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THE GREENING OF THE FOREST: FOREST PEST MANAGEMENT INTO THE 21ST CENTURY

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Introduction

Canada's forest land represents almost 45% of the land base in this country and nearly 8% of the world's volume in forest resources. Approximately 1 in 10 jobs in this country are related, either directly (1 in 15) or indirectly, to the forest sector (Anonymous 1990). Timber products alone account for 18% of Canada's total exports (our single largest earner of foreign exchange). In addition, the complex ecosystems of Canadian forests are extremely important to tourism, an industry expanding at 17% per year, as well as through a variety of ecological processes including, watershed stability, water and air quality protection, and maintenance of a diverse pool for genetic resources and habitat (Anonymous 1990). The forests also represent an important source of public pride and beauty for Canadians.

The very nature of forest growth and production implies the need for sustainability. The Canadian Institute of Forestry has defined sustainable forest land management as **"Management which ensures that the use of any forest resource is biologically sustainable, and will not impair the biolcgical diversity or the use of the same land base for any other forest resource in the future"** (Anonymous 1990). Foresters have been trained for years in the concept of "sustained yield". This concept has meant maintaining a continuous supply of wood from the forest for an infinite number of harvests or rotations. Thus, it seems that foresters have always planted trees which will be harvested by their children and grandchildren. What has changed in recent years in Canada is the opportunity to put the concept of sustained yield into practice and the expansion of its definition to include multiple use objectives that go beyond the economic objectives of harvesting.

The following is an overview of management practices used to reduce the impact of feeding by forest insects. It is one component in the broader context of forest pest management which fits into a holistic approach to forest management. This review is an attempt to establish our current position or perspective on insect management in the forest, as well as identify our most likely directions in the future. In doing this, I have chosen to discuss, in sequence; the forests, the insect pests, the problems, and the solutions which are now part of forest pest management.

The Forests

Unlike the United States, Canadians own over 80% of their forested land. This land base is held by the provincial and federal governments in large tracts of Crown land. In most of these areas, we have two types of forests. First, the old, mature forests which we inherited from our parents and grandparents. In most cases, these stands were a result of natural succession from environmental conditions or events outside our control, eg. fire, wind storms, shifts in local water tables. In other cases, they resulted from human intervention, by manipulations of either aboriginal or immigrant peoples, eg. clearing or burning of the land for agricultural settlements, use for buildings and furniture. By the 1800's, a combination of these events produced relatively continuous areas of uniform forest types

(Great Lakes-St. Lawrence and Boreal forested areas) over large parts of Canada. Natural mortality and human utilization in these stands over the past 190 years has undoubtedly led to a more diverse mixture of tree species and ages than the original events might have produced. The national and provincial park systems in Ontario typify these mature forest types.

The second type of Canadian forest, and the one which will become increasingly more important, is the new forest. This type of forest has been established within the last 20-30 years and is currently being planted at a rate of ca. 100 million trees per year in each of our provinces. Although these forests will naturally age and become old forests, by definition, they will continue to be characterized by intensive forest management activities (seeding, fertilizing, thinning, and protection) which ensure a future supply of forest resources. These new forests are comprised of relatively large tracts of even-aged trees, usually planted as monocultures. Depending on the degree of past tending (removal of herbaceous or woody vegetation which competes with the crop tree), these plantations may or may not continue as strict monocultures.

The new forests have several specific uses, aside from direct timber or wood production. These may include areas for cone and seed production, nursery operations for seedling or ornamental and Christmas tree production, food or nut crops, energy biomass production, wildlife management, high use recreation, and watershed management. The new forests may also include urban treed areas which are being enhanced to improve the quality of life in cosmopolitan centres where the vast majority of Canadians now work and live.

Today, because a large part of the forest belongs to the public, both the old and new forest types are being put under increasing pressure to meet the demands of a variety of end uses for production and recreation. Although sometimes difficult to implement because of conflicting views, foresters have always considered this concept of "multiple use" in their planning objectives on forested land. Unfortunately, the employers of these foresters did not always share their broad concerns for sustained forest management, being side-tracked by short-term economic and political gains. Hopefully, the increased public pressure which has arisen with the environmental movement of the 1970's and 1980's will improve the opportunities of foresters to manage true multiple use forests for the benefit of all.

The Pests

In Canada, there are several key insects that feed on forest trees, causing levels of damage which are unacceptable in the sustained management of the forests. To some extent, old and new forests have similar pest species, however, for the purposes of the present discussion, I will separate insect pests which have been recently described or which are found only in high production stands from those occurring in mature natural growth forests.

In old forests, key pest insects include western species such as the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, the spruce beetle, *D. rufipennis* (Kirby), ambrosia beetles (Xylomycetophagus Scolytidae), the Douglas fir tussock moth, *Orgyia pseudotsugata* (McDunnough), the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), and the western spruce budworm, *Choristoneura occidentalis* Freeman. In Eastern Canada, the vast majority of the insects that damage old forested areas are defoliators, including the eastern spruce budworm, *Choristoneura fumiferana* (Clemens), the jack pine budworm, *Choristoneura pinus pinus* Freeman, the hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenee), the forest tent caterpillar, *Malacosoma disstria* (Hubner), and the gypsy moth, *Lymantria dispar* (Linnaeus). Most of these species experience dramatic changes in population density over varying periods of time, thus, reaching outbreak levels at regular intervals. Cerambycid species such as the whitespotted pine sawyer, *Monochamus scutellatus* (Say), are a problem in logging areas and some of the bark beetles such as the European elm bark beetle, *Scolytus multistriatus* (Marsham), also damage the wood directly. Both of these species are major vectors of disease pathogens which ultimately kill mature trees; Dutch elm disease (*Ophistosoma ulmi* (Buisman) C. Moreau) by the bark beetle and the pinewood nematode (*Bursaphelenchus xylophilus* (Steiner and Buhrer) by the sawyer beetle.

At this point, rather than discussing all the potential species which can cause damage to mature forests across Canada, I will elaborate on only three key species which cause problems here in Ontario and at which pest management programs are being directed.

Gypsy Moth: The gypsy moth moved into the Eastern Canada in the 1970's from the United States and thus, has not had time to establish regular cycles in population densities. Control for this species has cost more than any other defoliating insect in North America (Doane and McManus 1981). Through repeated defoliations, it has caused extensive damage to mature stands in the northeastern hardwood forests of the USA. The gypsy moth was first reported at damaging levels in Ontario near Kaladar, Ontario in 1981. Since then, it has spread westward to where its range now extends to the north shore of Lake Erie and northward to Parry Sound (FIDS 1989).

The gypsy moth feeds primarily on oaks, but in late instars, will defoliate all deciduous and coniferous forests (Anonymous 1985). After several years of a gypsy moth outbreak, mortality becomes apparent. This leads to disruptions in expected stand density or age and can have an impact on public and private recreational use as well as expected timber production. Historically, attempts have been made to reduce gypsy moth populations through manual removal of egg masses and large scale chemical or biological insecticide programs against the larval stage.

Forest Tent Caterpillar: The forest tent caterpillar is another hardwood defoliator in Ontario, feeding primarily on poplar, birch, oak and maple species. This is a native insect which reaches outbreak levels approximately every 10 - 15 years (Witter 1979). Outbreaks last from 3 - 5 years and are considered to be controlled naturally by a virus and the pupal parasitoid, *Sarcophaga aldrichi* Parker. In southern Ontario, primary damage occurs on oak and maple while in northern Ontario the principal species attacked is poplar (Sippell 1962)

Repeated defoliation by the forest tent caterpillar leads to tree decline and dieback. Damage to oak is of consequence to some southern park areas where this species predominates, while sugar maple results in reduced sap production and dieback thus, lowering maple syrup production. Although damage to aspen is currently not a concern, future utilization of this species by the forest industry and emphasis on poplar plantations for biomass conversion may raise the importance of this insect in poplar production. When warranted, forest tent caterpillar is controlled through either pruning of the egg masses or the application of *Bacillus thuringiensis* Berliner.

Spruce Budworm: The spruce budworm is another native defoliating insect which causes extensive damage to conifers throughout Ontario. Spruce budworm populations cycle naturally reaching outbreak levels approximately every 25 years, with high numbers remaining over about a 6 - 10 year period (Royama 1984). To date, the cause of these regular cycles has not been determined, although federal researchers are attempting to answer this question through continuing studies in Ontario, Quebec and New Brunswick.

The spruce budworm is the most damaging insect pest on coniferous forests in eastern North America (Sanders *et al.* 1985). In Ontario during 1988, over 5.2 million hectares of boreal forested areas experienced defoliation and tree mortality (FIDS 1989). Trees die within 3 - 7 years of continuous feeding by the budworm on foliage of conifer species such as balsam fir, white and red spruce. This has major impact on forest management plans in that this wood, projected for use in the next 5 - 40 years is no longer available for timber or pulpwood production. Park areas in the northern part of the province, which contain a high proportion of susceptible species, also experience problems in that the areas become unsafe for campers or outdoors people, because of dieback, whole tree mortality, dramatic changes in forest succession and increased fire hazard. Control of the spruce budworm usually entails the aerial application of chemical and biological insecticides or the cutting of dead or dying trees in areas which have already experienced extended periods of defoliation (salvage cuts).

Along with the development of our new forests, has arisen new insect pests. Intensive forest management has meant that we are now growing trees in a way similar to the production of agricultural crops. This has created the situation where trees, either young seedlings or older regeneration areas, are grown in monocultures with a continuing demand for a "high quality" product. Many insect pests which caused problems in agricultural crops in the past have now moved over into the intensive nursery and plantation areas and those which were once commonly associated with certain tree species at levels that went unnoticed, are now causing "unacceptable" damage under more stringent standards of production.

The new insect pests which are affecting these new Canadian forests are similar across the country. They include species attacking young nursery seedlings or burned areas that have been replanted, such as the black army cutworm, *Actebia fennica* (Tauscher), white grubs, *Cotinis nitida* (Linnaeus) and *Popillia japonica* Newman, the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and leatherjackets, *Tipula paludosa* Meigen and *T. simplex* Doane. In regeneration sites, species such as the white pine weevil, *Pissodes strobi* (Peck), and the spruce budmoth, *Zeiraphera canadensis* Mutuura and Freeman, are causing extensive problems. Ornamental and Christmas tree plantations experience problems with the pine false webworm, *Acantholyda erythrocephala* (Linnaeus), the spider mites, *Oligonychus ununguis* (Jacobi) and *O. milleri* (McGregor), and the root weevils, *Otiorhynhcus sulcatus* (F.) and *O. ovatus* (Linnaeus). In seed and cone orchards, species such as the spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munroe, and the seed cone maggots, *Strobilomyia laricis* sp. n., and *S. viaria* (Huckett), are reducing the amount of viable seeds for the establishment of new tree crops. Finally, in the urban setting, species mentioned previously, such as the introduced elm bark beetle, forest tent caterpillar and gypsy moth, as well as previously benign species such as the elm leaf beetle, *Pyrrhalta luteola* (Muller), and the oak leaf skeletonizer, *Bucculatrix ainsliella* Murtfeldt are causing increasing problems as more of our population move to urban areas and demand natural settings.

In Ontario, the key insect problems on new forests will undoubtedly be in those areas which are to supply our future wood supply needs, namely, regeneration sites and seed and cone orchards. The following section exemplifies two of these species which have the potential to significantly affect our future timber production.

White Pine Weevil: The white pine weevil is a native insect which has a long history of association with white pine throughout Ontario (Wallace and Sullivan 1985). In the last 10 years, white pine weevil has been reported on a number of other conifer species, including norway spruce, jack pine, white spruce, lodgepole pine, and sitka spruce. The adults appear in the spring, laying eggs in the leader of vigorously growing young pines. The leader of the current year's growth is killed as the larvae hatch and feed down the stem. It is not known how natural populations are regulated, although previous work has shown that overwintering survival and pupal mortality due to a predator, *Lonchaea corticis* Taylor, can affect populations significantly (Dixon and Houseweart 1982; Dixon *et al.* 1979).

Trees which have lost their leaders from feeding by white pine weevil lose growth in both height and diameter. Reductions in height growth mean that the tree will be out-competed for resources by taller, more dominant trees, and this, in turn, will change stocking (tree density and species composition). It may take 2 - 3 years for a tree to recover from a lost terminal and, in many cases, the internal damage remains, affecting sawlog timber when the tree is eventually harvested (Brace 1971). Reductions in tree diameter as a result of weevil feeding change the volume of timber expected to be harvested, ultimately changing the rotation age, usually delaying the expected harvest for several years. This damage is even more significant in those tree species where the weevil damages the leader beyond the current year of growth or where it attacks the same tree repeatedly, year after year (eg. jack pine). Control of the weevil is restricted to labour-intensive clipping of infested leaders or ground applications of registered chemical insecticides. Even some of these insecticides may not be available in the future as their registration status is currently under review.

Seed Cone Maggots: The seed cone maggots which attack larch and black spruce are native species Very little is known about their life history or behaviour because they have only recently become a concern. Sampling techniques to determine population size or development are currently being worked out to establish monitoring programs for predicting damaging levels of these species.

Seed cone maggots oviposit directly into the cone scales of developing seed cones, and thus, the cone appears normal when viewed from the outside except for a slight reduction in cone growth (Hedlin *et al.* 1981). It is not until the larvae have emerged from the scales or germination is attempted with the cones that the extent of damage is apparent. Reduced seed crops lower the availability of healthy seedlings for planting in regeneration sites. They also can disrupt provenance trials where superior trees are being grown to produce seedlings from the best genetic stock. No control measures are currently available for seed cone maggots.

The Problem

The major problem facing the forest sector in Ontario, today, as well as other parts of Canada, is that of a predicted "wood gap". In previous years, despite a policy of sustained yield, the optimism and avarice of the past 100 years has left us with a dwindling supply of old forests. By the year 2000, a significant amount of merchantable timber from these old forests will have been utilized by the forest industry in timber and pulp production. The remaining "old growth forests" will either have been bought up privately (and perhaps, fallen under the developers hands in urban regions) or have been set aside as wildlife and nature preserves for the use and enjoyment of the public. At the same time, our new forests, which we have been establishing, will not be fully functional for timber production until somewhere around the year 2030. This means that there will be a period between the years 2000 and 2030 when the timber industry, and thus, the people of Canada, will experience a wood shortage. As suggested in the introduction, this can have serious consequences for the economy of this country.

One way of addressing the predicted shortage of wood is maintaining or preserving those parts of the old forest which are likely to be lost between now and 2020. Similarly, if we can protect and accelerate the establishment and growth of the new forest from now into the year 2030, we may be able to close the gap which currently exists. By protecting trees from damaging insects and reducing losses, both on the old and new forests, we may get one step closer to this goal. Thus, forest pest management practices are aimed at reducing losses in the forests in order to maximize forest productivity. Sustainability simply means that we must continue this protection or pest management practices *ad infinitum.* The major problem facing us then is protecting our forests from damaging insects over the long-term.

At a more specific level, in the old forests, defoliating insects cause major changes in forest succession. By removing the photosynthate annually from large areas of forest, these insects accelerate nutrient cycling, erosion, dieback, and on a larger scale, succession. This generally is incompatible with forest planning, disrupting the size, number, and species of trees expected on a given area. It can also interfere with people's ability to enjoy the natural setting by changing wildlife distribution and abundance and reducing the visual and aesthetic qualities of the forest.

Insect pests attacking the new forests are a problem, not only because they disrupt forest management like the defoliators, but also because they destroy trees which have already cost money to establish. Unlike the defoliators, which are feeding on older trees planted by nature, insects in nurseries or on regeneration sites are consuming whole trees, or parts there of, which represent money that we, as a nation, have invested in for our future. Protection from such losses must be enhanced in order to ensure that we have forests for tomorrow.

The Solution - Forest Pest Management

Protection of the forest against damaging insects on a sustained basis requires the implementation of forest pest management (FPM). Stern *et al.* (1959) first used the term "pest management" to describe those activities which can be integrated to suppress damaging insects. Waters and Cowling (1976) and Waters and Stark (1980) later elaborated the definition, using the term to describe a broader decision support system in forestry. Today only a few of the aspects discussed by these authors are actually implemented in the field. The majority of components in their theoretical forest pest management system are still at the research level.

From the entomological perspective, Waters and Cowling's (1976) definition of FPM described two major components: impact assessment and control tactics. These components are an essential part of the solution to the "wood gap" problem. The following section describes our current status in forest pest management practices based on impact assessment and control tactics. Where possible, I have also tried to identify areas which have the greatest potential for implementation and for future research.

Impact Assessment: Central to the concept of FPM is the identification of insects which cause economic damage. In forestry, the economic threshold is considerably more difficult to ascertain than in agriculture because often the damage does not become economic until 10 - 60 years after insect attack, when the crop is harvested (eg. leader loss from weevil on 10-year-old jack pine stands that will not be harvested for a further 60 years). Many events can occur in the forest, both compensatory and more devastating (eg. fire, natural succession), in that time and thus, the results of preventative measures can be obscured or negated. The changes that result are often strongly associated with the interest rate expected on money invested over this long period of time and this is difficult to predict (Rawat *et al.* 1987). Also, because forests have many uses, over different stages of their development, the economic impact of insect damage is hard to put a dollar value on; eg. losses due to defoliation and changes in species composition for wildlife habitat or soil erosion.

To overcome the difficulty in estimating future worth of protected or damaged forested areas, computer simulations have become increasingly helpful. The literature is replete with references to models which have been developed to predict insect populations over long periods of time or the consequences of insect damage and protection on forest stands (MacLean and Erdle 1984; Régnière 1982; Rose 1973). These models have been built up from long-term experimental studies to measure the changes and probability of insect damage (MacLean and Ostaff 1989; Alfaro *et al.* 1985; Piene 1980). At the moment, these models tend to be too theoretical and specific to be of practical value, but they represent the basis on which truly integrated systems can be structured to study the impact on forest stands. Unquestionably, future research will continue in this area, as we become more knowledgable about the impact of insects on forest stands and advances are made in computer technology.

The development of efficient sampling systems will also have high priority in future pest management programs. Although Forestry Canada, through the Forest Insect and Disease Survey (FIDS), provides extensive surveys of pest populations from year to year, few sampling plans which accurately predict specific pest populations and damage are available to the forest manager. Some species have been studied intensively, like the spruce budworm, but these are rare in the annals of sampling research. In many cases, it is our inability to predict damaging populations that results in our considering an insect as a serious problem (eg. gypsy moth, white pine weevil, root weevils, etc.). In order to truly implement FPM programs in the future, rapid progress in the area of sampling design will have to be made.

Control Tactics: The second area of relevance to FPM is the identification and development of control measures which will be both effective and environmentally acceptable. One of the most influential and benign ways to reduce specific insect populations is through the manipulations of vegetation. Some of the insect problems which we are now experiencing on the old forests resulted from past activities which have changed the forest. A good example of this is the harvesting of preferred tree species in parts of eastern Canada which has left extensive areas regenerated to balsam fir. These stands are highly susceptible to outbreaks of the spruce budworm, and because the forest industry now utilizes balsam fir, long-term control operations are required.

Foresters have had considerable training in the area of stand manipulation, controlling forest conditions, such as the amount and distribution of understory vegetation and the density, age, and species of trees present. The production of white pine in Ontario today characterizes the potential of this type of pest management. Fast-growing poplar are often planted with young white pine to provide an overstory or shading effect. This reduces the attack by white pine weevil by obscuring the growing tips of the white pine and forcing them to grow tall and narrow (less suitable to weevil survival). In the future, we will continue to rely on this kind of expertise to manipulate forest stands to reduce insect attack, because it represents true sustainable pest management. This approach is preventative, however, and can only deal with long-term problems; it fails to address insect damage in the short-term.

Historically, our reaction to pest problems on forest stands has been short-term, being somewhat characterized as "crisis management". Much of our effort has been spent "putting out the fires" of insect damage. Since the 1940's, a key component in our arsenal has been chemical insecticides. Starting with the widespread use of DDT in the 1940's and 1950's and ending with the organophosphates and carbamates of the 1970's and 1980's, we have attempted to combat species on our old forests, such as the spruce budworm, Douglas fir tussock moth and hemlock looper, with aerial applications of these compounds (Prebble 1975). Because of public concerns about toxicity and the broader environmental impact of these insecticides, most provincial jurisdictions today do not condone the use of chemical insecticides in aerial applications on forested land. Unfortunately, this has left the forest manager with very few, if any, options for the short-term control of insect pests.

To meet this need for short-term solutions to pest problems in the context of FPM, research is continuing in a number of key areas. Much of this work is directed at finding effective and environmentally acceptable alternatives for reducing pest populations, including compounds that are increasingly host specific. Studies are being conducted by Forestry Canada, at their 6 regional and 2 national laboratories, as well as at some universities and provincial institutes.

One of these areas of research is the development of newer, more effective insecticides that have low impact on non-target species. These compounds can be considered "biorationals" in that they are based on natural biological products, but are now synthesized and produced in the laboratory. The products currently being researched include plant derivatives, insect growth regulators (IGR's), and disruption pheromones. With the plant derivatives, the emphasis is on compounds like the synthetic pyrethroids, which have low residual properties. Although these insecticides may be toxic to some non-targets, they could prove particularly useful in ground applications against foliar feeding species. Research to identify sex pheromones which will disrupt the natural mating cycles of some species such as the spruce budmoth is on-going in New Brunswick while researchers in Sault Ste. Marie have achieved experimental success using IGRs against such difficult species as the white pine weevil (Retnakaran and Jobin, in press).

The other area of intensive research in forest pest management is the use of true biological agents for suppression. This includes such naturally-occurring agents as bacteria, viruses, protozoa, fungi, nematodes, predators and parasitoids. Although in 1981, a significant component of Forestry Canada was devoted to research in this area (97 person years across Canada) (Hulme 1982), the complex nature of this work means that the results which are directly applicable to the field are slow in coming.

Undoubtedly the most successful biological control agent to have been developed to date is *Bacillus thurigiensis* Berliner. The use of this bacterial agent, which is found naturally in the soil and stored product insects, has been increasing exponentially since its commercial introduction in the 1970's (Morris *et al.* 1986). This has been due to two main factors: 1) more consistent results and 2) reduced operational costs. Research is now aimed at isolating and synthesizing the toxic crystal (the active ingredient) and improving the formulation and application of the product. *B.t.* is effective against most major lepidopterous insect pests in the forest and is currently the only insecticide applied aerially in Ontario against the spruce budworm, gypsy moth, and forest tent caterpillar. In other parts of Canada, it has been used against the western spruce budworm and the hemlock looper. Its limitations appear to be somewhat variable results when applied in unfavourable weather or under high population levels and its relatively broad effect on all lepidopterans feeding on foliage at the time of application.

Viruses represent another group of biological control agents which are being produced for application against forest insects. Perhaps the greatest success story with this agent is the use against the European pine sawfly during 1950's and 1960's which reduced this pest well below economically damaging levels. This insect is no longer considered a problem in pine plantations, principally due this virus. Although in the United States, two virus compounds are currently registered for application on forested lands, Virtuss® and Gypcheck®, viruses are not readily available in Canada. This is partially due to the stringent registration process required by our federal government and partially because these is as yet no commercial production. The Forest Pest Management Institute (FPMI) in Sault Ste. Marie has two products, TM Biocontrol® and Virtus®, registered for control of the Douglas fir tussock moth and another, LeContevirus®, available for control of the red headed pine sawfly. In Canada, viruses are being tested experimentally against the gypsy moth with some degree of success (one product, Gypcheck® has been submitted for registration), but have failed to provide satisfactory control of the spruce budworm in extensive tests conducted over the past 10 years (J. Cunningham, Forest Pest Management Centre, Sault Ste. Marie). The future development and use of viruses will depend, to a large extent, on the ability to register these products in this country and our assurance that they will be target specific.

A number of other studies have been conducted to determine the effectiveness of various biological agents or entomopathogens such as protozoa, fungi, and nematodes (Hulme and Green 1984). Most of this work has been conducted at federal government laboratories and universities over the past 10 - 20 years. The microsporidian, *Nosema fumiferanae* (Thompson), which is a factor in the decline of natural spruce budworm populations, has been studied since the 1970's. *Nosema* spp. have been used successfully against damaging herbivores such as grasshoppers in the prairies, and work by Wilson (1977) suggests that it has potential for suppressing budworm populations. Further studies may be warranted, particularly to develop an understanding of its impact in the population dynamics of this pest (Wilson *et al.* 1984).

Similarly, pathogenic fungi have been examined by several researchers for their potential use against forest defoliating insects, such as the hemlock looper, spruce budworm, and gypsy moth. Most of this work has been aimed at improving our basic understanding of the pathogen/host system. To date, however, no fungi have been developed for commercial application against forest insects (Wilson *et al.* 1984). Current studies are directed at genetic manipulation of fungi to improve virulence (Hulme and Green 1984).

Little work has been done on the use of nematodes for controlling forest insect pests (Hulme and Green 1984). Recently, however, these entomopathogens are being investigated for their potential against the spruce budworm, structural pests like termites, and ornamental pests such as white grubs and root weevil (D. Eidt, Forestry Canada-Maritimes Region). Continued research in this area should identify nematodes as strong candidates for biological control of forest insects, particularly those which are cryptic and found in dark moist habitats such as soil.

The remaining natural enemies of forest insects, including predators and parasitoids, have been investigated over the past 80 years in Canada. A number of success stories in biological control have been reported in forestry through the introduction of these agents for control of pest problems (McGugan and Coppel 1962; Reeks and Cameron 1971; Kelleher and Hulme 1984). Approximately one-third of the forest insect pests against which predators and parasitoids have been released in Canada have been almost permanently controlled and the remaining one-third can be controlled for one to several pest generations (Hulme 1988). In recent years, predaceous ants, in the genus *Formica* sp. released in jack pine plantations in Quebec have shown indirect evidence that they can reduce populations of the Swaine jack pine sawfly (Hulme and Green 1984). Other mammalian and avian predators also have potential for suppressing forest insect populations and further studies are needed to identify their impact on both target and non-target species.

Hulme and Green (1984) reported 31 species of parasitoids and predators released in Canada between 1969 and 1980; all but 3 where hymenopterans. Approximately half of these natural enemies have been shown to be established and are now linked to reductions in pest populations. In general, the emphasis has been on introductions of exotic species of parasitoids, but current thought suggests that native species may be just as appropriate for biocontrol programs. In the future, studies will concentrate not only on these inoculative releases but also on inundative releases with native or introduced parasitoids. The recent work on the egg parasitoid, *Trichogramma minutum* Riley, against the spruce budworm is a good example of the potential for inundative releases in modern forest pest management (Smith *et al.* 1990). Continued work in this area requires basic research on the rearing of natural enemies and knowledge about the population dynamics of the pest insects against which they will be used (Hulme and Green 1984).

Conclusions

Insect species which attack trees in old forest areas are often difficult to control because the areas in which they are found are relatively rugged and inaccessible from the ground. On the other hand, species which damage the new forest present difficulties because there are often no known sampling programs, the levels of protection required are high, and control measures are either non-existent or extremely labour intensive. These factors will determine the future direction of research for pest management.

It is quite possible that the insects which we now consider pests in our old forests, such as the spruce budworm and gypsy moth, may be of less concern in the future. Evidence for this can be seen in European forests, where these stands are generally more intensively managed than in Canada and widespread outbreaks of defoliators are rarely encountered. How we adapt to the projected changes in our forests and the systems we design to deal with the arising pest problems will be determined by our creativity and ability to support the necessary research. As pointed out by Wallace (1990) in a recent review, research in the areas of survey and impact assessment, population dynamics, and improved control techniques, including biological agents, must be supported in order to meet the challenge of sustained pest management.

The crisis of the "wood gap", although the major challenge facing the forest sector, is not the only one. Increasingly, an educated public is becoming involved in the programs for forest management conducted in this province. Their pressure to develop multiple use areas and ensure environmentally acceptable management programs makes any proposed activities subject to intense scrutiny, including pest management. This, combined with world recognition of the desire and necessity for forest health and conservation, places an even greater burden of responsibility on the shoulders of our foresters.

Sustainability means that our forests will remain green indefinitely. In order to achieve this, our foresters will have to make sound pest management decisions based on the availability of impact assessments and acceptable tactics for control. Without continued support for research and development, these tools for a green forest will become a scarce resource.

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