct central nest area). Treatments were then randomly assigned to the selected ant nests.

The central nest area, or nest area, was defined for purposes of these tests as the above-ground manifestation of the nest characterized by dense concentrations of entrance/exit holes surrounded by mounds of soil particles brought to the surface by the ants. Scattered peripheral entrance/exit holes were not included in the nest area. Application rates were based on the area of the central nest (length x width, estimated by pacing) and expressed in ml of toxicant per m² of nest area. Test 1 was a rate test. The amount of toxicant injected in each hole, and consequently the nest area covered by each injection, varied among colonies in this test. The amount of toxicant injected per hole was standardized in subsequent tests and is expressed as nest area per injection (Table 1). Tests 2 and 3 were similar but conducted at different sites and seasons. Two levels of nest area per injection (many injection holes with small amounts of toxicant in each vs few injection holes with large amounts of toxicant in each) were compared in Test 4.

Table 1. Application dates, rates, and efficacy for Earthfire® (1% ai resmethrin) applied as a thermal fog to *Atta texana* colonies in east Texas, 1986-1987

Test no.	Date of applic.	Applic. rate	Nest area /injection ^a	Mean nest area	Reps	% Reduced act. ^b @ (wk)	Signif. level ^c	% Inactive colonies @ (wk)
1	24 MAY 86	5.1 ml/m ²	variable	43 m ²	6	70.9 (4)	0.0012	33 (16)
	24 MAY 86	10.2 ml/m ²		67 m ²	6	97.7 (4)		67 (4)
	29 MAY 86	20.3 ml/m ²		96 m ²	4	98.2 (4)		50 (4)
		0		60 m ²	6	-		0
2	4 SEP 86	10.2 ml/m ²	9.8 m ²	271 m ²	5	56.6 (2)	0.0037	40 (10)
	11 SEP 86	10.2 ml/m ²	9.8 m ²	417 m ²	5	99.3 (2)		60 (20)
		0		292 m ²	5	-		0
3	15 DEC 86	10.2 ml/m ²	8.7 m ²	157 m ²	6	98.5 (16)	0.0109	83 (8)
		0		139 m ²	3	-		0
4	15 JAN 87	10.2 ml/m ²	8.7 m ²	192 m ²	6	100.0 (4)	0.0055	100 (4)
	15 JAN 87	10.2 ml/m ²	26.5 m ²	177 m ²	6	91.6 (4)		80 (16)
		0		312 m ²	3	-		0

^a Nest area per application: variable - the area covered by each injection varied in Test 1; 9.8 m² - ca. 100 ml applied per injection hole; 8.7 m² - ca. 90 ml applied per injection; 26.5 m² - ca. 270 ml applied per injection.

^b Percent reduction in number of active holes in central nest relative to untreated check colonies at the indicated time interval following treatment; data presented in this table are for the interval when the maximum control attained was first observed.

^c Significance of treatment differences for percent of initial activity in each test according to Kruskal-Wallis one-analysis of variance.

To evaluate the effect of treatments on ant colonies, the number of active entrance/exit holes (defined as those with ants present, fresh deposits of soil, or fresh vegetative materials in or around them) were counted just prior to treatment and periodically following treatment (usually at 4, 8, and 16 weeks). Untreated check colonies were included and monitored in each test to account for possible seasonal trends in ant activity. The percent of initial activity was calculated for each colony at each post-treatment check and differences in mean percent of initial activity among treatments were tested for significance with the Kruskal-Wallis one-way analysis of variance (Daniel 1978) utilizing SPSS procedures (SPSS Inc. 1986). Percent reduction of activity compared to check colonies was calculated for each treatment at each post-treatment interval, as well as the percentage of the colonies which were totally inactive.

Results and discussion

Results of field tests are summarized in Table 1. The data selected for presentation represents the maximum control attained for each treatment. The post-treatment interval when this maximum level of control was achieved is indicated in parentheses.

Significant treatment differences ($P < 0.05$) were observed in each test. Earthfire® delivered as a thermal fog is highly toxic to *A. texana*. Ants coming in contact with the fog are quickly paralyzed and die within minutes. Maximum reduction in activity in treated colonies was generally observed at the first post-treatment check and activity on most surviving treated nests increased gradually during the post-treatment monitoring periods.

Greater than 90% reduction of activity compared to check colonies was observed in all treatments except the 5.1 ml/m² application rate in Test 1 and the 4 September 1986 application in Test 2. It appears that 5.1 ml/m² was insufficient toxicant to provide adequate control while 20.3 ml/m² did not increase efficacy over the 10.2 ml/m² rate. The application site, methods, and rates were identical for the two September application dates, but the data were separated due to obvious differences in efficacy between these application dates. Resmethrin is very unstable in sunlight. It is suspected that the Earthfire® applied on 4 September 1986 was less effective due to photodegradation. All treated colonies were completely controlled at 10.2 ml/m² and 8.7 m² per injection in Test 4. Numerous injection sites provided better control than few injections. It also appeared that several of the colonies which were not completely controlled survived in a small peripheral portion of the nest which may not have received sufficient toxicant. Distribution of the fog throughout the entire nest may be necessary to obtain complete control.

Factors warranting further investigation are time of year and soil condition relative to efficacy of this treatment. The efficacy of this control method, as well as that of fumigation with methyl bromide, may vary with season depending on soil moisture, soil porosity, and distribution of ants in the subterranean nests (Moser 1984).

The time required to treat *A. texana* colonies with the thermal fogging technique described in this paper is highly variable depending on the size of the colonies, the distance between colonies, and the type and amount of vegetation covering the nest area. Assuming ant colonies are in close proximity and average 100 m², a two-person crew with one thermal fogging injector system would be able to treat ca. 12 to 18 *A. texana* colonies in an 8-hour day. Although one person could operate the injector system, it would be highly recommendable to work in two-person crews for efficiency and safety.

The Earthfire Injection System[®] vaporizing chamber and lance become extremely hot after continued use and can cause severe burns. The petroleum solvent in the Earthfire[®] solution is highly flammable. The thermal fog and liquid should be kept away from open flames. Breathing the thermal fog or prolonged contact with the skin should be avoided.

Conclusion

Resmethrin (1% ai) applied as a thermal fog effectively controlled the Texas leaf-cutting ant in tests conducted in east Texas. Factors identified as important for optimal control were application rate, distribution of injection sites, and nest area covered by each injection (amount of material applied per injection). Earthfire[®] applied at 10 ml/m² in 90 ml portions per injection (ca. 8.5 m² per injection) evenly spaced over the central nest area provided 100% control in January. The results of this study led to the U.S. Environmental Protection Agency registration of Earthfire[®] for the control of *A. texana*.

As indicated by others (Cherrett 1986; Vilela 1986), thermal fogging is efficient and effective on leaf-cutting ant colonies of small to medium size. But this control technique requires complex equipment which has to be transported and maintained, the central nest must be located, and it is time consuming to apply on large colonies. Currently, the Earthfire Injection System[®] is not widely used to control *A. texana* as it is available only on a contract basis applied by personnel from Ant Fire, Inc. However, thermal fogging for controlling leaf-cutting ants could become more widely used if a small self-contained and relatively inexpensive injection system were made available to the general public.

Acknowledgments

I thank Carol Riggs and Charles Ware for their help with field work in this study; Lee Rayburn for assistance with statistical analyses; and Ronald Billings and Joe Pase for their critical review of the manuscript. Also, I wish to thank Charles W. Evans II, formerly with the SAC Research Center, and Brooks Goodhue, Dale Slaughter, and George Smith of Ant Fire Inc., Beaumont, Texas for providing equipment and assisting with thermal fog applications. Finally, I thank Champion International, Erwin Roemer Jr., and James Brown for providing study sites.

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Effects of crude aqueous neem extracts on defoliation of *Khaya nyasica* by *Heteronygmia dissimilis* (Lepidoptera: Lymantriidae) in East Africa¹

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Abstract

An outbreak of the mahogany defoliator *Heteronygmia dissimilis* at Morogoro, Tanzania, prompted an investigation of, among other aspects, potential controls for this insect by locally available means.

Boiled and unboiled crude aqueous extracts of the neem tree, *Azadirachta indica*, obtained from pulverized foliage (1% conc.) and seed kernel (0.5 and 1%), were applied to foliage of mahogany, *Khaya nyasica*, and offered to first, third and last instar larvae of *H. dissimilis* under laboratory conditions. Feeding response was monitored by way of leaf areas consumed.

Neem kernel extracts at the 1.0% concentration afforded complete protection against defoliation by all instars. The 0.5% seed kernel and 1% leaf extracts offered only partial protection, i.e., about two-thirds and one-third, respectively, with decreases of efficiency against later instars. Boiling of extracts increased foliar protection slightly. Mortality of larvae was attributed to starvation.

Résumé

Une épidémie du défoliateur de l'acajou, *Heteronygmia dissimilis*, à Morogoro en Tanzanie, a entraîné la tenue d'une étude portant notamment sur les moyens de lutte éventuels et localement disponibles contre cet insecte.

Des extraits aqueux bruts bouillis et non bouillis de margousier *azadirachta* (*Azadirachta indica*) faits à partir de feuilles pulvérisées (conc. de 1%) et de graines (0.5 et 1%) ont été appliqués sur des feuilles d'acajou (*Khaya nyasica*) qui ont été offertes à des larves de *H. dissimilis* à leur premier, troisième et dernier stade de

¹ Results of a student research project, required of seniors at Sokoine University of Agriculture at Morogoro, Tanzania

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développement. Le degré de prédation a été établi en fonction de la surface foliaire consommée.

Les extraits à base de graines de margousier, à une concentration de 1%, ont assuré une protection complète contre la défoliation causée par tous les instars. Les extraits de graines à 0.5% et de feuilles à 1% n'ont procuré qu'une protection partielle, soit des deux tiers et du tiers respectivement, leur efficacité contre les derniers instars allant en décroissant. Les extraits qui ont été bouillis ont procuré une protection du feuillage légèrement supérieure. La mortalité des larves a été attribuée à l'inanition.

Introduction

Since the early 1970's, the neem tree (also Indian lilac or margosa), *Azadirachta indica* A. Juss (= *Antelaea azadirachta* (L.) Adelbert), has been the focus of considerable interest (Jacobson 1982a). This native of tropical Asia and Africa, now grown in many parts of the tropics, combines easy culture in semi-arid climates with numerous benefits and uses (Michel-Kim and Brandt 1982; Radwanski 1980), such as energy applications (firewood, shade, and methane production), soil amelioration, and miscellaneous pharmaceutical properties.

One of this tree's most promising assets, however, is its potential in pest control. Neem itself is vulnerable to few insect pests (Schoonhoven 1982), and extracts from its leaves, bark, and fruit are known to have repellent, antifeedant, growth-disrupting, sterilant, and other biocidal properties against many agriculturally and horticulturally important insect species in various orders (Steets 1975; Warthen 1979). As a matter of fact, no plant material with greater activity or with activity against a broader spectrum of pest insects has yet been found (Jacobson 1982a).

Neem research in the USA has been intense (Jacobson 1982b), and presently a refined commercial neem formulation (Margosan-0) is already being considered for registered use on vegetable and ornamental crops. As unrefined neem extracts generally compare favorably with the more elaborate formulations commonly tested in developed countries (Jacobson 1982b), natural neem biocides are of particular appeal for Third World countries. The tree is a local resource in the tropics, and extraction of the toxic ingredient is rather easily accomplished by cottage industry or self-help, obviating dependence on imports and major expenditures (Michel-Kim and Brandt 1982).

Phagodeterrent and repellent effects of neem extracts can, however, differ considerably between insect species (Schmutterer et al. 1982). On certain plant species it is also possible that innate attractants may negate repellency effects by neem applied to them (Ladd 1982). As a result, protectant effects of neem need to be tested for each candidate pest species and its hosts. An outbreak of the defoliator *Heteronygmia dissimilis* at Morogoro, Tanzania (Schabel et al. 1988), on African mahogany, *Khaya nyasica*, a meliaceae relative of *A. indica*, prompted a simple test with locally produced neem extracts as antifeedants against this insect.

Materials and methods

Neem and mahogany trees on the campus of Sokoine University of Agriculture at Morogoro, Tanzania, provided all leaves and fruits, as well as the insects used in this study. Experiments were conducted in August and September at ambient temperatures under laboratory conditions.

Insects

Eggs and larvae of *H. dissimilis* were initially obtained by collecting gravid females on or near 10-year-old mahogany trees during March. The caterpillars were reared in cages (30x30x60 cm) consisting of 0.3-mm-mesh mosquito netting. Fresh *Khaya* leaves, petioles immersed in water, were offered daily. Resulting adults were allowed to mate in the cages, to assure subsequent (August/September) availability of specimens for experiments.

Neem extracts

Ripe fruits were collected in mid-April from about 5-year-old neem trees. Decortication was accomplished by first soaking them in cold water for two days, then manually removing the pulp. After air-drying for three days, the seeds were pounded lightly in a crucible and winnowed to obtain the kernels. These were sun-dried for another three days before being powdered in a blender. Leaves obtained from the same trees were sun-dried for three days, then powdered.

Kernel and leaf powders were stored in separate plastic bottles in a refrigerator until used four months later. Commercial detergent of the FOMA brand (made by Sabuni Industries, Tanzania) at a strength of 0.02% in distilled water served as a wetting agent for suspension of the powders, and as an additive in the controls.

Experiment

Following preliminary experiments to determine approximate minimum dosage levels, aqueous neem kernel extracts of 0.5 and 1.0% strength, and leaf extract of 1.0%, were tested with respect to foliage protection against *H. dissimilis*. Suspensions were shaken for five minutes, then fresh leaflets of *Khaya* were immersed in each formulation. After drying for 30 minutes, the leaves were offered to five individuals each of first, third, and last instar larvae, all of which had just gone through a 12-hour starvation period. For three consecutive days, one newly treated leaf was added daily to the beakers containing the test caterpillars. Controls were treated identically except that no neem extracts were added. In a second identical test all formulations were first boiled for one hour, then allowed to cool to room temperature before being used. Leaf areas consumed were measured with the aid of a millimeter grid.

Results and discussion

The antifeedant effects resulting from neem treatment of *Khaya* leaves were readily evident (Figure 1). Complete foliar protection against all instars of *H. dissimilis* was achieved by the application of 1% kernel extract, whereas control leaves were freely consumed. Leaves treated with 1.0% leaf and 0.5% kernel extract revealed limited feeding by caterpillars, i.e., afforded partial leaf protection with greater effects in the 0.5% kernel treatment. Leaf protection against older instars decreased in treatments involving 0.5% kernel and 1.0% leaf extracts, with the least protection being afforded by leaf extract treatments. Thus the superior quality of 1% neem kernel extract for the protection of mahogany leaves against early to later instars of *H. dissimilis* was clearly established for laboratory conditions. The slight gains in leaf protection resulting from boiling of formulations do not appear sufficient to justify this practice.

Protection of *Khaya* leaves by neem extracts apparently was a result of phagodeterrence and caterpillar mortality. In the 1% kernel treatment, caterpillars did not consume any foliage at all, while in the other treatments consumption was limited, compared to the control (Figure 1). Mortality effects decreased with more advanced instars, and increased from 1% leaf, to 0.5% and 1% kernel extracts (Figure 2). Complete mortality of first instar larvae resulted on the second day in the 1.0% boiled kernel, and on the third day in the 0.5% boiled and unboiled kernel treatments. In the third instar group, the 1.0% boiled kernel treatment produced complete mortality on the third day, but only 60% in the 0.5% boiled and unboiled kernel treatments. Last instar larvae suffered 60 and 100% mortality in the 0.5 and 1.0% boiled kernel groups, respectively. Boiled and unboiled leaf extract treatments yielded 80, 40 and 20% mortality on the third day in first, third, and last instar larvae, respectively. No mortality was experienced in the control groups. The no-choice situation which the caterpillars were subjected to under laboratory conditions may diminish the practical significance of these mortality data.

Although 1% leaf extract proved less effective for leaf protection than did kernel extracts, leaf extracts in concentrations exceeding 1%, may deserve to be explored. Adhikary (1982) obtained 25% mortality of larvae of *Plutella xylostella* L. by the use of 3% neem leaf extract. Unlike seeds, leaves of the evergreen neem are available throughout the year, are not subject to animal consumption, and are not dependent on tree maturity and fluctuations in fructification. Mixing leaf and seed extracts of appropriate strength may be of interest, whenever seed extract is in short supply, and thus it deserves to be investigated.

Neem application timed against early instar larvae would appear to recommend itself as a most promising approach for control of *H. dissimilis* on *Khaya*. Unfortunately, various instars of this multivoltine defoliator tend to overlap (Schabel et al. 1988). As a result, higher neem concentrations which may be effective against a wider range of instars are advisable.

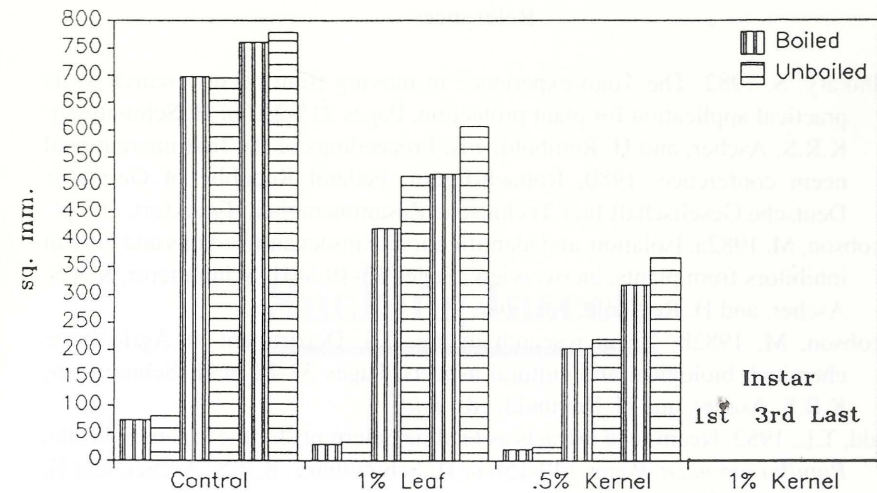


Figure 1. Leaf consumption (mm²) in three days exposure to neem-treated foliage.

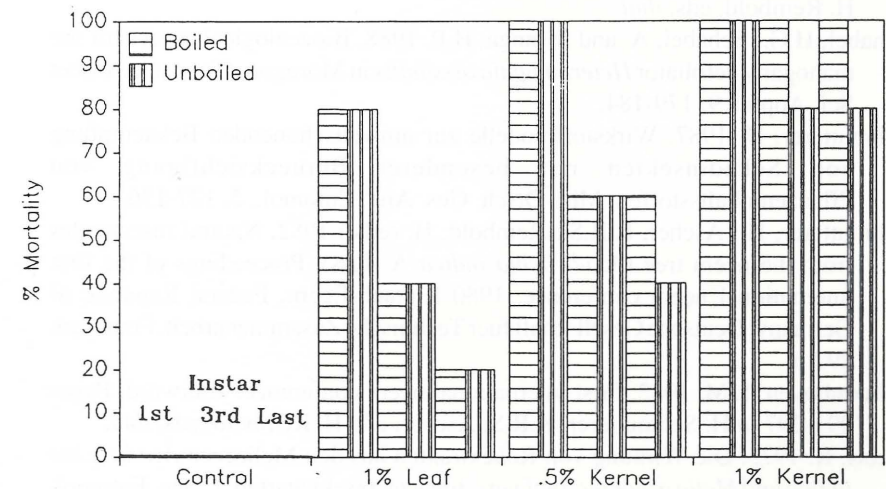


Figure 2. Mortality of various instars after three days of exposure to neem-treated foliage.

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Sucking Insects

The morphology and biology of *Cinara pinikoraiensis* (Homoptera: Lachnidae)

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Abstract

The morphology and biology of *Cinara pinikoraiensis*, an aphid feeding on branches and stems of young Korean pine, *Pinus koraiensis*, in China, is reviewed. Keys are presented to separate *C. pinikoraiensis* from *C. pinea*, *C. cembrae* and *C. shinjii*.

Résumé

Ce rapport traite de la morphologie et de la biologie du *Cinara pinikoraiensis*, un puceron qui se nourrit à même les branches et les tiges des jeunes pins de Corée, en Chine. Des legendes aident à distinguer le *C. pinikoraiensis* du *C. cembrae* et du *C. shinjii*.

Introduction

The pine aphid, (*Cinara pinea* Mordvilko), is a common species in branches and stems of young pine. It is distributed throughout the northeast, north and northwest of China. Its hosts are Korean pine (*Pinus koraiensis*), Chinese pine (*Pinus tabulaeformis*), Japanese red pine (*Pinus densiflora*), Scotch pine (*Pinus sylvestris* var. *mongolica*) and other pine species. (Fan Zon-min 1958, 1962; Anonymous 1974, 1983).

In 1985, we observed and identified the species damaging young Korean pine in natural and artificial regeneration, in clear cuts and in city trees. We concluded that the species damaging Korean pine is *Cinara pinikoraiensis* and not *C. pinea*.

1. Morphological characters and differences from other relative species

According to the literature, we know that the aphids damaging five-needle pine are four: *C. pinea* Mordvilko, *C. cembrae* Chol., *C. shinjii* Inouye, and *C. pinikoraiensis* Zhang. *Cinara pinea*, which has been recorded in Europe, Asia, and

Table 1. Morphological characteristics of *C. pinea* and *C. pinikoraiensis*

	Species	
	<i>C. pinea</i>	<i>C. pinikoraiensis</i>
Collecting place	England	Harbin
Host plant	<i>Pinus sylvestris</i>	<i>Pinus koraiensis</i>
Body length (mm)	3.1 - 5.1	3.1 - 4.3
Diameter of siphuncular cone (μ)	270 - 700	140 - 271
Mesosternal tubercle	absent	present
Chitinized rim of primary rhinaria	present	present
Sclerites on abdominal tergites 2-5	large	large
Length of antennal segments (μ)		
III	500 - 740	470 - 633
IV	220 - 360	156 - 182
V	280 - 400	239 - 316
VI	140 - 230	161 - 197
Length of rostral segment (μ)		
IV	210 - 290	270 - 311
V	110 - 170	73 - 104
First Segment of hind tarsus		
basal diameter (μ)	47 - 65	41 - 57
dorsal length (μ)	137 - 220	41 - 52
Hind tarsus segment		
1, ventral length	220 - 330	104 - 114
2, length	350 - 530	244 - 275
Hind tibia length (mm)	1.8 - 3.4	1.9 - 2.6
Length of longest hair on:		
Third antennal segment	90 - 210	57 - 104
Hind tibia	120 - 230	47 - 104
Abdominal tergites:		
3	95 - 210	57 - 104
8	120 - 230	104 - 145
Number of hairs on		
second antennal segment	5 - 9	12 - 14
Number of hairs on sixth		
antennal segment:		
Base	2 - 8	18 - 21
Subapical process terminalis	(3-)-4(-)5	>4
Accessory hairs on ultimate rostral segment	4 - 6	22±
Accessory hairs on subgenital plate	22 - 52	25 - 38
Abdominal tergites:		
5	18 - 49	>49
8	13 - 26	>26
Number of secondary rhinaria		
on antennal segments:		
III	0(-)4	0
IV	0(-)2	0 - 1
VI	0(-)2	1

North America, has a wider distribution and damages mainly Scots pine (*Pinus sylvestris*); *C. cembrae* is found in European parts of the U.S.S.R. and western Siberia and damages Siberian pine (*Pinus sibirica*); *C. shinjii* is found in Japan where it damages Japanese five-needle pines. Here we compared *C. pinikoraiensis* with the other three species above.

First, we compared our specimens with *C. pinea* as recorded by V.F. Eastop (1972) (apterous viviparae) (Table 1). This table shows that the species damaging Korean pine is *C. pinikoraiensis* and not *C. pinea*. Jiang Yucai (1985) cross-inoculated the aphids on Korean pine and Chinese pine, confirming this.

Secondly, we compared *C. pinikoraiensis* with the two aphids recorded by Munebayashi (1975) (Table 2); the differences between them are obvious.

II. Biological observations

Cinara pinikoraiensis is the most important pest of young Korean pine. It frequently increases to outbreak populations and affects the growth of young pines. In 1985, we observed selected spots in 15-year-old planted Korean pine stands in the botanical gardens of Heilongjiang Province.

Cinara pinikoraiensis has seven or eight generations in the city of Harbin. The various stages are as follows: eggs (overwintering fertilized eggs), fundatrix (apterous viviparae), alate viviparae (migrantes), apterous viviparae, sexuales (alate male aphids and apterous oviparae). Alate viviparae, which can disperse, occur every one or two generations. Apterous viviparae occur every three or four generations.

Cinara pinikoraiensis overwinter as fertilized eggs on pine needles. Fundatrix aphids hatch in early May, and they disperse by crawling, sometimes hiding under bark scales and under thick branches. Adult fundatrices appear in mid-May. Fundatrix reproduce by parthenogenesis and are viviparous. In mid to late May, large numbers of young aphids can be found on many main stems and thick branches of young pines. They excrete large quantities of honeydew, which attracts black ants. These are the viviparae of first generation of fundatrix and most of the nymphs have wing pads. At the end of May, most alate adults disperse to neighboring pines. A small number of apterous aphids crawl up to the young shoots and form small populations. At this time, alate aphids continue to disperse and the species, as well as their natural enemies (lady beetles, syrphid flies, etc.), increase. Disturbed aphid populations migrate. It is difficult to find large aphid populations on the main stems and thick branches in mid to late June. Only small aphid populations are present and all are on thin branches. By this time, they have finished dispersing. By the end of August, large numbers of aphid populations can be found again.

Sexuales appear by late September. Female aphids have no wings, are large, and their bodies are covered with white wax. Male aphids have wings, are smaller, and respond slowly when disturbed. In early to mid October, the female lay fertilized eggs after copulating. Eggs are laid in groups forming a single line on the

Table 2. Comparison of the morphological characteristics of *C. shinjii*, *C. cembrae* and *C. pinikoraiensis*

Characteristics	<i>C. shinjii</i>	<i>C. cembrae</i>	<i>C. pinikoraiensis</i>
Body length (mm)	2.7	3.5	3.94
Length of hairs on III antennal segment	2.8 times the length of the basal diameter of this segment	1.5 - 1.6 times	1.5 times
Accessory hairs on ultimate rostral	6	8 - 9	1 - 4
Sclerites on abdominal tergites	All present. Larger on I, II, VII, VIII segments; A lot smaller on other segments.	Only on I, VII, VIII segments; smaller on I, VII segments; larger on VIII segment.	All present. Smaller on VII segment; larger on other segments.
Diameter of siphuncular cone larger than diameter of siphuncle and number of hairs on the cone.	About 6 times. Have about 25 hairs.	About 3 times. Have about 40 hairs.	About 2.9 times. Have about 26 hairs.

needles; there are about ten eggs per line. These fertilized eggs are the overwintering stage.

Cinara pinikoraiensis populations avoid natural enemies, enlarge the area of distribution, and choose proper habitat by dispersing. They coexist with black ants who look after them and prevent the attacks of enemies. Aphids provide the black ants with honeydew.

The Korean pine aphid can feed only on bark of a certain thickness, which usually occurs on the stems and thick branches of 15-year-old Korean pine. It is also the species that favors sunlight. It occurs often in clearcuts, in under-stocked stands, and on the edge of forest. Population increases can be controlled by interplanting broadleaf trees in between the pine.

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