MANAGEMENT IMPLICATIONS OF INTERACTIONS BETWEEN THE SPRUCE BUDWORM AND SPRUCE-FIR STANDS

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Abstract. The impact of the budworm on trees and stands and conditions that lead to susceptible and vulnerable stands are discussed. Long-term and short-term options dealing with the spruce budworm problem are presented. Examples of questions that plant-animal interaction research have answered are presented in the following scenarios: (1) can the release phase of an outbreak be detected, (2) can spruce budworm impact be predicted, (3) are region-wide rating systems accurate, and (4) what, if any, relationships exist between site classification units and spruce budworm impact.

Introduction

The North American boreal forests have experienced periodic spruce budworm outbreaks for hundreds of years. Although the spruce budworm is an integral component of spruce-fir forests in North America, it normally does not prevent the continuity of spruce-fir forests. Fir and spruce usually regenerate after an outbreak, reaching a merchantable size in 40 to 60 years.

The spruce budworm was not considered a major problem in eastern North America until 40 years ago. Expansion and addition of numerous pulp and paper mills led to greater market demand for spruce and fir. More intensive forest management practices were needed to meet this demand and to reduce the amount of impact of the spruce budworm on spruce-fir stands. These practices had to be based on a thorough understanding of the interactions between budworms and forests under a variety of management scenarios.

As researchers, we understand the value of basic studies involving plant-animal interactions in forest ecosystems. However, we have not done a very good job in justifying this kind of research to the applied forestry community. Hopefully, this paper and others presented at this workshop will help show how both basic and applied studies on plant-animal interactions are vital if we are going to provide the land manager with sound forest pest management programs. This paper is divided into three sections: biological information, management options, and interesting scenarios involving plant-animal interactions.

Biological Information

Insect impact is any effect that insect activity has on a forest resource. Impact can be described as having a positive effect, negative effect, or no effect. Damage implies a harmful or negative effect. Land managers are usually interested in the evaluation of this negative effect.

The interaction between the spruce budworm and the spruce-fir forest involves the effect of the budworm on the forest and the effect of the forest on the budworm. The terms susceptibility and vulnerability have been applied to these interactions. Susceptibility is the probability that a stand will be attacked by the budworm. Vulnerability is the probability of tree mortality in the stand once a budworm attack occurs. In this section, we describe the impact of the budworm on trees and stands and conditions that lead to susceptible and vulnerable stands.

Impact on Trees and Stands

Budworm impact includes growth loss, cone and seed mortality, top-kill, tree and stand mortality, changes in stand composition, and various interactions between the budworm and other organisms in the forest (Table 1). Studies on growth loss in North America have shown a 30 to 90 percent reduction in radial growth in spruce-fir stands heavily defoliated by the spruce budworm for 2 to 6 years (MacLean 1981). A considerable increase in balsam fir cone and seed mortality occurs during an outbreak; few sound seeds are produced during a severe outbreak (Hudak and Raske 1981). Top-kill usually begins during the third year of an outbreak. The total number of dead tops often reaches 50 percent or more. Fir trees in the codominant and dominant crown classes usually die after about 5 years of repeated defoliation of current year's growth. Complete stand mortality can occur after 7 to 10 years of continuous heavy defoliation. Mortality in mature fir stands usually ranges from 70 to 100 percent, while mortality in immature stands varies from 30 to 70 percent (MacLean 1980). Budworm attack can result in changes in stand composition (Ghent et al. 1957, Turner 1952). However, spruce budworm destroyed forests usually regenerate with spruce and fir. Repeated removal of current year's needles by the budworm results in reduced tree vigor and subsequently makes the trees more susceptible to bark beetles and fungi (Basham and Belyea 1960, Belyea 1952). The impact of spruce budworm attack may be transitory or long-lasting (Batzer 1969, Blais 1958).

Conditions Leading to Susceptible and Vulnerable Stands

Any spruce-fir stand or host tree in eastern North America is susceptible to a spruce outbreak. As a general rule, certain factors usually increase the amount of volume loss and tree mortality in a spruce-fir stand during a

Table 1. Succession of events associated with a spruce budworm outbreak, on balsam fir (modified from Montgomery et al. 1982).

Years of severe defoliation[a/]	Impact
1	Flowers and cone crops die. Radial growth loss occurs in the upper crown.
2 to 3	Small roots begin to die. Radial growth loss occurs over the entire stem. Height growth ceases. Some treetops die.
4 to 6	Suppressed trees in the understory and mature and overmature trees in the overstory begin to die. Tree growth and wood production nearly ceases.
7 to 15	Budworm populations begin to collapse. More trees die, particularly balsam fir. Some seedlings and saplings die. Dead trees begin to deteriorate as a result of disease, secondary insect attack, and wind breakage. Protective cover in deer yards is diminished.

a/ 75 percent or more of current year's growth.

Table 2. Factors that increase the amount of damage (volume loss and tree mortality) in a spruce-fir stand (from Witter et al. 1983).

General factor	Conditions leading to severe damage
Intensity and duration of outbreak	Stand mortality usually increases with the severity and length of outbreak.
Species composition	Stands with large balsam fir components have greater potential for mortality than stands comprised mostly of spruce and hardwoods.
Stand age	Mature fir stand (60 years or older)
Stand density	High basal area of balsam fir, red spruce, and white spruce
Stand structure	Open stands in which spike tops of host species protrude from forest canopy
Site condition	Poorly drained stands, abnormally dry or wet
Stand size	Extensive stands of mature host trees (except black spruce)
Stand location	Stands located downwind (often east) of the current outbreak
Topography and latitude	Stands growing at elevations lower than 2300 ft (700 m) and south of 50° latitude

budworm outbreak (Table 2). Stand mortality usually increases with the duration and severity of the outbreak. Percent tree mortality is greatest in stands with the highest proportion of balsam fir followed in descending order by white, red, and black spruce. Mortality is usually much higher in stands greater than 60 years old. Open stands in which spike tops of host trees protrude from the forest canopy often suffer more damage. Stands on abnormally dry or wet sites usually sustain more damage.

The factors presented in Table 2 usually hold true, but there is great variation within the boreal forest (Mog et al. 1982, Blais 1968). For more information, Witter et al. (1983) presented a detailed review on the impact of the budworm on trees and stands.

Management Options

From a land manager's perspective, nothing can be done to prevent or control a regional outbreak of the spruce budworm since management actions are directed at individual stands (Simmons et al. 1983). There are three types of options available to the land manager: (1) actions directed at the stand (i.e., silvicultural techniques), (2) actions directed at the budworm (i.e., microbial or chemical insecticides), or (3) no action. None of these management options will result in the control of a regional outbreak.

The land manager can influence the time, place, and quantity of mortality that will occur in his or her forest. Various intensive forest management practices reduce spruce-fir vulnerability by replacing budworm-prone forests with less susceptible forest types. The following recommendations are good long-term goals (Flexner et al. 1983):

(1) Shorten the rotation age of fir to 50 years or less.
(2) Break up the continuity of extensive areas of mature forest.
(3) Maintain a mixed-species composition whenever feasible.

(4) Convert the stand to less susceptible species.
(5) On a regional basis, optimize the spatial diversity of different even-aged stands.

Research on plant-animal interactions will help us to plan better forest management approaches for reducing future budworm impact. However, even the best approach will never prevent budworm outbreaks.

Once an outbreak occurs, short-term options available to help protect or to harvest the trees in the most seriously threatened stands are salvage operations and spraying valuable stands with microbial or chemical insecticides.

Using biological information, the land manager can rank the probability of damage to his or her stands. Salvage operations can be conducted first in the highest risk stands. A land manager may decide to spray an insecticide in the most valuable mature spruce-fir stands that are heavily attacked by the budworm and may die within a few years. If markets are poor, the land manager may choose to abandon the stand.

Interesting Scenarios Involving Plant-Animal Interactions

Current studies are helping land managers and researchers to better understand interactions between the budworm and spruce-fir forests. These studies have and will continue to produce techniques to reduce the amount of budworm-prone forests and to provide more environmentally sound techniques to reduce the impact of the budworm on the forest. Four scenarios are presented to show the examples of some of the questions that research on plant-animal interactions have answered or are trying to answer.

Scenario 1: The Release Phase Of An Outbreak Can Be Detected -- Yes, No, Maybe

In studying the current outbreak in Quebec, Hardy et al. (1983) found that the outbreak started in seven epicenters. All were located in mixed-wood stands that included sugar maple, yellow birch, and white pine. Softwoods, about 50 years of age, occupied less than 30 percent of the stand. Ecological disturbances such as fire and logging occurred in all epicenters. The outbreak was first detected in areas with few balsam fir. Also, the major front of the outbreak was preceded by the establishment of a number of infestation centers distributed in an east-west pattern. If we can locate epicenters, early detection of incipient outbreaks may make modification of management plans possible.

An understanding of where epicenters may occur could be helpful to pest management specialists responsible for monitoring budworm populations. The use of a pheromone sampling system to monitor low population levels of the spruce budworm is now feasible (Allen and Dorais 1983). The pheromone sampling system is currently being pilot-tested in eastern North America. This type of sampling system, when it becomes operational, will allow a land manager to detect an increase in the budworm population as many as five years prior to noticeable defoliation.

Scenario 2: Spruce Budworm Impact Can Be Predicted -- Yes, No, Maybe

Land managers must be able to predict the type and amount of damage from the budworm to effectively manage their stands. A number of rating systems (both short-term and long-term) have been developed to assist the forest manager in determining the vulnerability of the forest to budworm attack (McCarthy et al. 1983, 1982; Blais 1975; Batzer 1973, 1969; Graham 1956; Bean and Batzer 1956; Westveld 1954, 1945; Morris and Bishop 1951; McLintock 1948, 1949; Balch 1946). Budworm impact can be predicted.

Many of the rating systems currently in use in eastern North America concentrate on short-term objectives. These rating systems are used to help managers determine which stands need to be salvaged or sprayed during the next year or two.

An example of a short-term rating system using 35mm aerial photographs is described by Olson et al. 1982. This system is based on the proportion of host species within the stand, average tree condition ranking for the stand, and the existing percent mortality of host species. The land manager uses the stand-rating mortality of host species. The land manager uses the stand-rating value for each stand to plan which stands should be salvaged or protected during the next several years. The system also has been adapted and used with a 70mm camera system.

Long-term rating systems are based on the concept of vulnerability and are used to help the land manager reduce the vulnerability of the forest over time. Lynch, Fowler, and Witter developed a long-term rating system for Michigan's Upper Peninsula to predict the amount of balsam fir basal area per hectare that will die due to the budworm. Factors which influenced budworm impact in the Upper Peninsula were: (1) the length of time the outbreak has been in progress in different parts of the Peninsula, (2) the quantity of balsam fir present in the stand, (3) stand species composition, (4) site factors, particularly drainage, and (5) past and present land management practices. This rating system will provide the land manager in the Upper Peninsula of Michigan with a useful management tool by estimating potential losses. The estimates can be used to plan preventive, presalvage, and salvage harvesting programs. The system can be easily implemented by land managers because the necessary data are readily available from routine compartment examinations and inventory systems.

Scenario 3: Regional-Wide Rating Systems Are Accurate -- Yes, No, Maybe

The rating systems developed so far do not have high predictive accuracy throughout the insect's entire range or have not been tested over the insect's entire range. However, a rating system developed to help the land manager determine the vulnerability of the forest to budworm attack at the management unit level in eastern Canada is compatible for both New Brunswick and Quebec (MacLean 1982, Blais and Archambault 1982). Their vulnerability index provides a rating based on the combined volume of balsam fir and white spruce, combined volume of black and red spruce, the maturity of balsam fir, and climate. This system depends on the availability of forest inventory data and is not fully operational at this time. Long-term rating systems in the Great Lakes Region do not appear to be compatible over the entire Region. For example, Lynch, Witter, and Fowler had to use five models to predict the amount of balsam fir basal area per hectare that will die due to the spruce budworm in the Upper Peninsula of Michigan. Their system differs from the system developed by Batzer and Hastings (1981) for Minnesota. The answer to the question on whether region-wide rating systems are accurate appears to vary by region. The land manager must be very careful about using any rating system that has not been validated for his or her area.

Scenario 4: There Is A Relationship Between Site Classificiation Units and Impact From The Spruce Budworm -- Yes, No, Maybe

Stand mortality is not evenly distributed within a state or province. These differences may be partially due to site conditions. A number of site classification systems are currently being developed in North America. A logical approach is to break an area into ecosystem units that are consistently found in the stand. These ecosystem units can be distinguished by differences in physiography, soils, and vegetation (Barnes et al. 1982). Individual characteristics such as topography, drainage, aspect, slope, depth of organic matter, soil pH and tecture, and plant species groups may be incorporated into a site classification scheme. Hix et al. (1983) developed a classification system for spruce-fir stands in the Ottawa National Forest in Michigan's Upper Peninsula based on site and vegetative characteristics. Currently, the possible relationships between site classification units and damage is being analyzed. This type of study helps determine if there are relationships between sites, the budworm, and damage.

Final Discussion

If we are going to manage the forest in a way that is both ecologically sound and financially rewarding, a thorough understanding of the interactions between the budworm, site conditions, and stands is necessary. Progress has been made during the last decade in building a knowledge base as shown by the scenarios in this paper and in the other papers presented at this workshop. The implementation of this knowledge base has already resulted in improved management decisions. We must continue to support long-term studies on plant-animal interactions in order to further improve our knowledge base and decision making abilities.

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