BOREAL ODYSSEY:

Proceedings of
the North American Forest
Insect Work Conference
May 14-18, 2001
Edmonton, Alberta, Canada

W.J.A. Volney, J.R. Spence, and E.M. Lefebvre, editors

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ABSTRACT

The third North American Forest Insect Conference was held in Edmonton, Alberta, Canada May 14-18, 2001. Included in these proceedings are two plenary sessions, three concurrent panel discussions, and 150 workshop presentations. Many presentations focussed on the continuing battle to understand bark beetle and spruce budworm populations, whose impacts so profoundly affect any discussion of forest environments. The consequences of exotic pest invasion, the ethics in conducting scientific work, outcomes of present-day forest management, and resource sustainability were highlighted in other workshops, amid a sense of urgency in finding solutions. Apropos to this, presenters highlighted government policy and regulations and the influence of foresters, forest scientists and stakeholder groups on decision-makers. The effects of global climate change on insect populations and forests, forestry practices and attitudes, and the politics of forestry were discussed. Other presentations concentrated on the effects of fire on forests and insects; forest health research, experimentation and restoration; forest insect epizootiology; urban forest pest management; ecophysiology; and biological processes and controls in pest management. Participants were brought up-to-date on decision support systems; future prospects in forestry; aerial survey tracking systems; teaching forest entomology; hazard rating systems and remote sensing; and computer mapping systems. The opening addresses, founders award speech, poster abstracts and moderator summaries included herein touched on many of these trends. The insistence on publishing these abstracts of workshops and panel discussions is to provide a record of issues that concern forest entomologists at the opening of the 21st century.

RÉSUMÉ

La troisième Conférence nord-américaine sur les insectes forestiers a eu lieu à Edmonton (Alberta), au Canada, du 14 au 18 mai 2001. Deux sessions plénières, trois discussions de groupe simultanées et 150 présentations aux ateliers sont résumées dans le compte rendu de la Conférence. Nombre des présentations ont fait état des efforts soutenus pour tenter de comprendre les populations de scolytes et de tordeuses des bourgeons de l'épinette, dont l'impact marque si profondément toute discussion sur les milieux forestiers. Les conséquences de l'invasion par des ravageurs exotiques, l'éthique dans la conduite des travaux scientifiques, les résultats de l'aménagement forestier d'aujourd'hui et la durabilité des ressources ont été rapportés dans d'autres ateliers, au milieu d'un sentiment d'urgence dans la recherche de solutions. À ce propos, les présentateurs ont mis au premier plan la politique et la réglementation gouvernementales, ainsi que l'influence des aménagistes forestiers, des chercheurs en foresterie et des groupes d'intervenants sur les décideurs. Les effets des changements climatiques planétaires sur les populations d'insectes et les forêts, les pratiques forestières et les attitudes à l'égard des forêts ont été discutés, ainsi que les politiques en matière de foresterie. D'autres présentations ont porté sur les effets du feu sur les forêts et les insectes; la recherche sur la santé des forêts et l'expérimentation pertinente, notamment le rétablissement sanitaire des forêts; l'épizootiologie des insectes forestiers; la lutte contre les ravageurs forestiers en milieu urbain; l'écophysiologie; et les processus et moyens de lutte biologiques contre les ravageurs. Les participants ont été informés des plus récents systèmes d'aide à la décision; des perspectives en foresterie; des systèmes de suivi par relevé aérien; de l'enseignement de l'entomologie forestière; des systèmes d'évaluation du danger et de la télédétection; et des systèmes de cartographie informatisée. Nombre de ces tendances ont été soulignées dans les allocutions d'ouverture, le discours prononcé lors de l'attribution du prix des fondateurs, les résumés des communications affichées et les résumés des modérateurs. Les résumés de ces ateliers et discussions de groupe sont publiés afin de servir consigner l'état des questions qui préoccupent les entomologistes forestiers en ce début du XXIe siècle.

ACKNOWLEDGMENTS

We thank the many people who contributed to the success of the third North American Forest Insect Work Conference. This includes the Steering Committee, for their advice and guidance, and the Local Arrangements Committee, who contributed much time and effort towards conference preparation, field trips, and social and companion events. Our sponsors, Alberta Newsprint Company, Alberta Pacific Forest Industries Inc., Carolina Biological Supply Co., Certis (formerly Thermo Trilogy) Corp., Daishowa-Marubeni International Ltd., IPM Technologies, Phero Tech, Weldwood of Canada Ltd., and Wetaskiwin Aerial Applicators Ltd.; the Government of Alberta Department of Sustainable Resource Development; the University of Alberta; and Natural Resources Canada–Canadian Forest Service are gratefully acknowledged for making the event financially viable. We also thank the Sustainable Forest Management Network for supporting the travel of overseas scientists; Brent Lange and Larry Macdonald and the staff of Wetaskiwin Aerial Applicators for the special field day activities; Elston Dzus and his staff at Alberta Pacific Forest Industries Inc. for arranging and guiding the interpretive forestry field trip; Crystal Jones from the City of Edmonton for arranging our use of facilities at Fort Edmonton Park; and Sherry Christie and her staff of Elizabethan Catering for providing the excellent banquet. Certainly not least of those we thank are Julie Durand and the staff at the Crowne Plaza– Chateau Lacombe Hotel for the excellent service and facilities at the meeting. The preparation and production of this publication benefitted significantly from the invaluable help and supervision of Brenda Laishley, Head of Publications, Northern Forestry Centre. Finally, we thank all the participants whose attendance and contributions made the North American Forest Insect Work Conference a reality.

A MESSAGE SEEN ON LEAVING *THE DRUID*'S ESTABLISHMENT:

"Success is a Matter of Luck"

The roll of the dice or the bounce of the puck.

To the extent that we were successful:

Luck is the friend who helped unselfishly to stage the event,

Luck is the colleague who came trustingly to the event,

Luck is your spirit of cooperation and tolerance of the inconvenient!

To the extent that we were unsuccessful:

Luck is knowing that if ever there is a need to complain,

You alone will shoulder the blame,

Luck is knowing that there are some things that you need help to change.

Thanks to all!

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SUSTAINABLE FOREST HEALTH MANAGEMENT FOR THE 21ST CENTURY

Yvan Hardy
Assistant Deputy Minister
Natural Resources Canada
Canadian Forest Service

Welcome

It is a pleasure to welcome you all to Canada and to Edmonton, Alberta. Welcome also to the third North American Forest Insect Work Conference. I note that there are participants from Africa, Europe and South America in addition to Mexico, the United States and Canada. I hope that your visit to Canada will be personally and professionally rewarding. On a personal basis, it is always good to see old friends and make new ones. I would particularly like to mention and greet Dr. Douglas Allen, my major professor and the originator of the North American Forest Insect Work Conferences.

On a professional level, Canada is a forest nation, and we are proud of this fact. We are the custodians of 10% of the world's forest resources covering some 417 million hectares, an area equivalent to central Europe. We take this responsibility seriously.

Historical Development of Natural Resources in Canada: an Outline

Our roots in the management of natural resources in Canada go back a long time. Our First Nations people living in the boreal forests were largely dependent on forests for food, fiber, shelter and transportation. One of the first examples of successful technology transfer in forest products by the First Nations people in North America was the adoption by Europeans of the canoe for transportation. North American forest resources were the main attraction for Europeans to this continent, and the fur trade, which began in what is now Quebec, led to the founding of the first European colonies in Canada during the sixteenth century. Fish stocks led to the discovery of Newfoundland in 1497, and they remain the basis of a fishery even today. Towards the end of the seventeenth century, the King of England granted all lands drained by rivers flowing into Hudson's Bay to a company that became known by the name of the Hudson's Bay Company. This charter allowed the company, now know across Canada as "The Bay", to utilize the natural resources of the area. Edmonton, where this conference is being held, originated from one of the Hudson's Bay Company's fur trading posts.

The main impact on forestry during early European settlement was due to the clearing of land by settlers. The Royal Navy's reserve of large blocks of timber for ships' masts led to conflicting demands for the resource. By the early nineteenth century this evolved into the first forestry legislation in what was to become the country of Canada. These issues initially involved limits to logging and the imposition of timber dues, but also the recognition by the country's first prime minister of the trade potential in forest products and the need for conservation. Subsequently, the appointment of a Chief Inspector of Timber and Forestry by the close of the nineteenth century led to a highly professional corps of forestry practitioners and the regulation of forestry practices in the country. Nevertheless, many of the issues that confront us today have been with us since the founding of the European colonies: First Nations' forestry opportunities, global issues relating to trade and natural resource use, and conservation.

Canadian Forest Service and Innovative Solutions in Canada's Forests

The appointment of the Chief Inspector of Timber and Forest in 1899 led to the formation of what we have come to know as the Canadian

Forest Service. Over the past 100 years we have developed a number of innovative solutions to forestry problems. We could mention a few of these: worldwide, we are leaders in forest fire management, the development of containerized seedling production, the development of growth and yield predictors, the anticipation of aspen management with research conducted in the 1960s, and the utilization of somatic embryogenisis in forestry.

Our forté has been in the area of forest health management, however. Over the years this has assumed several different names, some of which are "insect and disease control", and "integrated pest management", but the focus is essentially one of protecting forest resources from catastrophic losses caused by inimical agents. We lead the way in the development of operational spray programs to control spruce budworm outbreaks in the 1950s. Although we use different agents today, having learned that DDT produced unacceptable side effects, the treatment technology is essentially the same as that originally developed. Today we use BTK instead of DDT and this innovation for forest pest control operations was pioneered by our scientists. We can also mention the seminal work in the use of life tables and population dynamics studies in the Green River project and their impact on animal ecology. Our work in the control of the European spruce sawfly is worthy of attention because it was one of the most successful biological control programs in forestry. There are other examples, not the least of which are the basic studies on the taxonomy and natural history of insects and disease- causing organisms in our forests.

Today, the world has changed; no one agency can claim supremacy in forest research. There are many more players, including universities, provincial research establishments, industry, and organizations with a special interest in forest resource issues. Furthermore, local forest resource issues often involve global concerns.

Forest Health Management at the Threshold of the 21st Century

It is fair to say that today's issues are more complex. The scarcity of resources becomes even more so, as human populations grow and nations advance technologically, driving the demand for forest products even higher. Pests aggravate this situation and we can ill afford to tolerate elevated pest losses. The special concerns of different organizations and public interests and their insistence on being heard are emerging as important elements in forest health management today. Although we might start from an integrated pest management perspective, that is not enough. Let me illustrate: today the policy decision not only demands a better understanding of control measures but we have to consider long-term silvicultural options, the ecological processes involved, biodiversity issues that are impinged by forest health management policies, sustainable forest management issues and the criteria and indicators of sustainability, forest health implications of certification on sustainable forestry practices, the use of genetically modified organisms, socio-economic impacts, traditional uses of landscapes and, no doubt, other concerns. The important message, if you ask me, is that no one person can be an expert in all these areas and we have to learn to play with others!

Just as with the individual, agencies have to integrate their efforts. We need to work in partnership with others to address the global problems we face. This is increasingly evident in the evolution of forest resource research in Canada. There is considerable cooperation between Natural Resources Canada (the Department in which the Canadian Forest Service is located) and the Natural Science and Engineering Council of Canada, the Networks Centers of Excellence for Sustainable Forest Management, provincial governments and corporations. The inclusion of the Social Sciences and Humanities Research Council of Canada in these partnerships signals the important message that not everything in natural resources management is necessarily technical. This is further emphasized by the involvement of the public in important capacities within these partnerships. In general, the role of government in forest health management is becoming more like that of the overseer than the manager as a result of changes in public policy. The net result is that there are several new stakeholders, with increasing, even competing demands, dependent on decision making that must be undertaken at an ever-increasing tempo. The one thing that is constant is change.

Forest Health Management for the 21st Century

From my perspective, several of the trends identified above will continue, and recently developed techniques will be elaborated upon and adapted to new applications. These include: continued use of biotechnology to solve scientific problems and produce different host and control materials for pest management; an increased reliance on information technologies to enhance data acquisition/manipulation and decision making as it relates to forest health management; an enhanced integration of social sciences with the hard sciences to better evaluate the practice of sustainable forest management; a greater cooperation among agencies, researchers and practitioners to solve pressing problems of the day; and the combining of globalization and global biogeochemical cycles to prevent new forest health management problems that are now coming to the fore. We have already mentioned the introduction of alien species, such as the European spruce sawfly; these introductions will become more frequent and of greater concern as we attempt to protect and preserve the integrity of native ecosystems while entertaining greater world trade. The problems of climate change engendered by an imbalance of the carbon budget will also become increasingly important.

The possibilities of using the control of wide-spread outbreaks of native species such as the spruce budworm to offset the effects of carbon emissions will be an important pressing problem in the next few decades. How do we mitigate the effects of climate change on outbreak frequency and duration? Do we do this through increased inventory control? Through increased forest protection by population suppression or foliage protection? We will have to seek protection of biodiversity while maintaining a competitive forest industry and mitigating climate change effects. Innovative programs such as Forests 2020 can provide an opportunity for afforestation and fibre production while permitting us to meet our conservation targets and manage old-growth stands.

The challenge of how to manage the research and development enterprise for Canada has also changed. We now have to consider two dimensions: the axis that runs from the individual to the collective (whether we are considering scientists or organizations) and the axis that runs from the local, through the landscape, to global problems. One tangible undertaking that has addressed this challenge is the EMEND (Ecosystem Management Emulating Natural Disturbance) experiment here in Alberta. While it is a model that addresses the multidimensional problems of forestry research, it is also being watched to see what works and what does not. Finally, an important new dimension that is increasingly mentioned in the conduct of scientific work are the ethical concerns associated with forest health practice.

In Conclusion: a Challenge

Your program lists plenary sessions, panels and workshops that will address all these topics in far more detail than can be covered here. The challenge is to take what is presented at the meeting and make it relevant to your own future. The extent to which you are successful with this exercise is the measure of how rewarding this conference will have been for you. Take time out to enjoy your colleagues and their work, and enjoy your stay in Edmonton. Best wishes.

SPEAKING NOTES

Cliff Henderson
Assistant Deputy Minister
Land and Forest Service
Alberta Sustainable Resource Development

Good morning, forest practitioners and guests. Welcome to Edmonton, Alberta. It is my pleasure to bring greetings on behalf of Minister Mike Cardinal. Minister Cardinal was recently appointed to the newly created provincial Department of Sustainable Resource Development.

This conference is one of the cornerstones of a healthy forest and sustained landscape. I recently had the opportunity to meet with the United States Secretary of the Interior, and the Chief of the United States Forest Service. Their messages were clear: programs will be implemented to create healthy forests. Unhealthy forests are subject to catastrophic fire and insect mortality. North American societal views suggest that people are no longer prepared to live with "high risk forests" and they are telling forest practitioners to make them healthy. I challenge you to use the third North American Forest Insect Conference as a focal point to move your programs forward.

As forest practitioners, there are three major forest landscapes where you must develop prevention and remedial action plans:

1. Urban/watershed community forests
2. Extensive multiple use forest lands
3. Protected areas

These landscapes are under private, provincial, state or federal ownership. Each of these landscapes may require significantly different responses or remedies. Treatment programs either inflict mortality on the insect to push it back to lower levels, or create such an unfavourable habitat that the insect leaves or succumbs.

Some of the tools you have include:

1. Green tree removal
2. Dead tree removal
3. Chemical applications

The other tool, which requires further discussion, is mutual co-operation between jurisdictions. Insects do not recognize borders. Effective control programs must become seamless and be completed in harmony with various jurisdictions.

I assume other jurisdictions have budget constraints similar to those in Alberta, so action plans that consider integrated opportunities will be the most successful. For example, timber harvesting and sequencing to remove high-risk or infected stands, and replacement with a new forest, is my interpretation of an integrated opportunity. During your working sessions, I encourage you to review our integrated control programs, like the Pine Bark Beetle Program from the early 1980s, and our present Spruce Budworm Management Program in the northern Boreal Forest. This integrated program has resulted in a significant reduction in our *B.t.* spray programs.

One of the challenges you have is how to implement programs to manage insects in protected areas. A challenge, indeed, but there is an increasing awareness within the public that healthy forests are required for healthy ecosystems and wildlife populations. The flawed concept of total preservation is now showing it does not address the needs of the disturbance-originated forests of the West. My goal is to challenge you as forest practitioners to develop programs to make our forests healthy. You must successfully carry this challenge so our societies have sustainable as well as healthy forests.

It is also my pleasure to recognize the fellow sponsors of this conference:

1. The Canadian Forest Service, and Director General Boyd Case;
2. The University of Alberta, and Dean Ian Morrison; and
3. You, the participants.

Thank you.

CONTENTS

POSTER ABSTRACTS

PLENARY SESSIONS

PLENARY SESSION 1

INVASION OF NORTH AMERICA BY EXOTIC SPECIES: IS THERE HOPE FOR THE FUTURE?

MODERATORS:
A.M. Liebhold, *US Forest Service, Morgantown, West Virginia*
D.L. Wood, *University of California, Berkeley, California*

Moderator Summary: David Wood's presentation concentrated on the transportation of organisms from one continent to another, which began with the first migrations of humans out of Africa some 1.7 million years ago. Today, foreign organisms are arriving in North America at alarming rates. The United States has now become the world's leading importer of wood and wood products. Currently, four significant pathways are wide open for the continued introduction of pests into North American forests. These are: railroad ties, unprocessed logs, solid wood packing material (SWPM), and lumber. Present regulations cannot stem the flow of these exotic organisms. To stop the flow of pests into the forests of North America, we must take actions that realistically have a chance to reduce this risk. These actions should include heat treatment of all railroad ties, logs, lumber and SWPM to 71ºC at the center of the largest piece for 75 minutes. Otherwise cease trading these items.

Countries that have joined the World Trade Organization must follow the principles and procedures detailed in the Agreement on the Application of Sanitary and Phytosanitary Standards, called the SPS Agreement, in setting their phytosanitary rules. Faith Campbell felt that the SPS Agreement and the International Plant Protection Convention (IPPC) have gone too far, the result being that countries will be hampered in their efforts to prevent the introduction of potentially damaging exotic organisms. The SPS Agreement and IPPC demand levels of precision that are beyond the capacity of scientists to provide. Furthermore, these international agreements conflict with the advice of experts on bioinvasion, who recommend a focus on pathways of introduction rather than individual pests. The SPS Agreement and IPPC further undermine effective phytosanitary measures by forcing countries to delay acting to forestall known dangers. Unlike regulations adopted by USA and Canadian phytosanitary agencies, international standards are adopted with little or no public input and no environmental assessment. The IPPC and NAPPO have accepted the concept of a "pathway approach" for SWPM. However, the standards they have adopted do not yet fulfill that goal; instead, they continue to rely to a large extent on inspection.

Jon Bell spoke on the issue of introduction of new foreign pests under current regulations. When we talk about placing regulations on a product that poses a risk to the importing country, an assessment has to take place to quantify the risk as well as the size of the problem itself. A vessel can discharge approximately 130 m^3 of poor quality lumber from an unknown source. Wood dunnage is not wasted—it can be reused so the origin of dunnage cannot always be attributed to the last port of loading or the associated cargo. Wood in items such as wooden wire rope spools and pallets is easier to regulate, once identified, but the challenge is finding the new pathways and then verifying pest freedom. In a utopian world, all wood that is used in international trade would be treated, i.e., kiln dried to ensure the destruction of all fungi, nematodes and insects, so that no nation would be exposed to the risk of an exotic pest. Unfortunately, that will never be reality, and at present the levels of control vary widely. The best world standards for preventing the movement of forest pest and diseases will come to naught, if audits and enforcement are not coupled to national regulations. Tracking treated wood will become a major sinkhole for staff usage for all quarantine agencies concerned about the movement of forest exotics. From experience we know that a regulation is only as good as the enforcement applied to that regulation.

Andrew Liebhold's presentation focused on managing invasions. Because of the tremendous ecological and economic impacts of invasions, this area has drawn the attention of numerous studies focusing on the applied aspects of invasions. But biological invasions also may be considered miniature "ecological experiments" and, therefore, yield new insights into basic problems in ecology. Out of this work has evolved the field of "invasion ecology" that combines the following ecological sub-disciplines: community ecology, population ecology, landscape ecology, animal ecology, and plant ecology.

When considering the population biology of biological invasions, it is possible to recognize three processes underlying all invasions: arrival, establishment, and spread. All three phases have been the object of considerable research. These components of the invasion process also are critical to understanding efforts to manage or control invasions: there is a unique correspondence between each stage of the invasion and their strategies for management.

There has been considerable interest in modifying international quarantine and inspection procedures in order to limit invasions by directly influencing rates of arrival. These efforts are clearly appropriate because invasions and their associated impacts may be adverted with relatively minimal effort. But even if revolutionary changes were to occur in these matters, it is unlikely that changes in quarantine and inspection practices would prevent most arrivals. This means that the only other avenues for limiting new invasions are via management of the establishment and spread processes.

Phyllis Windle's presentation dealt with research and policy. As scientists, we envision progress as a series of linear steps, beginning in research and ending when that research is successfully translated into policy. The conference organizers sought to be thought-provoking when they titled this session, "Is there hope for the future?" Answering that question goes well beyond science and policy. It requires examining the nature of hope and how we become hopeful. First, we might consider the sheer amount of research being published on invasive species and its trends over time. By this criterion, the future of research is bright. Second, the future of a field is bright when participants focus work on mutually established priorities and seek to affect public policy by matching their research to decision makers' needs. Last December, the first National Conference on Science, Policy, and the Environment met to set an agenda for the new century. More than 450 scientists and decision-makers divided into 14 working groups. The invasive species group began with the 59 recommendations laid out by the groups named above and selected the following priorities: conduct integrated and comprehensive planning; apply models of multi-agency action; encourage interdisciplinary research; and articulate the role of humans. A third way to assess the future of research is to look at the resources it receives, especially in funds and staff. Here the future is not so clear.

In the United States, about one-half of all the federal money spent on invasive species goes to prevention, e.g., port inspectors and quarantine. More detail on federal expenditures in the United States must await the National Invasive Species Council's first attempt to construct a cross-cutting budget for fiscal year 2002. We share grave concerns about the future of research in the US Forest Service. The total number of scientists dropped by almost one-half between 1985 and 2000. These drops are especially notable for entomologists and plant pathologists, just when we need them most. Concern about invasive species policy is growing quickly. Unfortunately, the lag between concern and new policy is long. Scientists have played a major role in changing invasive species policy already. In the United States, more than 500 scientists and managers signed the letter to former vice-president Gore that resulted in former president Clinton's Executive Order on invasive species. They changed the structure and goals of the US Government's approach on this issue. In Canada, more than 400 signed "The Scientists' Declaration to Conserve Canada's Coastal Temperate Rainforests." Scientists' role in speaking with the press is exceptionally important.

And to work for change, we must have hope.

Let us spend this time together and share what we know. Let us be convinced of our ability to change policy. Let us create an epidemic of hope. And let us return home to do more.

POST-ARRIVAL METHODS OF MANAGING INVASIONS AND ALLEE DYNAMICS

A.M. Liebhold, *US Forest Service, Morgantown, West Virginia*

Since the time of Elton's (1958) seminal book on biological invasion, there has been growing attention by ecologists to various aspects of this subject (Liebhold et al. 1995). Because of the tremendous ecological and economic impacts of invasions, this area has drawn the attention of numerous studies focusing on the applied aspects of invasions. But biological invasions also may be considered miniature "ecological experiments" and, therefore, yield new insights into basic problems in ecology (Vitousek et al. 1996). Out of this work has evolved the field of "invasion ecology" that combines the following ecological sub-disciplines: community ecology, population ecology, landscape ecology, animal ecology, and plant ecology.

When considering the population biology of biological invasions, it is possible to recognize three processes underlying all invasions: arrival, establishment, and spread (Dobson and May 1986) (Table 1). All three phases have been the object of considerable research. These components of the invasion process also are critical to understanding efforts to manage or control invasions: there is a unique correspondence between each stage of the invasion and their strategies for management.

There has been considerable interest in modifying international quarantine and inspection procedures in order to limit invasions by directly influencing rates of arrival. These efforts are clearly appropriate because invasions and their associated impacts may be adverted with relatively minimal effort. But even if revolutionary changes were to occur in these matters, it is unlikely that changes in quarantine and inspection practices would prevent most arrivals. This means that the only other avenues for limiting new invasions are via management of the establishment and spread processes.

Sharov and Liebhold (1998) present a theoretical model that can be used for evaluating the relative economic efficacy of eradication and containment, versus no action. That model uses information about rates of spread, costs of containment, and predicted economic costs to identify optimal management strategies. While some of this information may be difficult to estimate for some newly arrived exotic organisms, the model serves as a framework for identifying when eradication and/or containment of exotic species are appropriate.

Myers et al. (2000) provide a brief overview of the biological and sociological aspects of eradication. They point out that eradication may often involve complex social issues and they sometimes generate considerable political and scientific controversy. While they provide considerable insight into many important social

Table 1. The three basic population components of any biological invasion

Process	Description	Management approach
Arrival	Transportation of organism to a geographical location outside of its normal range	International quarantine, inspection
Establishment	Population growth to densities such that extinction is impossible due to random chance alone	Detection, eradication
Spread	Range expansion	Domestic quarantine, barrier zones (containment)

and biological issues, they probably neglect one important ecological phenomenon that is often of considerable importance, namely Allee dynamics.

When Warder Allee (1931) wrote his text on animal population ecology, he recognized a phenomenon that exists in populations of certain species: low-density populations are affected by a positive relationship between population growth rate and density (inverse density dependent mortality). The result of this relationship is that low-density populations are driven toward extinction (Fig. 1). This phenomenon, termed the "Allee effect", may result from a multitude of biological mechanisms, e.g., cooperative hunting, predator satiation, and failure to find mates at low densities (Courchamp et al. 1999). The Allee effect has been recognized as critical to understanding patterns of extinction from the perspective of conservation biology (Stephens and Sutherland 1999), but less is known about its role during biological invasions. Obviously some organisms (e.g., parthenogenetically reproducing aphids) may not exhibit any Allee dynamics but many species (presumably this would include any species that must mate to reproduce) would be expected to exhibit some form of Allee effect at low densities. Hopper and Rousch (1993) used historical data on successes of attempted introductions of varying numbers of individuals of different parasitoid species to show that the successful establishment of these species was explained by Allee dynamics. It is likely that Allee dynamics may be of critical importance to a number of invading species and therefore may be essential to understanding why some species establish more easily than others.

Understanding this process has important implications for management. The activity we call "eradication" is aimed at reversing the process of establishment; eradication is forced extinction. Different species of exotic organisms are likely to vary in the extent to which they exhibit Allee dynamics due to variation in their biology.

When eradication of an exotic organism is being considered, a variety of biological and sociological facts must be considered in order to identify the most appropriate response (Myers et al. 2000; Sharov and Liebhold 1998). Clearly there is variation among different types of organisms in the ease with which they may be eradicated. The existence of Allee dynamics is one of several factors that should be considered when evaluating the practicality of eradication.

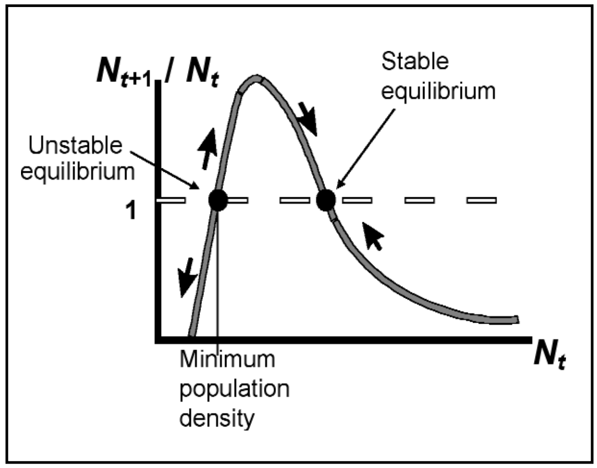

Figure 1. Schematic representation of the Allee effect. Change in population density, N_t+_1/N_t is plotted as a function of density at the beginning of the generation, N_t. This relationship determines change in population density $f(N_t)$ shown in equation 1. Note that when density is greater than the minimum population density, it will increase or decrease toward the stable equilibrium, but when it is below this threshold, density will decrease toward extinction.

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PRESENT AND FUTURE PATHWAYS

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The transportation of organisms from one continent to another began with the first migrations of humans out of Africa some 1.7 million years ago (Culotta et al. 2001). These organisms were associated with humans as parasites and pathogens and as "hitchhikers" on their bodies, clothing and paraphernalia. Today, foreign organisms are arriving in North America at alarming rates. The following examples indicate the diversity of these organisms:

1) "Chesapeake Bay receives some 10 billion litres of foreign ballast water each year. Each litre typically contains about a billion bacteria and 7 billion virus-like particles... Vibrio cholerae (cause of human epidemic cholera) was found in plankton samples from all ships...the US receives 29 million tonnes of ballast water from overseas each year" (Ruiz et al. 2000).

2) "Humans have surpassed natural forces as the principal global dispersers of vascular plants" (Mack and Lonsdale 2001).

3) "Human activities often radically alter the density and composition of bivalve communities, inadvertently transforming ecosystem structure and function" (Strayer et al. 1999).

4) "All available assessments show that the movement of plant material and their associated pathogens is a trend that shows no abating" (Wingfield et al. 2001). Introduction of some species often require special funding to investigate their biology, impacts, spread potential, and control methodology (e.g., Haack et al. 1997; Storer et al. 1997).

"The United States has now become the world's leading importer of wood and wood products....In 1990, for example, the United States imported more than $5 billion in logs, lumber and other unmanufactured wood articles" [United States Department of Agriculture–Animal and Plant Health Inspection Service (USDA–APHIS) 1998]. In my travels to the Soviet Far East in 1990 (now Eastern Russia), I observed very large log storage areas in the modern port of Nakhodka on the Sea of Japan and in Yakutsk on the Lena River which flows northward to the Arctic Ocean. These logs were destined for markets throughout the world. In early 1991, APHIS undertook a pest risk assessment of the importation of larch from Siberia and the Soviet Far East (USDA–FS 1991). This report concluded the following: "In summary, importing unprocessed larch logs...into North America can have serious consequences because of the potential for introducing exotic forest pests. Measures must be implemented to mitigate the risks of pest introduction and establishment."

Inspections of untreated timber products by the Oregon Department of Agriculture intercept exotic pests regularly. For example, long-horned beetle larvae, an ambrosia beetle (*Trypodendron lineatum*) and a sap stain (*Ophiostoma brunneo-cilliatum*), were found on Russian cross ties in 1998 (N.K. Osterbauer and J.R. LaBonte, personal communication). Over 20% of the cross ties were infested with insects and over 40% of the ties exhibited the sap stain. The present rules for importation of cross ties are as follows: "From all places except East of 60 degrees East and North of the Tropic of Cancer (they) must be stripped of bark, then imported with a promise that they will be pressure treated within 30 days" (*Code of Federal Regulations Part 319, subpart 40*). Cross ties from Russia are an obvious open pathway for exotic wood-infesting pests to enter North America.

In 1998 I also visited the Carter, Holt, Harvey Mill near Rotorura and the Port of Tauranga on the North Island of New Zealand. Logs are cut and debarked at the mill, and then transported to the port by rail. The USDA–APHIS personnel oversee further bark removal from these logs when required. Logs are loaded on ships and fumigated with methyl bromide. "Logs derived from Monterey pine and Douglas fir grown in plantations in Chile and New Zealand must be from healthy trees apparently free from plant pests, pest damage or decay...barked and fumigated before they arrive in the US...once in the US, kept segregated until processed...moved by direct route between port and processing facility...At the processing facility, logs and lumber must be heat treated and then processed within 60 days" (USDA–APHIS 1998).

How do we separate trees that are apparently free from plant pests from those that actually are free from plant pests? For example, we know that the following root diseases that are native to New Zealand are found infecting Monterey pines: *Armillara novae-zelandiae*, *Junghuhnia vincta*, *Peniophora sacrata*, and *Phytophthora* spp. In addition, non-native root rots caused by *Leptographium procerum*, *L. truncatum*, and *Ophiostoma piceaperda* are established in Monterey pine plantations (Ridley and Dick 1996). In 1998, sap stain fungi (*Graphium* sp., *Ophiostoma picae*) were isolated from New Zealand logs that had been fumigated (Oregon Department of Agriculture). Parasitic fungi from many genera have also been isolated from these logs.

In spite of these records, APHIS concludes that "...log importations under the current regulations present a negligible plant pest risk. According to APHIS' pest database, no log shipments have been found infested with exotic forest pests" (USDA–APHIS 1998). Furthermore, the efficacy of fumigants against such pests as wood wasps (*Siricidae*) and long-horned beetles (*Cerambycidae*) that tunnel deeply into wood is not well known. Unprocessed logs from New Zealand and Chile are an obvious open pathway for exotic wood-infesting pests to enter North America. Dutch elm disease and the pinewood nematode are classic examples of pest introductions via logs. Recently, the red-turpentine beetle (*Dendroctonus valens*) has been found killing *Pinus tabulaeformis* over large areas (estimated 500 000 ha) in Shanxi Province (500 km west of Beijing), China. The suspected vehicle for this introduction is thought to be from infested mine timbers cut from ponderosa pine in the western USA (P. Shea (Retired), USDA Forest Service, personal communication).

"By far, the greatest current pathway of exotic forest pests into the United States is through use in international trade of untreated solid wood packing materials (SWPM)" (From USDA–APHIS 1998). "Solid wood packing materials accompany 52% of maritime shipments and 9% of air shipments imported into the USA. Solid wood packing materials may be associated with over 200 different commodities....Port inspections alone are inadequate to mitigate the pest risk associated with SWPM" (USDA–FS and USDA–APHIS 2000). For example, 3–8 million containers are handled by the Port of Long Beach, California, each year. About 52% (2.0 million) contain SWPM. Three percent (60 000) are checked each year and 5.8% (3 480) are found to contain pests of wood (P. Fitterer, USDA–APHIS, personal communication). Thus 97% (1 940 000) of these containers are not checked and 112 000 (1 940 000 x 5.8%) containers with pests of wood enter into the USA each year through the Port of Long Beach. Examples of recent pests introduced on SWPM are:

1) 1984 – eucalyptus borer (*Phoracantha semipunctata*),
2) 1992 – pine shoot beetle (*Tomicus piniperda*), and
3) 1996 – Asian long-horned beetle (*Anoplophora glabripennis*).

Parasitic fungi from many genera, including *Fusarium*, *Graphium*, *Polyporus*, and *Trametes* have been found on Asian SWPM (N.K. Osterbauer, Oregon Department of Agriculture, personal communication). The conclusion reached by Dr. George Carroll, President of the Micological Society of America, is apropos here: "Instead of relying on inspection to detect hazardous organisms, such pests should be assumed to be present and the commodity treated accordingly with appropriate sanitation procedures. So far, the only sanitation procedure demonstrated to reduce risk to acceptable levels is heat treatment with or without moisture reduction (Morrell 1995). The Animal and Plant Health Inspection Service recommends that wood be treated to 71.1ºC for 75 minutes in the center of the log or manufactured wood articles (USDA–APHIS 1995). Solid wood packing material is an obvious open pathway for exotic wood-infesting pests to enter North America.

Rules for importation of lumber have been established by APHIS. "Lumber from the region east of 60 degrees east and north of the Tropic of Cancer must be heat treated and kept segregated...Lumber from all other places—

including New Zealand and Chile—may be imported if heat treated...Raw lumber from all places except the "Asian zone"—including Chile or New Zealand—may be imported without previous treatment; once imported, the wood must be shipped to an APHIS-approved facility, where it must be treated within 30 days."

We are presented with the APHIS enigma: New Zealand logs do not have to be heat treated, while lumber must be so treated. What is the logic behind these rules? As shown here, pests have arrived on logs from New Zealand and on SWPM from Asia, Australia, and Europe. Lumber is an obvious open pathway for exotic wood-infesting pests to enter North America.

Summary: Currently, four significant pathways are wide open for the continued introduction of pests into North American forests. These are: railroad ties, unprocessed logs, solid wood packing material, and lumber. Present regulations cannot stem the flow of these exotic organisms. Growth of various imports such as agricultural and natural products and horticultural/nursery products are projected to increase steeply (1–3000%) in the next 20 years. Enserink (1999) states "...and whereas globalization may be the mantra of the new economy, for the environment it may spell disaster." To stop the flow of pests into the forests of North America, we must take actions that realistically have a chance to reduce this risk. These actions should include heat treatment of all railroad ties, logs, lumber and SWPM to 71ºC at the center of the largest piece for 75 minutes. Otherwise cease trading these items. If one of these options is not exercised, pests will continue to be introduced into North American forests and continue to exact their tremendous economic, environmental, and esthetic toll.

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IMPLICATIONS OF INTERNATIONAL TRADE—MODIFICATION OF AGREED PROCEDURES

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Phytosanitary agencies no longer work independently when adopting measures to protect plant resources. Countries which have joined the World Trade Organization (WTO) must follow the principles and procedures detailed in the Agreement on the Application of Sanitary and Phytosanitary Standards, called the SPS Agreement, in setting their phytosanitary rules.

I believe that the SPS Agreement and the International Plant Protection Convention (IPPC) have gone too far. The result is that countries will be hampered in their efforts to prevent the introduction of potentially damaging exotic organisms. In my view, the SPS Agreement and IPPC demand levels of precision that are beyond the capacity of scientists to provide. Furthermore, these international agreements conflict with the advice of experts on bioinvasion, who recommend a focus on pathways of introduction rather than individual pests.

The Global Invasive Species Program calls the pathway approach "Integrated Vector Management", defined as the use of all available control and management techniques at the appropriate multiple times and points in the vector "life" to reduce the number and diversity of transported organisms (Carlton and Ruiz n.d.).

The SPS Agreement and IPPC discourage a "pathway" approach. According to David McNamara (in discussion), Assistant Director of the European and Mediterranean Plant Protection Organization, pest risk analysis may be performed on a "pathway". However, "this is only the starting point – thereafter, you have to pick named pests that might be associated with that commodity and subject each one to a pest risk assessment...[You]can't take measures against a commodity because of unnamed or unknown pests." McNamara also said that the IPPC'S acceptance of a pathway approach for solid wood packaging material (SWPM) should not be seen as a precedent for using the pathway approach for other types of commodities.

Other sources agree that risk assessments done to comply with the SPS Agreement must be very specific about potential pests and threats. In one case, WTO dispute bodies ruled that "...it is not sufficient...that there is a possibility of [introduction] and associated biological and economic consequences. A proper risk assessment...must evaluate the "likelihood", i.e., the "probability", of entry, establishment, or spread..." (WTO 1998).

In a second case, the WTO dispute bodies ruled that the "scientific studies [on which the Europeans based their "level of risk"] must evaluate the carcinogenic potential of the specific hormones in question at residue levels found 'in food', more specifically, 'meat or meat products' when the hormones are 'used specifically for growth promotion purposes'." (WTO 1997). A more general discussion of the risks associated with hormones was insufficient as a justification for the European regulation. When such detailed information is unavailable, the SPS Agreement allows countries to adopt "provisional" measures. However, the countries must actively seek the missing information. I argue that the agency should better focus on addressing other unregulated pathways of introduction.

I think it is a real question whether scientists can ever provide the specificity demanded, given that scientists have named only a small fraction of the Earth's species, understand the ecological role of a much smaller proportion, and experience great difficulty in predicting how even well-known species will behave in new environments.

The SPS Agreement and IPPC further undermine effective phytosanitary measures by forcing countries to delay acting to forestall known dangers. According to Roddie Burgess (in discussion, on-line symposium 2001) of the British Forestry Commission, logic counsels acting before a problem arises, but the SPS suggests we need to "wait until the existing controls have been proved insufficient and then beef them up." For example, when the Europeans found live pinewood nematodes (*Bursaphelenchus xylophilus*) in softwood packing material shipped from Canada, China, Japan and the USA, they tightened their import requirements for those countries by adopting a temporary emergency measure which becomes effective October 1, 2001. Since they have not yet found live pinewood nematodes (PWN) in coniferous wood packaging from Korea and Taiwan (where the pest is also present), Europe has continued allowing imports under less stringent measures from those countries—until PWN is detected on their wood packaging. However, it is widely recognized that deepwood pests such as the PWN are extremely difficult for inspectors to find. In consequence, it is probable that nematodes in packaging from Korea and Taiwan will reach Europe for months if not years before they are detected and the more protective phytosanitary measures applied.

The cost of preparing risk assessments can be significant. Since 1991, the US Department of Agriculture–Animal and Plant Health Inspection Service (USDA–APHIS) has spent almost $700,000—not including the salaries of the government scientists involved—in preparing five risk assessments for imported logs and lumber (Wallner n.d.). The Animal and Plant Health Inspection Service has a backlog of about 400 risk assessments that it must complete to bring current regulations into compliance with the SPS Agreement (Richard Dunkle, Deputy Administrator, APHIS, personal communication). Many assessments need not be as expensive as were some of the log risk assessments. However, some of the low-cost risk assessments contain so little information and analysis that they cannot be accepted as adequate. Already, many countries have expressed worry that they lack the resources needed to do these studies (McNamara 2001).

The SPS Agreement encourages countries to base their phytosanitary measures on international standards adopted by the IPPC and other named bodies. International standards do not have to be based on risk assessment—indeed, it is not clear on what such standards are based, other than the negotiating skills of the various countries participating in the process. In addition, it is questionable whether the 170 IPPC countries can agree on a standard that is sufficiently stringent to be effective.

Unlike regulations adopted by USA and Canadian phytosanitary agencies, international standards are adopted with little or no public input and no environmental assessment. The United States Department of Agriculture–Animal and Plant Health Inspection Service played a leading role in developing both the regional standard for wood packaging [adopted by the North American Plant Protection Organization (NAPPO) in 1998] and the IPPC's draft international standard. Now, in writing its own rule, APHIS is required by law to consider both public input and an environmental assessment. What happens if the domestic rulemaking process points to an approach significantly different from that adopted—at US prompting—by NAPPO or the IPPC? Should APHIS follow the domestic procedures and adopt different rules? Or follow the international standards on which it was so active? Another complication is that the NAPPO standard and draft IPPC standard differ on some important provisions. Which takes precedence?

The SPS Agreement and IPPC strictly limit what actions countries can take to prevent continued introductions of a pest that is already established in the country. Phytosanitary treatment targetting an established pest is allowed only when:

- the species is not widespread and is the subject of an "official control program"; or

- the newly introduced organism differs genetically from its relative in the importing country in a way that demonstrates the potential to cause greater damage.

The draft IPPC definition of "official control program" requires that the program involve “active enforcement of mandatory phytosanitary regulations...with the objective of eradication or containment ...”; the IPPC's parent organization, the United Nations Food and Agriculture Organization, has defined “official programs” as those established, authorized or performed by a nation's phytosanitary agency. Unfortunately, APHIS lacks sufficient resources to manage programs targetting each of the 8 000 exotic pests and plants already established in the country. Accordingly, APHIS should lack authority to prevent additional introductions of most of these invasive species.

How does APHIS solve this dilemma? Animal and Plant Health Inspection Service staff have told me that they are ignoring the international law and applying remedial treatments when they detect pests at the border—regardless of whether an "official control program" exists. Any of our trade partners could challenge APHIS' action at any time.

Considering the second option, genetic variability, I doubt that scientists have sufficient information about the genetic makeup of most alien organisms—and how any genetic differences might express themselves in a new environment—to make the required finding.

Although the SPS Agreement allows countries to set their own "appropriate level of risk", there is little flexibility. The "appropriate level of risk" must be justified through a risk assessment, subject to all the problems to which I have already alluded. Furthermore, it must be "consistent" with the "levels of protection" applied in "comparable" situations. David Victor (1999) of the Council on Foreign Relations has said that these comparisons could be made to a wide range of environmental and public health rules. Any gaps in protection in one of these rules could become a ceiling limiting phytosanitary measures.

The US Department of Agriculture–Animal and Plant Health Inspection Service has rarely specified what "level of protection" it strives to achieve with regard to any particular pest risk. In some cases involving imports of logs, APHIS has appeared to settle on "negligible" risk, which the agency appeared to equate with a 3% risk. However, the US receives approximately 30 million shipping containers each year (Robert Kanter, Port of Long Beach, personal communication). If 3% of these are infested with forest pest, that means imports of 900 000 infested shipping containers each year. Similarly, the USA imports 3.5 million m^3 of roundwood from countries other than Canada (http://www.fao.org/forestry/fo/country/; Tkacz 2001). If 3% of these logs are infested, that results in 105 000 m3 of infested logs imported each year. The Oregon Department of Agriculture has disputed both APHIS' level of risk and the effectiveness of the measures it has adopted with the intention of achieving such protection.

When phytosanitary agencies decide how to carry out their duties, their implementation decisions doubtless are influenced by those agencies' understanding of their broader role. According to David McNamara of the European and Mediterranean Plant Protection Organization (discussion), "Recently, (plant protection agency officials) have come to realize that our work has changed from preventing introduction of pests while not interfering unduly with trade, to facilitating trade while doing our utmost to prevent pest introduction. The signing of the SPS Agreement was the moment when the switch was completely turned. And until we can convince our politicians that protecting plants is more important than international trade, that is the way it is going to stay."

The Executive Director of the North American Plant Protection Organization, Ian McDonell, disagrees (discussion, on-line symposium April 2001); according to him, the NAPPO mission remains to protect plants first while facilitating trade second.

The *US Plant Protection Act* (Title IV of PL 106-224), adopted last year, contains the following troubling language:

> Congressional "finding"
>
> "(3) it is the responsibility of the Secretary [of Agriculture] to facilitate exports, imports, and interstate commerce in agricultural products and other commodities that pose a risk of harboring plant pests or noxious weeds in ways that will reduce, to the extent practicable, as determined by the Secretary, the risk of dissemination of plant pests or noxious weeds;"

I fear that this will result in APHIS putting even higher priority on facilitating trade, even at the risk of allowing introductions of harmful pests.

I am encouraged that the IPPC and NAPPO have accepted the concept of a "pathway approach" for SWPM. However, the standards they have adopted do not yet fulfill that goal; instead, they continue to rely to a large extent on inspection. For example, many bark beetles continue to arrive in Canada and the United States on wood packaging, despite regulations adopted in 1995 that require shippers to remove bark. Unfortunately, the IPPC draft standard says that countries may not apply phytosanitary treatments to SWPM that has undergone "universal" treatment if bark is present. Instead, "...On wood packing to which a universal measure has been applied, action should not be taken on signs of pests or presence of bark alone. Action can be taken based on sign of live pests...or bark in raw wood if quarantine pests have been found to be associated with such signs at the time of inspection, or on previous inspection(s) of equivalent consignments....In the case of consignments of a new commodity or consignments from a new source, it may be practical to take emergency action based on the signs of live pests or bark without detection of the pest."

Contrary to David McNamara, I urge use of the pathway approach to many other types of imports, not just SWPM. I believe that national phytosanitary agencies will experience similar difficulties trying to "characterize the risk" associated with these other vectors, especially imports of living plants.

The SPS Agreement and IPPC also fail to factor in other important concerns. For example, they do not appear to allow countries to consider the cumulative impacts of hundreds or thousands of introductions when assessing a potential new pest that is thought unlikely to cause "catastrophic" impacts itself. How can countries carry out other legitimate social goals, such as reducing use of the inexpensive fumigant, methyl bromide, to protect the stratospheric ozone layer? The NAPPO SWPM standard allows routine use of methyl bromide MB fumigation, while the IPPC urges that such treatment be used only in emergency situations.

Finally, I encourage scientists to speak out in the political forum to bring about improved international phytosanitary agreements. Scientists can have considerable influence in policy fora. The US Department of Agriculture–Animal and Plant Health Inspection Service adopted its "comprehensive" regulations governing wood imports in 1995 in response to scientists' bringing pressure through their members of Congress (United States Congress 1993). Former president Clinton issued his Executive Order on invasive species in response to a letter from more than 500 scientists and resource managers, supported by scientists inside the federal agencies.

Please, use this power.

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THE THREAT OF NEW INTRODUCTIONS UNDER CURRENT REGULATIONS—A WORLDWIDE PROBLEM

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When we talk about placing regulations on a product that poses a risk to the importing country, an assessment has to take place to quantify the risk as well as the size of the problem itself. Is any one really aware of the volume of wood moving in international trade? Last year when looking at a bulk steel carrier, we tried to assess the amount of dunnage from that one vessel. A vessel can discharge up to a dozen dumpster loads of dunnage. Loosely packed (50% volume), each dumpster contains about 11 m^3 of solid wood. Approximately 130 m^3 of poor quality lumber from an unknown source from one vessel for one voyage. Now, look at the number of vessels on the oceans of the world, and the volume of wood becomes enormous. Much of it is downgraded material that did not meet structural or quality standards in the country of origin and can range from tropical hard woods to coniferous species. Wood dunnage is not wasted—it can be reused so the origin of dunnage cannot always be attributed to the last port of loading or the associated cargo. This type of dunnage (break bulk) tends to remain around port areas and can be subject to some types of regulation within the port authority.

The risk with containers is quite different from bulk break dunnage due to the mobility of containers and contents. Typically, a container will be packed at the point of cargo manufacture, sent by rail or truck to the exporting port, and shipped to the importing country. Then by truck or by rail it goes directly to the importers warehouse, regardless of destination in that country. Examination of the contents at the port of arrival is difficult and expensive (CAN $600–800 per container) and more importantly, can causes expensive time delays to the importer. From our experiences in Vancouver, it is the "hidden or undeclared" wood used in association with traditionally non-risky items that now presents us with the largest challenge. Wood in items such as wooden wire rope spools and pallets is easier to regulate, once identified, but the challenge is finding the new pathways and then verifying pest freedom.

As we have moved into the new century of globalization and freer trade, forest pests and phytosanitary issues associated with the international movement of wood have caused an international shift in the regulations and standards to stop the movement of infested/infected wood. In a utopian world, all wood that is used in international trade would be treated, i.e., kiln dried to ensure the destruction of all fungi, nematodes and insects, so that no nation would be exposed to the risk of an exotic pest. Unfortunately, that will never be reality, and at present the levels of control vary widely.

The best world standards for preventing the movement of forest pest and diseases will come to naught, if audits and enforcement are not coupled to national regulations. Some will argue for higher standards than the proposed new standard of 56°C for at least 30 minutes at core; or pressure treatment with a chemical; or fumigation, to achieve zero risk. Zero is not attainable. You only have to look at the leakage of wood through an infinite number of entry routes that are not at present being blocked or monitored, and in fact are impossible to prevent. From a practical point, wood will be associated or built into many articles, and we, as regulators, will have to go out and find them. Not everything can be regulated; for example, the artificial Christmas trees whose main trunk, is, in fact, a piece of coniferous wood infested with *Callidiellum rufipenne* from China and imported into the USA. The list of "watch for" items has moved from the obvious large dimensional timbers associated with heavy equipment, to wooden wire spools, to bamboo plant stakes, to weightlifting equipment. There will be no end in the near future to the growing list of items found with pest contamination. Obviously the risk will diminish but it will never reach zero. The recent dunnage and solid wood packing material (SWPM)-based introductions of the pine shoot beetle *Tomicus piniperda*; Japanese tsugi borer *Callidiellum rufipenne*; Asian longhorn beetle (ALHB) *Anoplophora glabripennis*; and brown spruce longhorn *Tetropium fuscum*, into North America have kick-started the regulators to take decisive action. In the face of push-back from domestic and international traders using wood in their products, it has not been easy to reach consensus. The recipient of these new standards and regulations is the private sector, who will have to pay the bill for our (regulators) actions and recommendations to reduce the movement of exotics. It is safe to say that economics will direct the future use of wood in the shipping industry.

It could have been so easy to have had Vancouver listed as an infested site for ALHB, along with New York and Chicago. In 1992, a container arrived from Asia with large steel pipe flanges stabilized with dimensional wood, and emerging from that wood were hundreds of black and white beetles. The importer's staff phoned us, the cargo was treated, and no ALHB were found in Canadian trees in the area; but if we had not been alerted, ALHB would have established itself in local trees.

Tracking treated wood will become a major sinkhole for staff usage for all quarantine agencies concerned about the movement of forest exotics. From experience we know that a regulation is only as good as the enforcement applied to that regulation. How will we control pallets that claim compliance to the new heat or chemical treatments, look at all pallets and check any new wood added for repairs? It is just not feasible. We will only reduce the risk to a minimal level and accept that some things will get through.

So, in the future we will have standards and laws that will protect our natural resources from exotic pests. This is true only if we get the word out to the widget manufacturers in a third-world country and get their buy-in, either for environmental or financial reasons. The impact of moving forest exotics must be passed down to the producers and users of dunnage and SWPM, and at the same time built into letters of credit so that everyone understands the financial liability for moving exotics. It is not acceptable to put so much international effort into having standards and laws, only to find paint ball gun holster imports found to be infested with *Erthesina fullo*, a pest of pine and hardwood trees in Asia.

RESEARCH AND PUBLIC POLICY: MEASURING HOPE

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As scientists, we envision progress as a series of linear steps, beginning in research and ending when that research is successfully translated into policy. I was asked to address the future of both research and public policy. In a sense, then, I am assessing the first and final stages of invasive species work—providing the outer brackets for this, our first session.

The conference organizers sought to be thought-provoking when they titled this session, "Is there hope for the future?" Answering that question goes well beyond science and policy. It requires examining the nature of hope and how we become hopeful. I conclude this paper with those topics.

The Future of Research

We can assess the future of research in a number of ways. Here are three.

1. **Amount of Research**
   First, we might consider the sheer amount of research being published on invasive species and its trends over time. By this criterion, the future of research is bright. In 1990, when I entered the field, it was easy to read all the relevant work. Scientific papers were scattered in a few journals. Government documents were few. Now it is hard to keep up. We even have our own journal, *Biological Invasions*. The number of non-scientific articles on invasive species has increased exponentially since 1972 (Fig. 1). I suspect the same is true for scientific publications.

2. **Focus and Priorities**
   Second, the future of a field is bright when participants focus work on mutually established priorities and seek to affect public policy by matching their research to decisionmakers' needs.

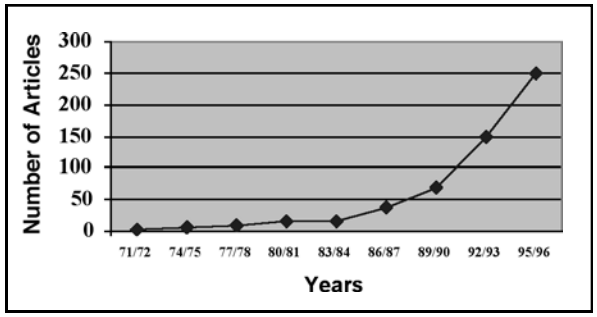

Figure 1. Number of nonscientific articles written about biological invasions (Source: Reichard and White 2001).

Jack Ewel and others (1999) published one of the first such attempts, based on a 1997 workshop. They suggested several key areas for future work, all regarding deliberate introductions of species: risk-benefit assessments, research on alternatives, safeguards for introductions, and impact mitigation. Also, they identified three information gaps related to public policy: the development of a broadly accessible information system to help evaluate organisms; evaluations of impacts based on recipient communities as well as the organism introduced; and classifications of organisms by their potential effects, with regulations matched accordingly.

Since 1999, at least three additional groups have laid out strategic approaches to invasive species research. The Global Invasive Species Programme identified ten "strategic responses" needed to address problems (GISP 2001). Building research capacity was one. In 2000, the US National Science and Technology's Committee on Environment and Natural Resources also developed an invasive species research strategy (NSTC 2000). And, in 2001, the US Invasive Species

Council released its first national management plan (NISC 2001). Together, these three reports identified 59 specific research topics or types of research that needed to be addressed. Topics included the basic biology of invaders, social science research, methods of information management, and means to build research capacity and funding.

Last December, the first National Council for Science and the Environment (NCSE) Conference met to set an agenda for the new century. More than 450 scientists and decision-makers divided into 14 working groups. The invasive species group began with the 59 recommendations laid out by the groups named above and selected the following priorities:

General Recommendations
1. conduct integrated and comprehensive planning;
2. apply models of multi-agency action;
3. encourage interdisciplinary research;
4. articulate the role of humans.

Specific Recommendations
1. support programs that quantify ecosystems before, during and after invasion;
2. expand research: to identify pathogens and vectors; on taxonomy and systematics; to detect and rapidly respond to invasions;
3. research on methods to control and eliminate invaders, especially environmentally sound ones;
4. conduct research on: ecosystem vulnerability and roles of multiple stressors; human dimensions; disruption of ecosystem services; and minimizing industries and social forces that ease invasions (NCSE 2001).

This conference report is just one example of the increasing consensus on the kinds of research needed. Hendrickson's findings (n.d.) on invasive alien species in Canadian forests are another. Two typical areas of agreement are the need for multi-agency approaches and better knowledge of fungi.

3. **Research Resources**

A third way to assess the future of research is to look at the resources it receives, especially in funds and staff. Here the future is not so clear.

In the United States, about one-half of all the federal money spent on invasive species goes to prevention, e.g., port inspectors and quarantine (Table 1). The US Department of Agriculture accounts for 88% of all these expenditures (GAO 2000). That is putting a lot of eggs into this one basket. Because new pests continue to be introduced, it is hard to think we are getting our money's worth.

Another large proportion of the US budget goes into research. As scientists, it is hard to argue with this high percentage. Of course aggregated figures can mask a host of problems. More detail on federal expenditures in the United States must await

Table 1. US federal obligations by invasive species activity

Activity	Fiscal Year 1999 (millions USD)	Fiscal Year 2000 (millions USD)
Prevention	262.9	308.5
Control	99.1	143.8
Research, development	94.6	104.9
Education, outreach	29.2	39.9
Detection, monitoring, information management, restoration	28.0	34.6
Total	513.9	631.5

Source: US General Accounting Office (2000).

the National Invasive Species Council's first attempt to construct a cross-cutting budget for fiscal year 2002.

More precision is available for Canadian and US expenditures on research in the Great Lakes (Great Lakes Commission 1996) (Table 2). Here, 52-70% of research funds are spent on ecosystem impacts, and 4-5% on prevention. This looks out of kilter, even though ecosystem research is relatively neglected (Parker et al. 1999). A completely different set of interest groups is involved in agriculture versus the problems of aquatic invaders. For the latter, there is no clear lead agency and public policy is relatively recent—factors which contribute to how research dollars are allocated.

I know that we share grave concerns about the future of research in the US Forest Service. The total number of scientists dropped by almost one-half between 1985 and 2000. These drops are especially notable for entomologists and plant pathologists, just when we need them most. The United States and Canada have been trying to limit introductions in ballast water since the early 1990s. Recent studies document significant failures in the policies adopted then. In part, these failures resulted because the policy cart preceded the research and development horse. I fear the same situation may arise for introductions occurring with solid wood packing material (SWPM). Now, the risks have been well documented (USDA 2000). The next steps are developing and applying mitigation measures—which require that we halt the erosion of forestry research.

The Future of Public Policy

Concern about invasive species policy is growing quickly. For example, two major studies of Canadian biodiversity noted the significance of invaders. These were the first national compilations of species status (Canadian Endangered Species Conservation Council 2001) and ecological integrity (Panel on the Ecological Integrity of Canada's National Parks 2000). The United States is beginning to implement its first national management plan on invasive species. In both countries, experts have described the limits of current federal, state, and provincial law.

Unfortunately, the lag between concern and new policy is long. We urgently need scientists and regulators to contribute their best ideas—like Jon Bell's proposal to use letters of credit to make exporters more accountable for species they introduce. Then those of us in environmental groups help you turn these good ideas into real policy.

Scientists have played a major role in changing invasive species policy already. Our activism takes a number of forms, e.g.,

Table 2. Summary of 250 research projects related to aquatic nuisance species in the Great Lakes Basin, by category, 1972–1997

Research category	Canada		United States	
	1 000's USD 0.715	%	1 000's USD	%
Ecosystem effects	2 219	70	13 712	52
Biology and life history	578	18	4 494	17
Control and mitigation	72	2	4 650	17
Spread of established populations	142	5	2 019	8
Prevention of introduction	129	4	1 325	5
Socioeconomic analysis	14	<1	393	1
Total	3 154	na	26 593	na

na = not applicable.
Source: Great Lakes Commission, December 1996.

volunteering for the working groups that prepare major reports and lending our names to sign-on letters.

In the United States, more than 500 scientists and managers signed the letter to former vice-president Gore that resulted in former president Clinton's Executive Order on invasive species. They changed the structure and goals of the US Government's approach on this issue. In Canada, more than 400 signed "The Scientists' Declaration to Conserve Canada's Coastal Temperate Rainforests." Its organizer say that the letter contributed to an agreement between British Columbia and the First Nations for ecosystem-based planning. Another letter, on the failings of the proposed Species at Risk Act, is targeted at Canada's prime minister; the organizers' aim is 1 000 signatures from North American experts.

Scientists' role in speaking with the press is exceptionally important. Sarah Reichard surveyed the people who bought nursery plants on several internet sites (Reichard and White 2001). The majority (68%) had learned about invasive species from their newspapers and magazines. These were the people who most wanted to avoid buying invasive plants in the future.

If you have been involved in these kinds of policy-related activities, I hope you will continue. If not, I hope you will start. If you are not comfortable dealing with policy issues (or even if you are), I hope you will join groups like mine or Faith Campbell's. Each environmental group has its own system for alerting you to significant opportunities. In the Union of Concerned Scientists (UCS), it is the Sound Science Initiative. Our e-mail list keeps you abreast of the science and policy, provides you with the tools to make your voice heard, and makes the process of working with the media and elected officials easy and painless.

To Work for Change, We Must Have Hope.

To take part in any group such as UCS', we must set aside our cynicism. That is, we must have hope. And what is hope?

"Hope is the thing with feathers
That perches in the soul
And sings the tune without the words
And never stops at all"

–Emily Dickenson

The idea of hope has engaged thinkers of all sorts. These include ones you might expect, like Simon Weisenthal, Desmond Tutu, and Lech Walesa. These also include ones you might not expect, like Margaret Mead, Jane Goodall, and Charles DeGaulle. Plus, of course, a host of psychologists and theologians have written on this subject. Generally, they agree that hope is not optimism. Optimists tend to minimize the tragic sense of life. Studies of depression show that optimists are usually happier than pessimists, but they are also less in touch with reality. Hope is based in reality.

Hope is often born of the worst kinds of reality: experiences of the Holocaust, slavery, rape, the death of a child, watching someone die of AIDS. But hope is also born of the best kind of experiences. St. Paul is the source of a common view: "Now hope that is seen is not hope. For who hopes for what [one] sees?" But here is the paradox. We must have tasted that for which we hope in order to want more. Thus, Soren Kiekegaard amends St. Paul: "Hope is passion for the possible." At this point, the psychologists and theologians part company. The former see hoping as fundamentally like desiring, wishing, and wanting. Theologians say, no, hoping is different. We want, desire, or wish for what is concrete—a grant, a better law, a new house. In contrast, hope is broader and deeper. It helps us weather the times when our wishes are disappointed, when our desires are frustrated, when we are disillusioned. When our profession seems declining, when we fear the onslaught of new pests will never end, when our governments' policies are foolish—that is when we need hope.

Often, we are tempted to see hope as an interior strength possessed by only the fortunate few. But Madeline Blais, writing about the Amherst, Massachusetts, championship girls' basketball team, titled her book, *In These Girls, Hope Is a Muscle*. The young women, their coach, and their parents all agreed that the team's hope came from hard-earned changes the players made in attitude and behavior.

We are not athletes, so how do we exercise this muscle called "hope?" We exercise it when we articulate our most deeply held values. Like when we state that greater knowledge is a good thing. And when we say that our grand and glorious forests are worth protecting. Also, we exercise this muscle when we lay claim to the policy process. Then we confront authority at the highest levels—even approaching presidents and prime ministers. We speak out when policy decisions are short-sighted. In addition, we exercise this muscle when we mobilize our friends and colleagues effectively. Then, we gather hundreds of allies to our causes. So we become a force to be reckoned with.

Some claim that hope is not a solitary thing but that it is formed in our relationships with each another. That is why it is contagious. Some say it is a lot like love and so it is related to what the Rev. Martin Luther King, Jr. called "the beloved community." Yes, this is a scientific gathering. It is also a gathering of one kind of community, as Dave Spence noted in his opening remarks—a beloved community that cares deeply about the same issues.

So I conclude with this recommendation. Let us spend this time together and share what we know. Let us be convinced of our ability to change policy. Let us create an epidemic of hope. And let us return home to do more.

> "To hope is to risk frustration. Let us continue to risk frustration."
>
> –Thomas Merton

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PLENARY SESSION 2

GLOBAL CLIMATE CHANGE: IMPLICATIONS FOR FOREST INSECTS

MODERATORS:
W.J. Mattson, *US Forest Service, Rhinelander, Wisconsin*
R.A. Fleming, *Canadian Forest Service, Sault Ste. Marie, Ontario*

Moderator Summary: Global change is occurring because the scale of human activities now exceeds that of all other species and affects biospheric fluxes of matter and energy. Temperatures, atmospheric CO_2 concentrations, nitrogen inputs, tropospheric ozone, and the prevalence of adventive organisms are all increasing at rates unprecedented in human history. Precipitation patterns are becoming more erratic and events more extreme. Global change encompasses the direct and indirect effects of all these and other changes in atmospheric composition, biological diversity, land use, and climate, and as such, global change represents a major, long-term threat to the well-being of our species. Global climate change is one component of global change, but because it interacts with other components of global change, its implications for forest insects should be considered in the context of global change as a whole.

As a whole, the plenary focussed on the implications of changing climates on forest insects in the context of shifting, low-level, atmospheric compositions. However, no reported work dealt directly with simultaneous change in both these components of global change. In studies of the effects of changes in low-level, atmospheric composition, experimentally elevated CO_2 levels have generally decreased the host quality of trees by decreasing foliar nitrogen and increasing phenolic concentrations. Foliar terpene concentrations in conifers have been less responsive to increased CO_2 levels, but this may be an artifact of experimental exposure regimes shorter than the life-span of the leaf. Most studies have concerned folivores, which often compensate for decreased host quality by increasing consumption, but the ecological significance of this response has not been investigated. The effects of higher CO_2 levels on herbivore responses in the field, tri-trophic interactions, resistance mechanisms to stem-invaders, and induced responses of plants are also inadequately understood. Most of the work reported in the plenary dealt directly and only with climate change effects on forest insects, and then, focussed mainly on temperature. This is because temperature is the climate variable for which there is most confidence in predicting its future [Intergovernmental Panel on Climate Change (IPCC) 2001] and for which most is known about its effects on insects. The potential rate of increase of many insects is strongly dependent on temperature, and their survival is impaired at low and high temperatures. Thus changes in both mean temperatures and the extent and frequency of extremes can have major impacts on insect populations. The indirect impacts mediated through biological interactions (such as competition, herbivory, parasitism, and predation) are even more sensitive to changes in temperatures climate, and hence their potential consequences are even greater.

This presents a dilemma to developing models of how forest insect populations might respond to climate change. Detailed models of how climate change might affect life-cycle processes (such as phenological development, survival, dispersal, feeding, growth, fecundity, mating success, etc.) may be incapable of accommodating any but the simplest forest-insect systems. On the other hand, empirically based descriptive models that implicitly consider the whole forest-insect system, also implicitly assume that climatic effects can be extrapolated from historical records when climates, atmospheric compositions, and land use were all different. Embracing the variety of approaches between these extremes in the hope that their forecasts bound the realized future seems the most prudent approach. The IPCC has followed this strategy with the General Circulation Models used to forecast future global climates (IPCC 2001).

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GHOST FORESTS, GLOBAL WARMING, AND THE MOUNTAIN PINE BEETLE

J.A. Logan and **B.J. Bentz,** *US Forest Service, Logan, Utah*
J.A. Powell, *Utah State University, Logan, Utah*

Maintaining an appropriate seasonality is a basic ecological requirement for insects living in seasonal environments. Critical life history events must be appropriately timed with seasonal cycles. Additionally, it is often selectively advantageous for individuals in the population to synchronize their activities. The two basic components of an appropriate seasonality are therefore timing (the time of year the event occurs) and synchrony (the range over time of the event). In most terrestrial insects, some explicit physiological mechanism, such as diapause, serves to maintain both aspects of seasonality. However, some ecologically important insects, such as the mountain pine beetle, apparently lack an explicit physiological timing mechanism like diapause. Seasonality of such insects is said to be under direct temperature control.

In this talk, we first discuss the mechanistic basis for direct temperature control of seasonality in the mountain pine beetle. Many, if not most, *Dendroctonus* species lack an explicit life-history timing mechanism like diapause. This is in spite of the fact that synchrony of adult emergence is absolutely necessary for the mass-attack strategy that overcomes tree defenses. We demonstrate that an appropriate seasonality is a natural consequence of the interaction between seasonal temperatures and stage-specific developmental rates. In doing so, we introduce a new paradigm for modeling direct temperature control of seasonality. This approach involves the graphical analysis of dynamical properties of a phonological model (Logan and Powell n.d.) of mountain pine beetle that incorporates microhabitat (phloem) temperatures with life-stage specific developmental rates. Appropriateness of projected seasonality is evaluated on three criteria: (1) Voltinism – the number of generations per year. Previous work has indicated that univoltinism is an ecological requisite for success of mountain pine beetle populations. Populations are restricted in both latitude and elevation by climatic conditions that simply do not provide sufficient thermal energy to complete the life cycle in one year. (2) Timing of adult emergence. Emergence must occur at time in the year that is late enough to avoid lethal cold temperatures, but early enough to provide time for oviposition. Appropriate timing of emergence is, therefore, a balance between maximizing ovipositional potential while minimizing mortality probability. Throughout the present mountain pine distribution, the appropriate time is late July or early August. (3) Synchrony of adult emergence. Previous work (Logan et al. 1998; Logan and Bentz 1999) discusses and demonstrates the necessity of synchronous adult emergence for successfully overcoming host tree defenses. Successfully meeting these criteria results in an adaptive seasonality.

We then utilized the modeling framework to first analyze the current geographic distribution of the mountain pine beetle, with respect to both latitude and elevation. Results from this analysis has provided insights into past outbreak events that occurred in high-elevation whitebark pine ecosystems. We also concluded from this analysis that the geographic distribution for the mountain pine beetle is comprised of adapted regional populations that differ significantly in their thermal ecology. These predictions were confirmed in empirical studies comparing northern populations (Idaho, Montana) to southern populations (southern Utah) (Bentz et al. n.d.).

We finally discuss the implications of our modeling work for climate change induced range expansion and invasion of new habitats by the mountain pine beetle. We conclude that some communities that have evolved without significant mountain pine beetle pressure are highly vulnerable under even conservative climate change scenarios. This potential is illustrated using extensive data that has been collected for the past 7 years at one high elevation whitebark pine site in central Idaho. Current climatic conditions result in semivoltine populations, violating the first of the three criteria for adaptive seasonality. Climate warming of 2.5ºC, however, resulted in model predictions of an adaptive, univoltin population. This amount of climate warming is well within that predicted by a CO_2 doubling scenario, an event that is predicted to occur before mid-century. The implications are dire indeed for whitebark pine and other high-elevation five-needle pines.

We further examine the potential for northern range expansion into previously unoccupied lodgepole pine habitat. Our analysis indicated that a 2.5ºC increase in mean annual temperature corresponds to a greater than 7.5ºC northern shift in latitude. A northern range expansion of this magnitude would allow mountain pine beetle range expansion into previously unoccupied jackpine habitat. The current distribution of jackpine is separated from mountain pine beetle populations by either being too far north, or by the impenetrable barrier of the Great Plains. If Mountain pine beetle populations expand north through lodgepole pine into contiguous jackpine habitat in Canada, then there is no apparent reason why a waterfall effect would not follow, spilling across the North American continent to jackpine in the Great Lakes region.

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GLOBAL CLIMATE CHANGE AND FOREST INSECTS: IDIOSYNCRATIC RESPONSES BY STEM INVASIVE INSECTS TO GREENHOUSE GAS EFFECTS ON TREMBLING ASPEN

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The world is changing at a record pace and in a plethora of ways. Driving these pervasive changes is the rapidly and inexorably rising world population. During the past century, human numbers have doubled twice, and show no signs of stabilizing in the near term. In fact, world populations, now exceeding 6 billion, are increasing at the net rate of about 225 000 per day. Along with humans, global mean temperatures and tropospheric levels of CO_2 and ozone (O_3) are also rising at alarming rates. Concentrations of these two greenhouse gases are both expected to double during the next 50–100 years (Dickson et al. 2000). The totality of these and many other varied and simultaneous changes is relentlessly driving world-wide ecosystem change.

In particular, forests and forest insects are already responding to these environmental changes. But is there any consistent pattern to the insect responses? Or is it totally idiosyncratic? For folivores, there has been a relatively common response to elevated CO_2: reduced larval growth rates, elevated consumption, and overall growth either 10–20% less than or not significantly different from controls (Bezemer and Jones 1998). This paper addresses non-folivore insect responses on aspen, to the indirect effects of rising concentrations of tropospheric CO_2 and O_3, those mediated through the responses of their host plants. The studies summarized here are being done at a FACE (Free Air Carbon Dioxide Enrichment) facility in Oneida County of northern Wisconsin, supported and operated by a consortium of federal, university, and non-governmental organizations. The study consists of three species of plants, trembling aspen, *Populus tremuloides*, paper birch, B*etula papyrifera*, and sugar maple, *Acer saccharum*, being exposed to elevated CO_2 and O_3 in a 2 x 2 factorial randomized block design. The four treatments consist of ambient CO_2 and O_3, elevated CO_2 and ambient O_3, elevated O_3 and ambient CO_2, and elevated CO_2 and O_3 (Dickson et al. 2000). This report addresses a very preliminary assessment of stem invasive insect responses, measured on more than 4 000 aspen trees, consisting of five different clones.

***Saperda inornata* (Coleoptera: Cerambycidae)**

There was a significant clone effect on the incidence of Saperda, the most susceptible clones having twice as many stem galls as the less susceptible clones. In general, trees exposed to elevated O_3 alone had significantly 50–100% more galls than ambient trees. On the other hand, CO_2 trees generally had the same or fewer galls than ambient trees, except for one clone, where the opposite was true. Trees exposed to the combined effects of elevated CO_2 and O_3 had 50–200% more galls than ambient in three clones, but no difference in two.

***Oberea schaumii* (Coleoptera: Cerambycidae)**

There was a significant clone effect on the incidence of Oberea, the most susceptible clones having twice as many insects as the least susceptible clone. In general, tree exposed to elevated O_3 alone had 20–60% fewer insects than ambient trees, unlike the pattern for Saperda. CO_2 trees generally also had 10–20% fewer Oberea insects than ambient, a pattern similar to Saperda incidence. Trees exposed to both elevated CO_2 and O_3 had 50–100% more galls than ambient in three clones, but 10% less in two; the pattern being similar to that for Saperda.

***Hexomyza schineri* (Diptera: Agromyzidae)**

There was a significant clone effect on the incidence of Hexomyza twig galls, the most susceptible clones having roughly 2–3 times as many galls as the two least susceptible clones. In general, trees exposed to O_3 alone had 10–20% fewer galls than ambient trees. On the other hand, CO_2 trees generally had 10–50% more galls than ambient, except for one clone where the pattern was opposite. Trees exposed to both elevated CO_2 and O_3 behaved essentially like CO_2 trees: they had more galls if CO_2 treatments for that clone were associated with more galls, and had less galls than ambient if CO_2 treatment did not elicit increased fly galls.

***Phytobia* sp. (Diptera: Agromyzidae)**

There was a significant clone effect on the incidence of Phytobia bark mines, the most susceptible clone having roughly 50% more mines than the other four mostly equally susceptible clones. Ozone alone had no significant effect on miners in two clones but about 20% reduced miner abundance in three clones, relative to ambient. On the other hand, CO_2 invariably lowered Phytobia indicidence by 20–50% in all clones. The combined effects of elevated CO_2 and O_3 generally followed the pattern of CO_2, but having a stronger depressing effect on miner abundance.

***Chionaspis* sp. (Homoptera: Diaspididae)**

Although there were apparent clonal effects on the abundance of Chionaspis, they were overshadowed by the large main effects of combined elevated CO_2 and O_3. Ozone treatments by themselves reduced the abundance of scale on 4 of 5 clones. CO_2, by itself, on the other hand, had no apparent effect. But the combination of elevated CO_2 and O_3 increased scale abundance by about 25–50% in four of five clones.

The effects of elevated ozone on stem infesting insects was often negative, except in the case of the Saperda beetle where it was postive. Likewise, the effect of elevated CO_2 on insects was usually negative or insignificant, except for the fly Hexomyza. On the other hand, the combined effects of elevated CO_2 and O_3 on insects were not additive nor very predictable. In four cases the dual treatment increased insect abundance and in the other it decreased abundance, and the effect varied strongly with clone. Therefore, attempts at globally understanding and predicting the general impact of steadily rising levels of tropospheric CO_2 and O_3 world wide on forest insects will be thwarted by the idiosyncratic responses of plants, and their herbivores. If one adds in other pervasive, concomitant stressors such as rising temperatures, and changing precipitation patterns, and increased deposition of N and S, then the task is even more daunting. The world is changing much faster than our capacity to understand its fundamental processes, and to predict its trajectory.

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RESPONSES OF INSECT DISTURBANCE REGIMES TO CLIMATIC CHANGE IN BOREAL FORESTS: ISSUES AND APPROACHES

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Climate change's greatest impact on ecosystem succession and functioning in North America's boreal forests will likely be brought about by changes in disturbance regimes such as those associated with insect outbreaks and wildfire; the resulting uncertainties directly affect depletion forecasts, hazard rating procedures, and long-term planning for harvest queues and disturbance control requirements. During insect outbreaks, particularly those of the spruce budworm (*Choristoneura fumiferana*), trees are often killed over vast areas; this extensive tree mortality shifts the forest toward younger age-classes which contain less biomass, and much of the residual carbon is later released to the atmosphere. A fundamental question is whether climate change will increase the frequency, duration, and intensity of natural disturbances, thus increasing accumulations of atmospheric CO_2 and accelerating the warming rate.

One possible approach to trying to understand how changes in insect disturbance regimes might develop is to focus on the insect lifecycle. This approach may prove superior for insects embedded in simple food webs, but may quickly become impractical when large food webs and complex ecological systems and relationships are involved. Conceptual modeling with this approach emphasizes the potential importance of threshold and scale effects, historical factors, phenological synchrony, rare but extreme weather events, and natural selection.

A second approach is to adopt the integrated ecosystem response assumption that as climatic zones move poleward (and to higher altitudes), species assemblages, and the ecosystems in which they are embedded, will track suitable environmental conditions from one geographic region to another as complete integrated units. In strict terms, this assumption will almost certainly be violated, but it may provide a useful approximation, especially in the near future while the extent of climate change remains relatively small. This second approach is not necessarily exclusive of the first, but is more immediately practical. Published scenarios which employ this second approach generally suggest that outbreaks of boreal forest insects will last longer and occur more frequently where the climate warms. This does not necessarily mean that the direct economic impact of these insects will increase. On the other hand, indirect effects such as the promotion of wildfire may become extremely important in the warmer, drier climates of the future so uncertainties in future damage patterns of some insects magnify uncertainties in future fire regimes.

To better understand the role of spruce budworm disturbance regimes in the boreal forests' carbon cycle, we have coupled geographic information systems with modern computer-based approaches to conducting spatio-temporal analyses. Detailed statistical analysis of historical data is also needed to quantify the large-scale interaction between fire and spruce budworm. Augmentation of these basic analyses of large scale spatio-temporal dynamics of the spruce budworm and of the fire-spruce budworm interaction by including climate data is an obvious next step to identifying important climatic influences. The expectation is that ultimately such analyses will provide scenarios of the spatial and temporal dimensions of the dynamic evolution of spruce budworm disturbance regimes and their interaction with fire as the climate changes.

Ultimately, we doubt that any single approach or scenario can be relied upon. Rather, confidence will be gained as a variety of different approaches bracket possible futures.

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THE MORAN EFFECT, GLOBAL CLIMATE CHANGE, AND FOREST DEFOLIATOR OUTBREAKS

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Despite the apparent lack of concern expressed by the leader of a certain North American country, climate change is a matter of considerable alarm in the field of environmental sciences. There is no question that over the last 50–100 years we have witnessed a very rapid increase in atmospheric $C0_2$ and this change could have catastrophic consequences to many physical and ecosystem properties of our planet (National Academy of Sciences 1991).

Among the many issues that are being raised is the question of what the consequences climate change might have on the population dynamics of forest insect pest populations. Different groups of scientists have taken a variety of different and valuable approaches to answering this question. Some have focused at the organismal level, concentrating their studies on physiological effects. Other groups have explored the use of process-oriented models to predict the consequences of climate change. Finally, a third group has used purely statistical ("black box") models that relate weather to insect outbreaks as a method of predicting consequences of climate change. In this paper, I report on at least one major problem encountered during studies using the latter approach.

Weather is usually considered the primary exogenous process affecting the dynamics of insect populations (Andrewartha and Birch 1954). Unfortunately, less certainty exists about the manner in which weather affects insect dynamics. While there are many examples of mechanisms by which weather directly affects population growth and death, or indirectly affects host populations either via hosts or natural enemies, the consequences of these effects on dynamics behavior are often not known.

There have been many studies that have attempted to relate changes in insect abundance directly to weather. Forest insects have provided excellent systems for evaluating the relationships between weather and insect dynamics because of the relative absence of anthropogenic interference. Graham (1939), Wellington (1954), and Martinet (1987) have reviewed numerous studies that related weather with forest insect dynamics. These studies used either statistical or qualitative methods to compare the historical abundance of insects (or their damage) with historical weather station data (temperature and precipitation). Most of these studies promoted some form of the theory of "climatic release" in which the transition from innocuous to outbreak levels is associated with some specific climatic anomaly or deviation from average. This concept of release was presented many years ago by Solomon (1949) who believed that abnormal weather might allow populations to escape from controlling agents. This concept was further developed by Morris (1963) and others who used it as part of a concept of bimodal dynamics (Southwood and Comins 1976) in which populations are regulated about either a low- or high-density equilibrium and abnormal weather may cause populations to escape a low-density equilibrium and enter an outbreak domain.

Different investigations of historical associations between insect abundance and weather data have often presented contradictory conclusions about relationships for the same species (i.e., they have identified the importance of different weather variables) (Martinet 1987; Elkinton and Liebhold 1990). One cause of these contradictory conclusions may be the statistical perils of these types of comparisons. There are virtually an infinite number of ways that historical station data can be combined or represented (e.g., number of days in January with less than 5 cm of precipitation). That problem, along with the inevitable temporal autocorrelation (and consequent lack of independence of serial observations) of historical insect abundance time series has probably led to a large number of spurious conclusions in these types of studies (Martinet 1987).

In addition to the methodological problems described above, there is also a conceptual flaw with the concept of climatic release. A common feature of outbreaks of most forest insects is that they exhibit some degree of periodic behavior (Myers 1988, 1998). If outbreaks were the result of climatic release, then this would imply that these weather anomalies occur with some regularity. Wellington (1954) stated that weather fluctuations are temporally orderly and fluctuate over periods corresponding with the temporal scale of the interval between insect outbreaks. However, the existence of climatic cycles is a matter of dispute among meteorologists (Burroughs 1992). Weather cycles, if they do indeed exist, are weak and difficult to statistically identify in historical data. With the exception of a few phenomena (e.g., the ENSO oscillation ca 4-year period; Rasmusson et al. 1982) weather patterns are dominated by random behavior (Anthes et al. 1981). Thus there is little support for Wellington's (1954) assertion that regular weather fluctuations cause periodic insect outbreaks and the entire concept of climatic release does not appear viable.

In contrast, it does appear that endogenous processes are fully capable of explaining the temporal patterns observed in historical insect data. Numerous studies have documented that simple interactions between insects and their hosts, interactions between insects and their natural enemies and physiological processes may result in a density dependent and/or delayed density dependent fashion and that even simple interactions of these type are capable of producing periodic or chaotic behavior (May 1974; Ginzburg and Taneyhill 1994; Varley et al. 1973; Anderson and May 1981; Hastings et al. 1993). Thus, it appears that the temporal patterns of insect abundance are dominated by endogenous processes and that weather may contribute a relatively small and random effect on the year to year changes in forest insect abundance.

A commonly observed characteristic of forest insect outbreaks is the existence of spatial synchrony (Myers 1988, 1998; Williams and Liebhold 2000; Shepherd et al. 1988). There are essentially two explanations for these patterns of synchrony: dispersal and weather. Various types of models show that even a small amount of dispersal among spatially disjunct populations will rapidly bring these populations into synch (Barbour 1990; Hanski and Woiwod 1993; Haydon and Steen 1997; Ranta et al. 1995, 1997). However, there is growing evidence that indicates that most cases of spatial synchrony are not primarily caused by dispersal (Hanski and Woiwod 1993; Haydon and Steen 1997; Myers 1998; Williams and Liebhold 1995, 2000). It appears more likely that spatial synchrony is caused by weather via the "Moran effect" (Moran 1954; Royama 1992). Moran theorized that the dynamics of two spatially disjunct populations may be dominated by endogenous processes, but weather may have a relatively minor effect on the temporal dynamics; but, if it has a similar effect on each of the populations, then it will bring their dynamics into synchrony. Several groups have used models to show that the Moran effect is a more likely explanation of spatial synchrony than dispersal (Hanski and Woiwood 1993; Haydon and Steen 1997; Williams and Liebhold 2000). Myers (1998) observed that there is at least partial congruence in spatial synchrony among different species of forest Lepidoptera, further supporting the importance of weather acting via the Moran effect versus dispersal as a cause of spatial synchrony.

Thus, the evidence collected to date indicates that the effect of weather on forest insect dynamics mostly does not occur via the "climatic release hypothesis" but instead functions via the Moran effect. The implication here is that fluctuations in insect populations are primarily the result of endogenous processes (e.g., predator–prey dynamics) and that weather modifies abundance in a random manner of relatively small magnitude. While these effects may have dramatic effects on spatial patterns (i.e., spatial synchrony), the effects on temporal patterns are much more subtle.

One consequence of these subtle effects of weather is that prediction of weather effects on forest insect dynamics may be very difficult. Because the effects of weather on dynamics may be small, development of predictive statistical relationships between weather and population dynamics may be impossible. While climate change may have profound effects on insect dynamics, predicting these changes via statistical models is therefore likely to be difficult.

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CONCURRENT PANELS

CONCURRENT PANEL

TREE RESISTANCE TO INSECTS AND DEPLOYMENT IN FOREST MANAGEMENT

MODERATORS:

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Moderator Summary: A variety of mechanisms are known to be important in resistance of trees to insects. This panel provides a summary of resistance mechanisms to insect defoliators and shoot insects; examples are demonstrated for the western spruce budworm (*Choristoneura occidentalis*) defoliating Douglas-fir (*Psuedotsuga menziesii*) and the white pine weevil (*Pissodes strobi*) attacking terminal shoots of spruce and pine. Deployment of antibiosis, antixenosis, tolerance and genetically engineered resistance traits against insect pests in short rotation clonal *Populus* systems are illustrated. Strategies for deploying Sitka spruce (*Picea sitchensis*) that are genetically resistant to white pine weevil are also discussed.

Resistance Mechanisms to Shoot Insects

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This paper provides a summary of the resistance mechanisms to shoot insects that we have uncovered either by examination of the literature or by detailed work on the white pine weevil, *Pissodes strobi*, a shoot insect affecting spruce and pine in North America. The review indicates that conifers rely on a combination of defense mechanisms to fend off herbivores that feed on their shoots. These range from defense strategies in which the host provides improper nutrition to the attacker, for example by being in the wrong phenology state at the time of feeding, to constitutive defenses, such as resin canals and sclerids, to inducible defenses, which are activated in response to the attack. The latter include the manufacture and mobilization of defensive chemicals to the site of wounding, and the production of traumatic resin in conifers in response to insect and fungal attack.

Mechanisms of Resistance in Trees to Defoliators

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At least 10 mechanisms are known to be important in resistance of trees to insect defoliators:

1) Phenological asynchrony between host trees and insect herbivores; 2) Host tree tolerance of defoliation; 3) Host tree compensatory photosynthesis and growth; 4) Toughness of leaves and needles; 5) Low nutritive quality of foliage; 6) Defensive compounds (or allelochemicals) in foliage; 7) Three-trophic-level interactions; 8) Host tree microbial mutualists such as mycorrhizae and fungal endophytes; 9) Induced defenses in host trees; and 10) Induced susceptibility in host trees. Examples of these mechanisms were illustrated using the western spruce budworm (*Choristoneura occidentalis*) and Douglas-fir (*Pseudotsuga menziesii*).

Deployment of Tree Resistance to Insects in Short Rotation Biomass Plantations

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Short rotation woody crop (SRWC) plantations use fast-growing tree species (such as Populus and Salix) grown under intensively managed conditions much like traditional agricultural crops (Dickmann and Stuart 1983). Typical rotation age ranges from 3–15 years, with the end products including energy and paper (pulp) products. Operational biomass plantations currently use a limited number of clones that probably exhibit modest host plant resistance to insects and may be promoting insect adaptation to resistance. Current control methods include clonal rotation and pesticide use (Abrahamson et al. 1977). There is a need to find and implement more effective insect resistance mechanisms and clonal deployment strategies into SRWC plantations.

Scientists still debate the number of clones needed for large-scale deployment. Theoretical models suggest up to 20 (Libby 1982, 1987) and even more than 30 (Roberds and Bisher 1997). However, most large scale operations currently use far less than that. More pest resistant clones need to be developed for use in SRWC systems in order to provide adequate pest control and to make the clonal deployment strategies work. Clonal deployment strategies of host plant resistance include monoclonal stands, mosaics of monoclonal blocks that contain varying resistance traits, clonal rows, and single tree and small groups of trees (Zsuffa et al. 1993). Pest risk in SRWC systems is negatively correlated with cultural intensity and financial input. Thus, risk decreases from monoclonal stands to single and small groups of trees, whereas the cost and labor required increases.

Monoclonal stands are large, single clone stands (up to 20 ha in size) both treated and harvested uniformly (Hall 1993). Of the four strategies mentioned, monoclonal plantations are the most cost- and labor-efficient and generally most-used by industry (Eaton 2000). However, large monoclonal blocks increase susceptibility to pest problems, as once a pest becomes established it can spread unimpeded throughout the entire plantation. The monoclonal block mosaic plantation strategy consists of several clones, each planted in relatively small monoclonal blocks so that no two like clonal blocks are adjacent (DeBell and Harrington 1993). This system allows clones to be continually removed and replaced, thus keeping a fully stocked plantation and constant supply of wood. From a pest management perspective, this planting pattern is more desirable than pure monoclonal blocks. In the event that one of the clones becomes infested with an insect or pathogen, individual clonal blocks can be managed separately. Clonal rows are generally used in selection trials and cutting orchards (Coyle, personal observation). Clones are planted in adjacent single rows, allowing the assessment of pest susceptibility and various growth parameters on many clones at one time. Research at Long Ashton, U.K. suggested that mixing rows of susceptible and resistant willow clones may both delay the onset of rust epidemics and reduce the movement and subsequent damage caused by chrysomelid beetles (Royle et al. 1998; Peacock et al. 1999). The planting method with the least pest risk entails single tree mosaics or small groups of trees. This method is by far the most time and labor intensive to establish but provides the greatest protection from pests. Single-tree or polyclonal plots also are subject to more inter-plot competition and therefore can result in overall reduced biomass production compared with monoclonal plots (DeBell and Harrington 1997). Single-tree plots can be beneficial for research activities, primarily because they eliminate environmental variances that can occur within plots (Libby and Cockerham 1980). However, should a single clone become infested, it is much more difficult to remove without harming the other trees.

Incorporating host plant resistance into SRWC systems can be accomplished in several ways. Traditional tree breeding is the standard technique in which superior clones are generated for SRWC systems. This method is labor-intensive and can take years to develop suitable clones.

However, opportunities to discover more lines of resistance may occur during large clonal screening trials. Also, this is the most socially acceptable and environmentally friendly means of improving stock used in SRWC systems.

Genetic engineering has recently surged to the forefront in many scientific fields, and SRWC clonal development is no different. There have been several attempts to use genetic engineering to insert resistance genes, including *Bacillus thuringiensis* and protease inhibitor genes, into *Populus* clones (McCown et al. 1991; Klopfenstein et al. 1997). However, environmental and societal concerns may affect the operational status of genetically-engineered clones. Transgene contamination in natural species and the possibility of transgenics escaping and becoming weeds are risks associated with genetically engineered crops (Gould 1998). Several mitigation options do exist, however, including plant sterility, wound inducible genes, and harvesting before trees reach sexual maturity.

Integrated pest management (IPM) incorporates several pest control methods into one pest management strategy. The development of an IPM plan for SRWC pests should be a priority. *Chrysomela scripta F.* (Coleoptera: Chrysomelidae) is the most damaging defoliator to *Populus* in the US (Burkot and Benjamin 1979). *Populus* clones vary in their susceptibility to *C. scripta* (Caldbeck et al. 1978). The use of resistant clones will serve as the foundation for *C. scripta* control, as beetles will spend less time feeding and ovipositing on these clones (Bingaman and Hart 1992). Leaf surface phagostimulant amounts also exhibit clonal variation (Lin et al. 1998), and could be used for clonal selection or trapping mechanisms. Natural enemies do contribute to *C. scripta* population control, but seemingly not to a great extent (Burkot and Benjamin 1979; Jarrard 1997). Because of the multivoltine lifestyle and reproductive potential of *C. scripta* (Coyle et al. 1999), natural enemies alone do not seem to be able to control populations effectively in plantations. Present management for *C. scripta* is dependent upon applications of insecticides, often on a calendar schedule. Unfortunately, this process encourages the development of resistant biotypes, thus negating the efficacy of the control method. Biorational sprays are an effective chemical control method (Coyle et al. 2000), but care must be taken not to overuse one formulation. Insecticide applications can be reduced further by incorporating an accurate economic injury level (EIL) (Pedigo et al. 1986) for *C. scripta* on plantation *Populus*. Economic gain would occur only when populations or damage above the EIL were treated.

Population monitoring is an essential aspect of *C. scripta* management. Visual (Coyle et al. 2000) and trapping (Nebeker et al. n.d.) methods have been used successfully to determine *C. scripta* life stages. This information could be used in conjunction with biorational sprays, as early life stages are the most vulnerable (Bauer 1990; Coyle et al. 2000). Plantation managers can use this information to best predict the optimal time to apply treatment. Degree–day (DD) calculations also can be used to predict appropriate spraying times (Nebeker et al. n.d.). Jarrard (1997) found that predicted DD requirements were within two calendar days of development observed in the field. This information can be used to create a better spray schedule based on insect life stage rather than on a strict calendar schedule.

In summary, many components of an IPM program for *C. scripta* have been developed. What is needed is the integration of all these aspects together for at least one rotation. This could serve not only to test the accuracy of the information elucidated to date, but would serve as a benchmark to determine the most effective directions for additional research.

Traditional agriculture's use of IPM strategies for pest management is more advanced than that of forestry systems. Future strategies using IPM for the control of insect pests of short rotation *Populus* systems will include a combination of host plant resistance, genetic engineering, biorational sprays, planting design strategies, and biological control. Research needed to reach this integrated approach includes further identification of host plant resistance, large-scale testing of different deployment schemes, and further examination of the impact that natural enemies have on *Populus* insect pests.

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Deployment of Sitka Spruce Resistant to the Terminal Weevil (*Pissodes Strobi*)

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R. Alfaro, *Canadian Forest Service, Victoria, British Columbia*

This paper describes some of the background to the resistant populations we have discovered and the selections we are making for weevil resistance. It outlines how we are quantifying this resistance and some of the strategies we are developing to deploy resistant stock, especially taking into account hazard rating. We also outline some of the considerations we are making in planning our breeding program. This program produces F-1 progeny for recurrent selection combined in such a way as to not only provide resistance durability, but to help us better describe the mechanisms of resistance and uncover the inheritance of these mechanisms.

CONCURRENT PANEL

FIRE-INSECT-TREE INTERACTIONS

MODERATORS:
R.A. Goyer, *Louisiana State University, Baton Rouge, Louisiana*
D.G. McCullough, *Michigan State University, East Lansing, Michigan*

Moderator Summary: The five panelists each provided both a regional overview of unique aspects of fire insect-tree interactions as well as certain research results from studies in which they are/were involved. This heavily attended session provided, first, a general discussion of fire/bark beetle response by Diana Six. Wildfires in ponderosa pine at three northern Arizona locations provided Tom Kolb with ample material to evaluate mathematic relationships between beetle colonization and tree crown scorch. Jaime Villa-Castillo discussed the important distribution, abundance and diversity of ground beetles with respect to several silvicultural and fire-related prescriptions using the ponderosa pine ecosystem in the southwest USA. Of notable significance to the panel was the in-depth analysis of fire intensity, fuel load and landscape interactions with bark beetles in lodgepole pine that Brad Hawkes provided. Rick Goyer provided a somewhat different management and ecosystem perspective on the on-going use and impact of prescribed fire and root and bole infesting insects and pathogens in restoration of longleaf pine sites in the southeastern USA.

It is apparent from the vast interest in prescribed burning and evaluation of wildfires, that innumerable opportunities exist for the individual and cooperative efforts currently underway in North America. Forestry, fire managers, entomologists and park managers need to work together to provide viable management solutions to minimize adverse effects of fire while preserving natural forest-fire-insect population processes. All factors must be evaluated within the context of individual resource management objectives set out for the varied forest landscapes in North America. We encourage interdisciplinary efforts to evaluate pathogens, site productivity, silviculture and insects in an integrated scheme to meet targeted objectives.

Effects of Fire and Thinning Management Prescription on Ground Beetle Assemblages in Northern Arizona Ponderosa Pine Forests

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M.R. Wagner, *Northern Arizona University, Flagstaff, Arizona*

Field experiments were carried out in northern Arizona ponderosa pine forests to determine the effect of four stand treatments (unmanaged, thinning only, thinning plus prescribed burn and wildfire) on ground beetle species assemblage. The unmanaged forest condition had the lowest diversity of ground beetles, and thinning only did not significantly change this low diversity. Both conditions were dramatically dominated by the species *Synuchus dubius*. Prescribed burn significantly increased ground beetle diversity and this condition was indicated by the species *Cyclotrachelus constrictus*. Wildfire had the most diverse assemblage; however, it was dominated by open-habitat species on the genus *Amara* and *Harpalus*.

Bark Beetle Infestations following Fire in Northern Arizona

T.E. Kolb, *Northern Arizona University, Flagstaff, Arizona*
C.W. McHugh, *US Forest Service, Coconino National Forest, Arizona*
J. Wilson, *US Forest Service, Coeur d'Alene, Idaho*

Fire is a natural phenomenon in ponderosa pine (*Pinus ponderosa*) forests, yet little is known about interactions between fire and bark beetles (*Dendroctonus* spp.). We studied such interactions on 1 367 trees that included a wide range of fire injury at three northern Arizona fires that occurred in 1996; beetle colonization and tree mortality were assessed for three years postfire. Dead trees had greater beetle colonization than live trees on all fires. Logistic regression models suggested that beetle colonization and crown scorch were important factors leading to tree mortality.

Bark Beetles and Fire

D.L. Six, *University of Montana, Missoula, Montana*

Fire and bark beetles interact on many temporal scales. In the year or two following fire, bark beetle population response is affected by many factors, including size of the bark beetle population prior to the fire, timing of the fire in the bark beetle life cycle, degree of damage to the phloem, cambium, roots and crown, and species of tree and beetle. In the long term, bark beetles and fire interact in ways that determine stand structure, composition, and continuity. These effects on the landscape, in turn, affect future bark beetle populations and fire occurrence and behavior. In order to develop effective, ecologically based management for western North American forests, there is a clear need for continued research on how fire, bark beetles, bark beetle natural enemies and host trees interact and contribute to ecosystem integrity.

Interaction of Fire and Mountain Pine Beetle

B. Hawkes, *Canadian Forest Service, Victoria, British Columbia*

There is a lack of understanding of the potential interaction of fire and mountain pine beetle (MPB) disturbances and their relation to the past, current, and future state of the forest. The current concept of natural variability could be useful to determine how natural variability, desired future conditions, and current conditions line up. A combination of susceptible host and favourable weather for MPB population growth usually results in an outbreak. Prior to logging and fire suppression, the percentage of the landscape in different age classes and species composition varied along with climatic conditions for insect development such that the susceptible host and good weather conditions for insect development did not always coincide.

There is currently a large MPB outbreak (approximately 575 000 ha) in British Columbia (B.C.); a previous outbreak occurred in the 1980s. British Columbia has vast areas of lodgepole pine susceptible to MPB due mainly to attempted fire exclusion and the lack of logging of this tree species prior to the 1970s.

Fuel changes following MPB outbreaks have not commonly been quantified, nor have experimental fire studies to quantify changes in fire behavior been conducted. The influence of MPB changes in the forest fuel complex on fire incidence has not been investigated widely.

Landscape prescribed burning was attempted in 1995-1997 in Tweedsmuir Provincial Park in central B.C. to control the spread of MPB. Limited fire spread and low fire intensity occurred due to calm and wet burning conditions, and a lack of dead surface woody fuels. A high fire intensity was found to be required to kill the beetle under the bark. The burn prescription required to achieved high fire intensities prior to beetle flight in mid-summer posed a number of challenges including a high risk of escape, more complete fire control measures needed to limit further fire spread, and potential lack of fire management personnel and equipment to conduct the prescribed burn because of other wildfire problems in the province during the dry and windy weather conditions needed to produce a high fire intensity.

Incidence of attack and brood production by MPB in lodgepole pine were assessed following a 600 ha controlled burn in Tweedsmuir Park by Dr. Les Safranyik and others at the Pacific Forestry Centre, Victoria, B.C. The burn was conducted September 20–23, 1995. Varying levels of fire intensity resulted in various degrees of crown scorch and tree bole charring. Attack and brood production were assessed in five burn intensity classes in trees attacked prior to and following the burn. In trees attacked prior to the burn, brood density was significantly reduced in the two highest burn intensity classes compared to the other classes. On average, beetle production per tree in burned trees was reduced by 47.5% and population increase in the burn was reduced to a static level. The year following the burn, attack, egg gallery and brood density were all greatest in the medium burn intensity class and lowest in the maximum burn intensity class. The respective average densities taken over all burn intensity classes were significantly lower than those for trees outside the burn. However, in trees attacked post-burn, the estimated average rate of population change was the same as in trees outside the burn.

Management implications of this information are discussed. Forest, fire, and park managers need to work together, along with the public, to find viable solutions to current and future fire and MPB problems within the context of the resource management objectives set for different parts of the landscape.

Effects of Fire Regimes in Longleaf Pine Restoration Efforts in the Southeastern US

R.A. Goyer, T.A. Bauman, G.J. Lenhard and **L.G. Eckhardt,**
Louisiana State University Agricultural Center, Baton Rouge, Louisiana

Forest managers employ prescribed burning as a tool to restore and maintain longleaf pine forests in the southern USA. However, using fire in management can have negative effects on tree health through increased beetle, weevil and pathogenic fungal interactions. This presentation will discuss these relationships as part of an on-going study of tree health responses to both dormant and growing season fires and insect/pathogen interactions.

CONCURRENT PANEL

LARGE-SCALE/LONG-TERM EXPERIMENTS AND FOREST INSECT CONCERNS

MODERATORS:

M.R. Wagner, *Northern Arizona University, Flagstaff, Arizona*

Moderator Summary: Presenters in this workshop consistently outlined the widely recognized value of large-scale and long-term experiments that test the effect of forest stand and landscape-level treatments on ecosystem responses, including forest insects. While these types of experiments are of great value, maintaining funding is extremely difficult. Three presenters discussed existing studies [one international, one US, and one regional (Arizona)] that are currently underway with long-term objectives. All of these studies have required substantial efforts in organization and planning to be successful. One presenter analyzed the characteristics of successful large-scale long-term studies and reported the "seven habits" of projects that contribute most to achieving experimental goals. The final presenter discussed how specific information gained only through long-term analysis of spruce budworm (*Choristoneura fumiferana*) populations was used to identify novel early intervention pest management strategies. Much of the discussion following the presentations focused on encouraging fellow forest entomologists to take the necessary steps to participate in long-term and large-scale studies because they offer significant opportunity to improve our understanding of the interaction between forest treatments and forest insect population dynamics.

Entomological Aspects of Long-Term Large-Scale Forest Health Research at Northern Arizona University

M.R. Wagner and **J.D. Bailey,** *Northern Arizona University, Flagstaff, Arizona*

A major research gap exists in our understanding of how landscape level forest activities and disturbance events influence forest health. A multi-year and multi-investigator project at the School of Forestry, Northern Arizona University is underway to fill this research gap. The project is called "Stand Treatment Impacts on Forest Health (STIFH). Four stand conditions/treatments are currently being examined: control, thinned, thinned and burned, and catastrophic wildfire. Each treatment is replicated 10 times and a minimum plot size is 100 acres. A broad array of response data are being collected, including biodiversity and community structure for ground beetles (Coleoptera: Carabidae), bark beetles (Coleoptera: Scolytidae), and wood borers (Coleoptera: Ceramhycida, Buprestidae, Platypodidae). Early results on some insect response variables is reported.

Seven Habits of Successful Large-Scale Long-Term Research Experiments

A.K. Mitchell, G.D. Hogan, and **D.G. Maynard**
Canadian Forest Service, Victoria, British Columbia

One paradox associated with research in the natural resources area is that there is an increasing need for long-term projects to answer complex questions in an era when funding agencies are looking for relevance and good value, and funding priorities change. Assuring the continuity of resources in the face of other pressures is a challenge for scientists and research managers alike. Successful large-scale long-term research experiments share a number of important characteristics that promote their relevance and longevity. These seven habits are drawn from common experiences with the design and implementation of long-term silviculture experiments at Shawnigan Lake (thinning and fertilization), MASS (silviculture systems), Zama (pest damage mitigation) and Turkey Lakes (air pollution):

(1) Foster strong project leadership and succession.
(2) Engage operations in research.
(3) Link scale and scope to resources.
(4) Design robust experiments with strong contrasts.
(5) Think multidisciplinarily and interdisciplinarily.
(6) Relevance leads to longevity.
(7) Protect your investment.

The reality for long-term large-scale research experiments is that forest management and ecological objectives can, have and will change. Practicing the seven habits will help to capitalize on new opportunities, to add value to established projects and to survive lean times. Success can be measured by partnerships within and without that outlive the project.

A National Study of the Consequences of Fire and Fire Surrogate Treatments: Planning and Implementation of Long-Term Interdisciplinary Forest Ecosystem Studies

P.J. Shea (Retired), *US Forest Service, Davis, California*

In our current social and political environment, management of our forest resources is a monumental challenge. Oftentimes this challenge is exacerbated because the consequences of various management decisions are unknown. Many North American forests, especially those with historically short-interval, low- to moderate-severity fire regimes, are too dense and have excessive quantities of fuels. These forests are in need of immediate management. Results of large-scale field experiments that test various treatment strategies of these fire-dependent forests can provide the data necessary to make sound management decisions and guide environmental policy. It is especially important these studies be national in scope and planned for long-term data collection. A team of scientists and land managers has designed an integrated national network of long-term research sites to address this need. In addition to the obvious effects of the treatments on living and non-living forest components, information is also being collected on the social, political and economic effects. This nationwide study is being supported by the US Department of Agriculture/US Department of the Interior (USDA/USDI) Joint Fire Science Program.

Understanding of Spruce Budworm Population Dynamics: Development of Early Intervention Strategies

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E. Bauce, *Laval University, Quebec, Quebec*
A. Dupont, *Société de protection des foréts contre les insectes et maladies (SOPFIM), Québec, Québec*
P. Therrien, *Ministère des ressources naturelles du Québec, Québec*
E. Kettela, *Canadian Forest Service, Fredericton, New Brunswick*
L. Cadogan, A. Retnakaran and **K. van Frankenhuyzen**
Canadian Forest Service, Sault Ste. Marie, Ontario

Is the current foliage protection strategy against spruce budworm (SBW) the best or only feasible approach to the management of this insect? This strategy consists in keeping alive the trees in stands selected for their commercial value and vulnerability. What is the possibility for early intervention, before an outbreak causes stand growth loss and mortality? Current understanding of the population dynamics of this insect indicates that widespread outbreaks are not the result of expansion from epicentres. An early intervention strategy could not therefore be based on elimination of hot spots. The SBW outbreak oscillation expresses a gradual fluctuation in large larval survival, an essentially local process. This fluctuation is the result of the interaction of several factors, including the influence of host plants and changes in the impact of natural enemies, all affected by environmental conditions that confer on the outbreak cycle its stochastic nature. In this context, the impact of moth migration is not mainly to move or spread an outbreak like a fire or an infection. Rather, migration represents a powerful regional synchronization mechanism that increases the amplitude and frequency of population fluctuations.

Introduction

The spruce budworm (SBW) is indigenous to North American forests. It belongs to a group of similar conifer-feeding budworms (Harvey 1985) most of which are outbreak species. These populations exhibit pronounced and more or less rapid and regular fluctuations, and the outbreaks probably constitute normal functions in the concerned ecosystems, at least since the last ice age (Volney 1985).

Since the early 1990s, a new outbreak of the SBW has started in the Ottawa River valley between Quebec and Ontario. The pattern of outbreak development is similar to the sequence of events surrounding the development of the 1968–1990 outbreak, in geographical (Hardy et al. 1986) and forestry terms (Hardy et al. 1983). This led certain authors to use the time sequence of the previous outbreak to predict the behavior of the next (Gray et al. 2000). However, the progression of the current outbreak seems slower (personal communication, B. Boulet, Ministère des ressources naturelles du Québec). Many have hypothesized that this slowing down is the result of the different forest composition prevailing now compared to that of the late 60s in the Ottawa River basin. Furthermore, Quebec's Société de protection des forêts contre les insectes et maladies (SOPFIM) has been using *Bacillus thuringiensis* (*B.t.*) in experimental programs in that area since 1995. These circumstances give some hope that humans could significantly influence the amplitude and extent of this natural process through forest management and population suppression.

To develop an enlightened control strategy against SBW, it is necessary to understand the main mechanisms involved in the insect's outbreak process. One must distinguish the part played by major factors such as climate, stand structure (composition, vigor, age, spatial arrangement), host-plant interactions (nutrition, defence mechanisms), natural enemies (predators, parasitoids, pathogens), and moth migration in triggering, maintaining, and causing the collapse of an outbreak.

In this paper, an overview of the basis of current understanding of SBW population dynamics is presented and the implications of this knowledge for integrated pest management are discussed.

SBW Epidemiology

Our view of SBW outbreak behavior comes from a variety of sources of varying quality. These include the chronicles of turn-of-the-century naturalists (Swaine 1922; Tothill 1924), tree-ring analyses (Bailey 1924; Blais 1964, 1965a; Morin and Laprise 1989; Morin et al. 1992), and defoliation or stand mortality mapping (Brown 1970; Kettela 1983; Hardy et al. 1986). Direct monitoring methods (Sanders 1980, 1988) and remote sensing (Ahern et al. 1991) have provided more recent information. The interpretation of such a diverse source of information is full of pitfalls. In particular, one must realize that the absence of damage (as measured by tree rings, aerial surveys, or remote sensing) does not imply the absence or even scarcity of insects (Régnière 1985).

Blais (1968), among others, considered SBW outbreaks as more or less isolated regional phenomena and distinguished several different outbreak regions in eastern Canada. In his view, outbreaks were triggered in over-aged balsam fir stands in which flowering was particularly abundant (Blais 1952) and in response to favorable weather conditions (Greenbank 1956; Blais 1985; but see also Royama 1992). The relationship between SBW and balsam fir flowering is still the subject of research (Carisey and Bauce 1997). According to Blais (1985) and others (Greenbank 1957), new outbreaks then spread into neighboring stands through moth migration and dispersal of small larvae, thus triggering a regional outbreak. Once triggered, this outbreak would subside only after susceptible stands had been killed. In their recent analysis of the historical defoliation records of Ontario, Candau et al. (1998) maintained this interpretation of SBW epidemiology.

While analyzing the details of the last outbreak's history in Quebec, Hardy et al. (1983) reached a different conclusion in terms of the stand characteristics that favor the development of outbreak epicentres. Outbreaks tend to occur in conifer stands with a high white spruce content growing in the mixed-forest zone along the St. Lawrence/Great Lakes valleys rather than in the boreal forest to the north or in the deciduous forest to the south. The high-resolution information collected over the past several years by the Ministère des ressources naturelles du Québec indicates that the defoliation in the currently developing outbreak does appear in stands with a high level of white spruce, often in plantations (personal communication, B. Boulet, Ministère des ressources naturelles du Québec). However, all these authors shared the opinion that SBW outbreaks were triggered by favorable conditions within populations otherwise maintained at normal endemic (rare) levels.

Royama (1984, 1992) interpreted differently the same historical information on the SBW. In opposition to Blais (1968), he insisted on the high level of regional synchrony exhibited by demographic information collected in New Brunswick during the 1900s. Starting from a concept where synchrony was imperfect, he reconstituted a generalized outbreak history over the past two centuries in eastern Canada. This history revealed density fluctuations of variable intensity and frequency where some could have left little or no evidence in tree rings. This view of a generalized, more or less synchronized outbreak over much of the forest expanse occupied by the insect was recently confirmed by spatial analysis of defoliation records over eastern North America (Williams and Liebhold 2000a).

These authors maintained that synchrony among SBW populations is of the same geographical scale as the correlation between climate extremes and that this synchrony could be the result of common climatic perturbations (the Moran effect). Régnière and Lysyk (1995) argued that synchrony over large expanses where ecological conditions vary could not be maintained simply through random, density-independent signals such as climate, but that moth migration would constitute a much more robust and plausible synchronization mechanism.

Population Dynamics of SBW

A major research effort into the population dynamics of SBW was carried out in New Brunswick in 1945–1960, the so-called Green River Project (Morris 1963). Results of this pioneering insect ecology research effort led to the formulation of the double equilibrium theory. According to this theory, SBW populations are held in check at an endemic level by a combination of mortality factors, the most important of which are bird predation and losses due to small larval dispersal. These two factors constitute the "predator pit", a depression in the recruitment curve that a population must overcome to reach outbreak level. This can occur through the accumulation of host foliage in ageing stands with sufficient conifer content, and can be hastened by an increase in recruitment rate (survival, natality), caused for example by highly favourable climatic conditions. Once the outbreak level is reached, the amount and quality of foliage regulates the SBW population (famine, dropping fecundity, emigration). The eventual exhaustion of the trees leads to an outbreak decline and the cycle starts over again. An analysis of the historical defoliation records between 1945 and 1980 supports this interpretation, especially in the zone where the insect's abundance is highest (Williams and Liebhold 2000b).

Royama (1984) reanalyzed some of the results of the Green River Project. He found that a gradual change in large larval (instars 3–6) survival was responsible for much of the rise-and-fall pattern of populations during the course of an outbreak, even in the absence of important damage to trees. Rapid and erratic fluctuations of apparent fecundity are superimposed on this gradual change in survival rate and result mostly from moth migration. Royama (1984) compared the resulting population fluctuations to a delayed density-dependent stochastic process similar in nature to a predator-prey oscillation. However, he was not able to identify the precise causes of the gradual change in survival except to limit it to natural enemies. He suggested that an unknown mortality factor (which he called the fifth agent) may be involved. The Canadian Forest Service and collaborators then launched a new population dynamics research program focused on outbreak decline and the following endemic period.

Most of the results of this research have yet to be published. Nevertheless, what was initially perceived as a relatively simple process now seems in fact quite complex. No fifth agent was found. Royama (1992) dropped the idea and recognized the complexity of the natural enemy complex of SBW. Statistical analysis of defoliation or population time series failed to prove that SBW populations are in fact regulated by a delayed density-dependent process (Turchin 1990; Williams and Liebhold 2000b). Reality is thus not as simple as theory.

The SBW forest system is complex. Outbreak populations are undoubtedly limited by starvation and foliage quality (Bauce and Hardy 1988; MacLean and Ostaff 1989; Bauce 1996), but these relationships are insufficient to explain the outbreak pattern (Mattson et al. 1991). In a new outbreak, the SBW population grows along a logistic trajectory that is modified by random slow-downs or accelerations in response to a range of environmental factors and the balance between emigration and immigration of moths. Nonetheless, the stochastic nature of this trajectory is fundamental to our understanding of the outbreak process.

In an ageing outbreak, several processes take place. Host trees lose vigor: foliage thins and become less nutritious, which leads to lower larval survival and adult fecundity (Blais 1953; Bauce 1996). Moreover, female SBW emigration may be influenced either by the level of damage to trees (Greenbank et al. 1980; Royama 1992) or by larval nutrition (Delisle and Hardy 1997). The growth capacity of SBW thus decreases.

The width of the probabilistic area of population density widens downward (because the upper limit is still determined by food availability). During this time, natural enemy numbers can build up in response to increased food resources. The more specific species, such as the parasitic wasps *Apanteles fumiferanae* and *Glypta fumiferanae*, require only SBW as a host. However, their numerical response is perhaps mitigated by a complex of hyperparasitoids (Royama 1992; Huber et al. 1996). The microsporidian *Nosema fumiferanae* is one of the few SBW natural enemies whose frequency is known to clearly increase in response to its host's abundance during the outbreak phase and to exert a regulatory influence (Thomson 1958a,b; Régnière 1984). Pauro-specific species and generalists represent the vast majority of SBW natural enemies. bird predators (Keindeigh 1947; Morris et al. 1958; Crawford et al. 1983; Crawford and Jennings 1989) and several species of parasitoids (Dowden et al. 1948; Blais 1965b) have the most impact on SBW at the end of outbreaks. These organisms can only partially respond to SBW abundance because they require alternate prey (hosts) to complete their life cycle. This is the case, for example, of the braconid *Meteorus trachynotus* (Maltais et al. 1989), of the eulophid *Elachertus cacoeciae* (Fidgen and Eveleigh 1998), of the ichneumonid *Tranosema rostrale* (Cusson et al. n.d.) and of the tachinid *Actia interrupta* (Régnière, unpublished data). The population densities of these organisms are therefore limited by resources other than the SBW and are also subject to considerable random fluctuations, which also results in a probabilistic logistic trajectory.

Together, natural enemies form a regulating complex. Many of the alternate food sources for this complex are found on plants other than the conifer hosts of SBW. This may explain how the species composition of a stand, especially deciduous content, can influence the severity and duration of SBW damage, as shown by Su et al. (1996). Furthermore, the structure of neighboring forests can influence the composition and growth rate of the natural enemy complex and the damage caused by a SBW outbreak (Cappucino et al. 1998, 1999).

An outbreak declines when mortality exceeds reproduction over several generations, unless the stand dies first. These conditions can occur through a drop in reproduction (loss of fecundity, increased emigration rate) or an increase in mortality. Several factors can contribute to increased mortality, but it is mostly the increased impact of the natural enemy complex that has been associated with the high mortality rates recorded during an outbreak decline. However, given that both SBW and natural enemy densities are random variables, the exact timing of decline is itself a random variable. Once a decline is triggered, the numerical importance of the regulating complex relative to SBW density increases such that mortality rates become, and remain, high for an extended period. A new outbreak of SBW starts when the overall impact of the natural enemy complex drops again. We hypothesize that this occurs after a long period when SBW is rare and natural enemies are

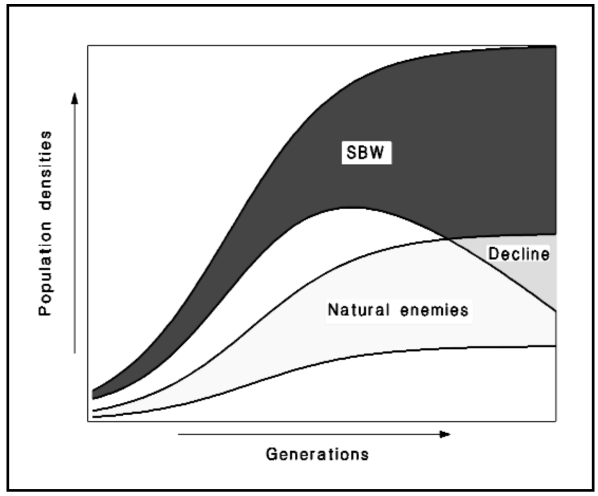

Figure 1. Conceptualized spruce budworm outbreak process. A decline occurs as soon as the spruce budworm population finds itself in the overlap band where natural enemies can inflict sufficiently high mortality rates.

decimated, switch to alternate prey, or move out of the stand. This could also occur as a result of a large influx from immigration or a random fluctuation in natural enemy abundance. During a new population growth period, SBW mortality from natural enemies is low (Régnière, unpublished data). This concept of SBW population dynamics is illustrated in Figure 1.

The main source of random fluctuations in population growth rate is moth migration (Royama 1984). The intensity of migration (positive or negative) depends on stand condition (or larval nutrition) as well as on the spatial distribution of neighboring SBW populations. During the growth period of a new outbreak, immigration of moths from nearby populations can act as an accelerator by increasing local growth rates; this does not necessarily act as a trigger, as was believed earlier (Greenbank 1957). Rather, such acceleration of receiving populations and the corresponding slowing down of emitting populations have as a consequence the synchronization of population oscillations (Figure 2).

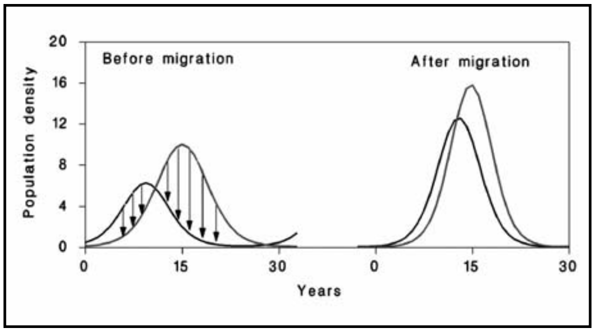

Figure 2. The synchronizing influence of spruce budworm moth migration. Migration homogenizes frequencies and increases amplitude of population oscillations.

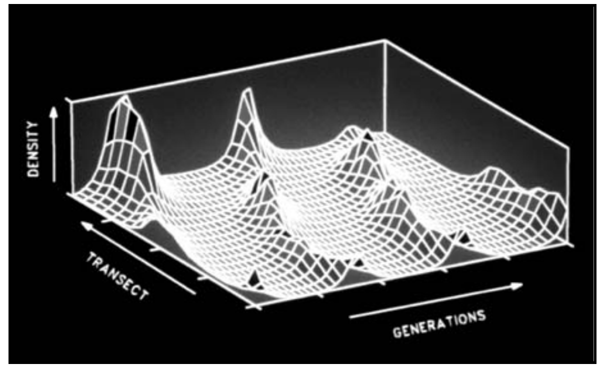

Figure 3. Simulation of the impact of migration on a series of adjacent populations along a north-south transect crossing a gradient of ecological conditions having consequences on the amplitude and frequency of local population oscillations. Note that populations in the centre of the gradient tend to oscillate faster and with lower amplitude than populations to the south or north where conditions may be less favourable for the insect. Based on the vertically transmitted disease model of Régnière (1984).

At the landscape level (at scales such as southern Quebec or New Brunswick), large abiotic (climate, soils, topography) and biotic (forest ecosystems and mosaics) gradients exist. The intrinsic frequency and amplitude of local population oscillations may differ to some extent. Theory suggests that higher intrinsic growth rates (characteristic of more suitable habitats) lead to faster and lower-amplitude oscillations (Berryman 1981; Régnière 1984). In the case of SBW, population "cycles" would likely tend to be shorter and of lesser amplitude in the more meridional sites and more pronounced (slower) and more extreme towards northern or higher elevation sites. Such geographical differences in intrinsic population dynamics cannot, however, be fully expressed because of the strong synchronizing influence of moth migration. In fact, models show that only vestigial traces of intrinsic oscillation frequencies and amplitudes remain under even very small migration rates. This imperfect synchronization is illustrated in Figure 3.

Spruce Budworm Pest Management

Currently, SBW management in eastern Canada is based mostly on the use of the biological insecticide *Bacillus thuringiensis* var. *kurstaki* (*B.t.*). The interaction between this insect pathogen and SBW is well understood and has been modelled in great detail (Cooke and Régnière 1996, 1999; Régnière and Cooke 1998). The efficacy of the pesticide is constantly improving. However, its use does not differ from that of chemical insecticides used during the previous outbreak of SBW in eastern Canada, i.e., foliage protection in stands that are most damaged or of highest value to forest industry. The improvements made in recent years are mostly at the level of phenological (Régnière 1987, 1996; Régnière and You 1991) and economic targeting (MacLean and Porter 1994), spray-parameter optimization (van Frankenhuyzen and Payne 1993) and GPS spray aircraft guidance. This reactionary approach, coupled with preventive harvesting, has little impact on the course of an outbreak and only allows trees to survive in a limited number of selected high-value and high-risk stands.

An Early Intervention Concept

The view of SBW outbreaks developed by Morris (1963) and Blais (1968) is at the heart of a simulation model developed at the end of the 1970s by a group of scientists at the Institute of Animal Ecology (Vancouver, British Columbia), under the leadership of C.S. Holling (Clark et al. 1979; Peterman et al. 1979). It is on the basis of this model that the first early intervention approaches were developed for SBW outbreak management. The original concept was based on the idea that SBW outbreaks are similar in nature to forest fires. They would start in a stand as a result of a failure of the endemic regulating mechanism and spread to neighboring forests. Thus, an obvious approach to early intervention would be the elimination of these outbreak foci (epicentres) by application of insecticides like water to control a fire.

This epicentre abatement approach was tested repeatedly during the last outbreak in Ontario (Howse and Sippell 1975), in the USA (Dimond 1976), and in Quebec (Blais 1963, 1965a). Sippell (1984) discussed these trials, and later called for an international program based on this approach (Sippell 1985). Some of these trials were reported as successes. Unfortunately, the best documented of these successes were in fact achieved in vestigial SBW populations rather than in early rising outbreaks. They appeared to be successful at inducing declines rather than preventing new outbreaks.

The current view of the SBW outbreak process indicates that an epicentre is an indicator rather than the source of a new outbreak. This is not a new idea (Stehr 1969). During the endemic period, SBW is present at low levels everywhere there is a sufficient number of host trees, as can be verified by pheromone traps (Sanders 1988). The increase in population density at the onset of a new outbreak is a phenomenon that occurs more or less simultaneously over large geographical areas where epicentres are merely the crests of a wave (Régnière and Lysyk 1995). The generalized increase of SBW populations is caused by a widespread decrease in the impact of natural enemies (Royama 1984, 1992; unpublished data). An attempt to stop an outbreak by eliminating such epicentres would be futile.

It remains possible, however, that interventions in rising populations could slow the progression of defoliation in the treated area as suggested by observations at Lake Burchell (Ontario) in the 1960s (Howse and Sippell 1975) and in the Ottawa River valley in the 1990s. In this respect, the experience of Manitoba and Alberta with population suppression with either *B.t.* or Mimic® (Rohm and Haas, Philadelphia, PA) are informative (personal communication, L. Matwee, Manitoba Department of Natural Resources and H. Ono, Alberta Sustainable Resource Development). In these provinces, SBW was suppressed for periods of a few to several years by insecticide applications. It therefore seems possible, under certain circumstances yet to be determined, to suppress SBW populations by insecticide applications several years apart.

In addition, it is probable that silviculture can offer interesting pest management options. This concept is not new either. Tothill (1919) suggested that avoiding large, pure balsam fir stands would decrease the risk of damage by SBW. Thinning also seems an interesting silvicultural tool (Piene and MacLean 1984; Piene 1989; MacLean and Piene 1995; Bauce 1996). Much literature exists on this topic (see Schmidt et al. 1984). The integration of natural enemies in the optimization of control programs against SBW was also extensively discussed (Nealis and van Frankenhuyzen 1990; You and Smith 1990; Nealis 1991; Cadogan et al. 1995). However, an integrated early intervention approach using new concepts in SBW population dynamics is not currently available.

In the context of population dynamics described here, an early intervention strategy against SBW (Fig. 4) could have at least one of the following objectives:

1. Suppression of populations below a defoliation threshold having an impact on tree growth (about 10–20%), so additional treatment is not needed for several years. Interventions aim for population reduction and are thus optimized for killing insects rather than protecting foliage. The more the applications are effective, the longer the amount of time allowable between treatments.

2. Slowing down the regional outbreak progression, and limiting its severity by decreasing emigration rates (through lower defoliation) and decreasing the average rate of growth in the treated area (insecticidal effect).

3. Inducing early decline by changing the balance between SBW and the complex of natural enemies. In this line of thought, a decline should be easier to induce in a diversified stand than in a pure conifer stand.

4. Integrating the use of insecticides with preventive silviculture. Thinning is one method that is aimed at increasing stand resistance to defoliation while decreasing the total number of insects per unit of land surface area. Thinning also offers the potential of altering the predator-prey ratio. Forest fragmentation is another landscape-level silvicultural approach, aimed at increasing regional biodiversity and reducing survival among migrating SBW moths.

The first objective is the pillar of this early intervention strategy. Currently, interventions against SBW aim at foliage protection to keep trees alive while the outbreak passes. During the outbreak period, this strategy may require that heavily infested stands be treated every year; in spite of protection, defoliation may still be high enough to interrupt tree growth. Early intervention aims at preserving tree growth by maintaining defoliation below 10–20%. The idea is to reduce SBW populations to the lowest level possible with a highly efficacious treatment optimized for maximum kill. The Alberta/Manitoba experience allows us to believe that population suppression of this type could result in less frequent treatments in a given stand, allowing several years without the need for intervention while the SBW population recovers. Ideally, once the level of natural enemy populations has reached its maximum in a stand, it will be possible to induce early decline by pesticide application. The higher the natural enemy population, the more likely such a decline would be and the shorter the treatment period required.

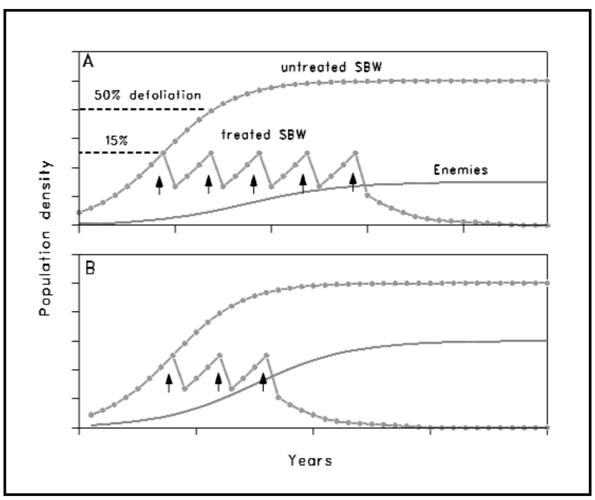

Figure 4. An early intervention concept for spruce budworm (SBW) population management: (A) Pure conifer stand; (B) Mixed stand.

Three main problems could hamper this ideal scenario. First, an increase in the number of natural enemies during an outbreak remains a hypothesis used to explain the observations made in collapsing SBW outbreaks during the last 20 years. This hypothesis has not been tested experimentally, and any early intervention strategy based on it will remain a conjecture as long as it has not been confirmed. Second, *B.t.* (or any other pesticide) applications could well have a detrimental effect on natural enemies either directly or indirectly through their alternate prey. These are believed to be mostly species of Lepidoptera that could be in the larval stages at the time of treatment and could serve as alternate food sources for predators and parasitoids after the SBW has completed its development. A negative effect of insecticide treatments on these organisms may well lead to an impoverished natural enemy complex and thus could actuallyprolong an outbreak. Third, SBW is highly mobile, especially in the adult stage. As a result, an early intervention over too small an area is bound to fail because immigration would bring the treated population back to the level of neighboring populations. The success of an early intervention program would therefore rest on the relationship between spray block size and the scale at which re-invasion becomes negligible. This scale is not currently known, but it will undoubtedly depend on the spatial context (proximity of neighboring populations).

A research project was recently set up to determine the following:

1. The extent to which an early intervention strategy resting on insecticide applications against rising SBW populations is possible given operational constraints (area to be treated, product efficacy) and the ecology of SBW (increase of natural enemy numbers, impact of treatments on these, re-invasion).

2. The circumstances (forestry context) where an early intervention strategy would be more appropriate, from an efficacy point of view (cost/benefit, reduced pesticide use), than the current foliage-protection approach.

More specifically, we propose to determine the effect of early interventions with *B.t.* on several key parameters of SBW population dynamics and its impact on trees by comparing measurements made in treated and untreated populations in forest stands of different types. We retained three important stand characteristics for contrasts: conifer content, thinning, and stand isolation.

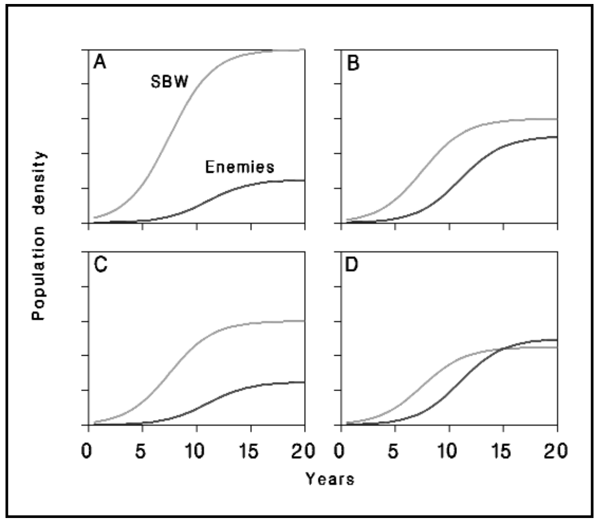

Figure 5. Probable relationships between stand structure and absolute densities of spruce budworm and its natural enemies: (A) dense pure conifer stands; (B) mixed stands; (C) thinned conifer stands; and (D) essentially deciduous stands.

The composition and density of stands should have an important influence on the abundance ratio between SBW and its natural enemies (Fig. 5). A dense pure conifer stand has a high SBW population per hectare and a relatively small population of natural enemies because of the lower number of plants supporting alternate prey (Fig. 5a). A mixed stand should contain fewer SBW and relatively more natural enemies (Fig. 5b). In a thinned conifer stand, the amount of SBW-host foliage may be lower, reducing SBW density, but not affecting the abundance of natural enemies (Fig. 5c). However, it is also possible that a thinned stand would produce more and better quality foliage. The ideal situation is illustrated in Figure 5d: a small amount of SBW-host foliage in an otherwise deciduous stand, i.e., a stand condition generally recognized as SBW-proof (Su et al. 1996).

Stand isolation can also have an important impact on susceptibility to SBW through its influence on the net movements of SBW moths and natural enemies from nearby stands. In this context, conifer stands located in a mixed or deciduous matrix hold the most interest, as SBW immigration rates should be small and net movement of natural enemies should be directed towards those stands when the SBW population increases. It has been shown that stand isolation has an impact on the amount of damage inflicted by SBW and levels of parasitism (Cappucino et al. 1998).

Conclusion

Pest management of SBW during the next outbreak in eastern Canada will be done mostly with *B.t.* in foliage-protection mode aimed at keeping the trees alive while the outbreak passes in targeted, high-value conifer stands. However, a more proactive approach is on the horizon, and it may be sufficiently well documented and validated to be applied at least over part of the range that will be covered by the impending outbreak.

Acknowledgments

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WORKSHOPS

WORKSHOP 1.1

TOWARDS AN INTEGRATIVE UNDERSTANDING OF THE POPULATION DYNAMICS OF CONIFER BARK BEETLES: INCORPORATING FACTORS FROM MULTIPLE TROPHIC LEVELS

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Integrating Multiple Factors

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Due to the complex interactions among even the main factors that drive a population system, simple effects of these factors in isolation are of limited value in understanding the dynamics of that system. Thus, we need to integrate these factors in a way that allows as to assess changes in population size and quality. This can be a challenging task as often information is lacking on some key components of the system. Integration of multiple factors mainly involves two approaches: 1) experimental, and 2) modeling. The purely experimental approach is mainly used when only a few factors are involved. For example, experiments designed to assess the effects temperature and crowding on rates of development, and survival of various brood stages. Integration of factors from the various trophic levels normally involves model building. A prerequisite is a conceptualization of the problem in terms of the nature and temporal sequence of interactions, and feedback loops among the main components of the system. Integration is often done using a so called rates of change model such as eq. (1).

$$dYi+1 / dt = f(X,Yi) \qquad (1)$$

where Yi is a vector of state variables that describe the bark beetle population at time t. These rates govern the movement of beetles through the various life stages and the production of the next generation. The vector X contains a collection of biotic and abiotic variables that affect the state variables. This includes development, mortality, and production rates. Assuming that we have satisfactory sub-models for the effects of various mortality factors that affect generation survival, one of the most challenging problems is how to combine these sub-models. Generation survival (Sg) is normally modeled as a product of survivorships during the various brood stages [eq.(2)].

$$Sg = (1- Me/Ne)(1- Mi/Ni)\ldots(1-Ma/Na) \qquad (2)$$

Mi = mortality in brood stage i; Ni = number of beetles at the beginning of brood stage 1.

In turn, survivorship in a particular brood stage is usually expressed as a product of the survival from each mortality factor acting alone. For example, egg survival (1-Me/Ne) would be modeled as in eq. (3).

$$(1-Me/Ne) = (1-m1/Ne)(1- m2/Ne)\ldots(1-mn/Ne) \qquad (3)$$

mx = number of eggs killed by factor x acting alone and the other symbols are as defined above.

However, this interaction model assumes that the various mortality factors act independently and their combined effect is synchronous. As the action of most mortality factors affecting bark beetle populations are neither independent or synchronous, appropriate modeling of their interactions can have a large effect not only on generation survival but on our ability to assess their relative importance in affecting bark beetle population change. The following are examples of modeling bark beetle brood survival in a specific stage following the action of two mortality factors under different assumptions regarding the nature of their interactions.

1) Two mortality factors operate independently and are synchronous:
   Sm = (1-m1/Nm)(1-m2/Nm)

   Sm = survival in stage m.
   Nm = Numbers of individuals at the beginning of stage m
   m1, m2 = mortality caused by factor 1 and 2, when acting alone.

2) Effects of two mortality factors are mutually exclusive:
   Sm = 1- (m1+m2)/Nm;

3) The probability of death from the second factor is a function of the probability of death from the 1st factor:
   Sm = (1-m1/Nm)(1-f(m1/Nm))

For example, larvae that had been weakened by prolonged stress from cold weather which had killed m1 of them directly may suffer further apparent mortality m2 due to stress-induced lowered resistance to disease.

Effects of Defoliation on Host Defenses, Acceptance Behavior and Population Dynamics of Bark Beetles

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Alterations of tree physiology resulting from defoliation can affect tree resistance against bark beetles. Defoliation may reduce whole-tree water stress and increase net photosynthetic rate per unit leaf area in the short-term. However, if responses to defoliation do not fully compensate for losses of photosynthetic capacity caused by leaf area loss, tree carbon reserves decrease. Such a decrease in available carbon may reduce tree capacity to produce carbon-based defenses against insects, such as resin. Crown size, condition, and intensity of defoliation can differentially influence resistance to subcortical insects. However alterations of resistance mechanisms and host acceptance behavior and impacts on population dynamics remain unclear. We evaluated the effects of varying levels of defoliation on tree physiological parameters, carbon-based host defenses, and subcortical insect colonization. Predawn water potential differed among defoliation classes. Leaf photosynthetic rate remained the same or was positively related to crown scorch intensity. September leaf photosynthetic rate was lower in trees with moderate crown scorch damage and higher in trees with severe crown scorch damage. Carbon-based defenses were also influenced by crown condition, and the relationship between defoliation intensity and carbon-based defenses was either curvilinear or linear, depending on intensity and time since the defoliation event. Subcortical insects first colonized trees with heavy to severe damaged crowns and later colonized trees with less damage. In northern Arizona where resident beetle populations are low, colonization of less stressed trees only occurred when synthetic pheromones were placed on the trees. However, the colonization sequence remained the same with or without the presence of synthetic pheromones. That is, colonization of trees with more crown damage was attempted before those trees without crown damage. Only after stressed trees are fully utilized did beetles attempt to colonize less stressed trees. This suggests that pheromones bring insects to potential hosts, but other cues such as host chemistry or population density, are responsible for colonization attempts.

Direct Control of Seasonality in *Dendrocotonus* Species

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Many, if not most, *Dendroctonus* species lack a life-history timing mechanism like diapause. This is in spite of the fact that an appropriate seasonality is absolutely required for success of key ecological strategies such as the mass-attack that overcomes tree defenses. We demonstrate that an appropriate seasonality is a natural consequence of the interaction between seasonal temperatures and stage-specific developmental rate curves. In doing so, we introduce a new paradigm for modeling direct temperature control of seasonality. We further discuss both the general implications of our results and the specific application to mountain pine beetle populations.

Role of Predators and Parasites

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Populations of the southern pine beetle, *Dendroctonus frontalis*, undergo regular outbreaks every 7–10 years. We present evidence that these oscillations are driven by interactions with the clerid predator *Thanasimus dubius*, utilizing time-series of predator and prey abundance, exclosure experiments, and predator-prey models. Attack densities and competitor abundance also increase during outbreaks, and could combine with predation to limit *D. frontalis* populations. We also present results from a geographic survey of pheromone preference in *T. dubius*, that suggests it prefers *D. frontalis* where the two species overlap. This specialization would likely enhance the oscillations observed in this system.

Role of Woodborers and Secondary Bark Beetles on the Population Dynamics of Primary Bark Beetles

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Primary bark beetles are adversity specialists adapted to overcome resistance by their hosts. Secondary species (including woodborers) are opportunity specialists adapted to compete for hosts with weak resistance. Competitive secondary species may orient to pheromones of heterospecifics, repel heterospecifics with their own pheromones, exploit the phloem resource rapidly, co-opt fungi as interference agents, and prey on larval competitors. When they attack the same host, adversity specialists often lose to opportunity specialists, which are better competitors. Pheromones of both may be exploited attractants for woodborers, and pheromones of secondary species may be used to induce competitive exclusion or displacement of primary species.

WORKSHOP 1.2

FOREST HEALTH IMPLICATIONS OF CURRENT MANAGEMENT OF PUBLIC LANDS

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Moderator Summary: One of the major differences between bark beetle management in Mexico and the rest of North America is land ownership. Most of the Mexican forest is located on land owned by small groups of people with different degrees of organization and knowledge of forest management. Bark beetle infestations are not reported and have increasingly become a legal way to expand agriculture boundaries, because landowners can legally cut down dead trees.

In the Southeast Region of the USA (R8), support for extension in longleaf pine forests has decreased and efforts have shifted towards reforestation. Only 6% of the land mass is National Forest Land in this district. Prescribed fires are being used again as silvicultural tools while management is based on species indicators and other objectives that are not very clear. The red oak borer in the Ozark National Forest, Arkansas is a widespread insect killing many oaks. Sanitation efforts to control the insect and preserve the forest and its values have been stopped by environmentalists, resulting in an expected increase in populations, as well as an impact on forest values.

In the Pacific Northwest Region of the USA (R5), forest management is focused on old growth forests. Managers now must take into account a list of over 100 protected species, which must be surveyed prior to any management activities. The workforce in the national forest service has been reduced by almost half over the past few years, making it difficult to address these issues. The timber harvest has also decreased, simultaneously diminshing the money available for roads and schools.

In western Canada [British Columbia (B.C.)], the forest has a variety of land tenures, which in turn have different management objectives and therefore different perspectives on forest health. Most forest health problems occur at the border of two different types of land tenure, especially on parkland. British Columbia Parks has a larger portion of forested land today to manage, with over 285 000 ha infested with mountain pine beetle at a growth rate of 30% a year. Prescribed fires are important management tools for this pest but cannot be used by Parks. Parks and federal land recognize different forest hazards, and open communication effort is essential to maintain healthy forests under this scenario. This implies good neighbor policies, acknowledgment of different management objectives, joint planning, and compromise to ensure an overall best approach.

In eastern Canada (Ontario), emphasis is placed on intensive forest management and long-term forest health. Recent policy initiatives that influence forest management are Ontario's Living Legacy, the *Crown Forest Sustainability Act*, climate change and wood certification. A major step currently being taken is to transfer forest management to the industry and to create a forest future trust from which funds can be drawn to address issues such as forest health. A major driving force behind the policy is what is considered acceptable to the public.

Conclusion: Management objectives influence the concept of forest health across North America, and consequently, real and perceived hazards differ under the different jurisdictions. Health problems are particularly important, and most difficult to address, at the boundaries of different land ownerships. Because public awareness and input is so strong in forestry, most forestry practices are influenced by human perceptions and decisions. The recent emphasis on old growth forests and the sustainability of natural forested ecosystems in many jurisdictions has led to conflicts, and in some cases, over-regulation. These conflicts have often resulted in delays or complete prohibition of appropriate sanitation measures that significantly affect long-term forest health.

Forest Health in Community-Owned Land in Mexico

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Forest management in Mexico follows mainly an uneven-aged management system, although even-aged management started to appear in the mid-1970s. Most forested land is owned by groups of people (ejidos and comunidades) who see the forest as future agricultural lands. Despite governmental regulation and technical assistance, forest management depends on the landowner's time, skill and equipment. Forest health issues, therefore, are seldom important, unless they are very conspicuous. Forest pest management in Mexico mainly is for control of bark beetles, is not managed at all, or is a low-tech, highly disrupted activity.

Impact of the Northwest Forest Plan on Management of Insects

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The Northwest Forest Plan (NWFP) was a Supplemental Environmental Impact Statement that amended Forest Service and Bureau of Land Management planning documents within the Range of the Northern Spotted Owl in April, 1994. The NWFP applies to more than 24 million acres of federal land. Approximately 30% of these acres have been Congressionally withdrawn. The remaining 70% was allocated as follows: Late Successional Reserves (30%); Adaptive Management Areas (6%); Managed Late Successional Reserves (1%); Administratively Withdrawn Areas (6%); Riparian Reserves (11%); and Matrix (16%). Although certain thinning and salvage activities could occur in the Reserves, programmed timber harvest would only occur in the 22% of the land designated as Matrix, or Adaptive Management Area.

Timber harvest, as well as any other habitat-disturbing activities, must comply with specific standards and guidelines designed to achieve objectives to conserve late-successional habitat. Standards and guidelines that have had a significant impact on timber harvesting and pest management include: the Riparian Reserve system, Watershed Analysis, Green Tree Retention, and Survey and Manage. The Riparian Reserves designate initial reserve widths for protected riparian areas. Watershed Analysis is a systematic procedure to characterize features in order to refine riparian reserve boundaries and prescribe land management activities. Green Tree Retention is a standard to retain at least 15% of the green trees on each regeneration harvest unit. Survey and Manage is a set of actions required prior to undertaking actions which could disturb the habitat of over 300 specifically listed organisms. Implementation of most standards and guidelines adds both time and expense to most projects conducted in areas where the NWFP applies.

The NWFP influences management direction on certain units administered by the Forest Service and Bureau of Land Management. Within California, the NWFP applies to all of the Klamath, Shasta-Trinity, Mendocino and Six Rivers National Forests, and to parts of the Lassen and Modoc National Forests. The Plan also applies to Public Lands administered by the Redding Resource Area, the Arcata Resource Area, and the King Range Natural Conservation Area of the Ukiah District of the Bureau of Land Management. The NWFP does not adopt new management direction for lands administered by the Fish and Wildlife Service, National Park Service, and Department of Defense. It does not establish direction or regulation for state, tribal or private lands.

Results of the first 6 years of implementation of the NWFP have been mixed. Few activities are actually prohibited by the Plan, and there are many exemptions granted where valid reasons exist. On the other hand, interpretation is often done at the local level, and is not uniformly implemented across the area. The Plan added additional layers of analyses, planning and surveys that take additional time and reduce responsiveness. The cost of the additional analyses and planning must be borne by the resource area proposing the habitat-disturbing activity. Because one of the underlying objectives for the NWFP is to manage habitat for late-successional dependent species, any harvesting or thinning activities tend to retain the larger diameter stems on-site, and attempt to remove the smaller diameter stems. This produces low volume, low value timber sales that are not capable of bearing the costs of additional analyses and surveys. Under the NWFP, timber sales volumes and receipts have declined, National Forest budgets have declined, and the number of permanent personnel has declined. The number of opportunities to implement pest management through ongoing timber sales has also declined. There is still interest in implementing special pest management projects; however, these are limited by the amount of appropriated funding available.

Forest Health Implications of Current Management in the Southern Region of the United States Department of Agriculture (USDA) Forest Service

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The forests of the South are constantly changing. During 1999 and 2000, the southern pine beetle, *Dendroctonus frontalis* (Zimmermann) populations were epidemic in the National Forests in Kentucky, Tennessee, North Carolina, Georgia, and Alabama. The lack and/or delayed suppression of southern pine beetle (SPB) resulted in impacts on the Daniel Boone National Forest in Kentucky that killed more than 90% of the conifer host type (southern pines and white pine). This loss resulted in the forest not having enough pine type to support its 14 colonies of endangered red-cockaded woodpecker. The colonies were moved to other forests. The Bankhead National Forest in Alabama lost 30 000 acres of pines from 1998 to 2000.

The Ozark and Ouachita National Forests in Arkansas have loss tens of thousands of acres of northern red oak, *Quercus rubra* (L.), black oak, *Quercus velutina* (Lam.),and white oak, *Quercus alba* (L.), to oak decline. Oak decline is a complex involving drought, red oak borer, *Enaphalodes rufulus* (Haldeman), diseases (*Armillaria* root rot and *Hypoxylon*), white oak borer, *Goes tigrinus* (De Geer), and carpenterworms, *Prionoxystus robiniae* (Peck) and *Prionoxystus macmurtrei* (Guerin). The red oak borers have become so numerous there are hundreds of attacks per trees. Trees are being girdled by the combination and the feeding of the first year larvae.

In the National Forests in Alabama, at least 50 000 acres have planted loblolly pine, *Pinus taeda* (L.), growing on upland longleaf pine, *Pinus palustris* (Mill.), sites. The loblolly pine on these sites becomes infected with littleleaf, (*Phytophthora cinnamoni* (Rands), and *Leptographium* spp.) by the time they are 20 years old. These diseases and/or SPB kill the trees before they are 60 years old. These sites then begin to change from their natural pine fire subclimax to hardwood. Mature pine stands are an essential component of forest health.

The management strategies in the forests in the Southern Region of the USDA Forest Service have allowed the impacts of SPB, oak decline, littleleaf and other diseases to have serious forest health implications. Whether these forests were healthy or unhealthy is a matter of opinion and definition; but it is agreed, the ecosystem has and will continue to change.

Forest Health Implications of Management of Public Lands in British Columbia

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British Columbia is a large province, encompassing a total land area of approximately 95 million hectares. Almost all of this area (about 95%) is considered public land in one form or another: productive forest land, approximately 48%; provincial parks, approximately 12%; and the rest made up of federal parks, other protected areas, community watersheds, urban areas and other. Each of these management tenures may have different management objectives and, therefore, different and sometimes conflicting perspectives on forest health.

Issues leading to conflicts or concerns may arise in interface areas where there is a potential for a damaging agent to cross into a tenure with differing resource objectives. It is necessary to avoid conflicts and move to resolution of such concerns through compromise and cooperation.

The following principles may help to ensure an overall best approach to management between agencies:

- Acknowledge the differing management objectives of other agencies or owners;

- Acknowledge that there are benefits in developing and implementing good neighbor policies;

- Establish and maintain regular communication so that concerns are raised and dealt with at an early stage; and,

- Endeavour to implement joint planning and compromise in interface areas.

Recent Policy Initiatives in Ontario and Their Implications for Forest Health

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Introduction

Increased public involvement in resource management combined with political responses to public pressure, have resulted in significant changes to forest management in several jurisdictions in North America. Although Ontario has not experienced such polarizing issues as spotted owl or old growth rain forests, the issues here have nonetheless been passionate, complex, and able to affect long-term changes in forest management.

These issues almost always have implications for forest health. Recently, four prominent issues have altered the way forest management is practiced. Each has both positive and negative implications for forest health.

Ontario's Living Legacy initiative, while setting aside 12% of the land base for protection and conservation, puts greater pressure on the remaining land to meet forest resource needs. The province's new *Crown Forest Sustainability Act* (CFSA) enshrined sustainability as a legal requirement, defining it as maintaining long-term forest health. It also removed the decision for funding forest protection programs from politicians, instead placing it in the hands of an independent committee.

Two other issues that are more publicly driven than politically driven, are climate change and forest certification. Climate change has emerged for many people to replace nuclear war as the most likely to cause the earth's demise. Insects in particular are likely to figure prominently in this issue. Certification has grown out of a desire to publicly demonstrate that forests are being managed sustainably. Ontario has decided to seek certification from the Forest Stewardship Council (FSC), an organization that opposes the use of pesticides, a move with potential significant implications for forest health.

Ontario's Living Legacy

For many decades now there has been unrest in the forest. Land use conflicts have continually arisen where users compete for the same resource and land area. Local people wanted control over resources, located mostly in the north. Southern Ontario, where most of the people (i.e., voters) live, wanted more land set aside to protect it from development (i.e., timber extraction, mining, roads). The Ontario Ministry of Natural Resources (OMNR), with support from Premier Harris, undertook a public consultation exercise called Lands For Life. It culminated in Ontario's Living Legacy, an agreement between forest industry, environmental groups, and the Ontario Ministry of Natural Resources. Ontario's Living Legacy sets aside 12% of the land base for protection and conservation. As part of Living Legacy, the three parties signed the Ontario Forest Accord. The Accord has brought some peace to the forest. The forest industry, environmental groups, and the province have agreed to work together to solve these land use conflicts. A formula now exists for determining any future set-asides, the industry has a promise that it can maintain its wood harvest levels, and a board of directors has been established to ensure implementation of the terms of the Accord.

The most important aspect of the Accord for forest health is likely to be ensuring forest industry maintains its harvest levels: no net loss in wood supply, now or into the future. With less land from which to harvest wood, depletions to the timber resource become less tolerable. The threshold at which mitigating actions must be taken becomes lower.

Greater emphasis must be given to forest health in the planning stages. Rather than reacting to forest health issues such as insect outbreaks, forest companies will need to incorporate the managing of these problems into their forest management design. Tree diseases, which for the most part are unmanaged, may represent an untapped wood supply that could be available by planning rotation schedules, multiple harvests, and thinning and spacing operations. Likewise, insect outbreaks, such as spruce budworm, jack pine budworm, and forest tent caterpillar, can cause loss of timber volume over extensive areas. Although spray programs have been conducted for spruce and jack pine budworm, the outbreaks run their course over most of the province without intervention to protect wood supply. For instance, during the recent spruce budworm outbreak, which peaked at some 18.8 million hectares, foliage protection programs never exceeded 2% of the outbreak, and were mostly less than 1%. The area of tree mortality from spruce budworm covered over 8 million hectares in northwestern Ontario in 2000. To maintain wood supplies, losses from such outbreaks are likely to be less tolerable. Strategies, such as aerial insecticide spraying, could be employed to reduce the losses.

Forest tent caterpillar reduces tree growth but normally causes limited mortality. Ontario has encouraged aspen-based industries in recent years, notably oriented strand board. Increased pressure on this wood supply may reduce the threshold for this insect as well.

Finally, the Accord lays the foundation for intensive forest management (IFM) as a means of getting more timber off the same land base. Not only could this result in lower thresholds as described above, but it could in itself create forest health problems. Intensive forest management puts emphasis on pre-commercial thinning, juvenile spacing, and commercial thinning as means of reducing rotation age, capturing volumes that would be lost as stands age, and increasing individual tree size and quality. Opening up the stands, though, can lead to problems such as sawflies that thrive in open stands of conifers with large crowns. Similarly, jack pine budworm, which requires abundant pollen cones, could increase its frequency or severity of outbreaks because thinning operations often lead to deeper crowns with more flowering. Experience from Newfoundland and Nova Scotia with balsam fir sawfly suggests that forest companies and provincial policy makers should anticipate these or similar problems if thinning operations are practiced on a broad scale.

The Accord also places emphasis on the need to make protection of IFM areas a priority. Thus, Ontario's Living Legacy, by creating the Forest Accord and the expectation of maintaining harvest levels, will result in greater need for forest health monitoring programs, plus early warning mechanisms, decision support systems, and pest control methods.

Crown Forest Sustainability Act

The CFSA established a new business relationship with forest industry and the OMNR. Although most of the land in Ontario is owned by the Crown, the CFSA transferred almost all the responsibility for managing the forest to forest industry. The one exception is forest health. In practice, small, local programs such as ground spraying in plantations, stump treatments for root rot, and seed orchard pests are conducted by forest industry. Aerial spray programs, though, have essentially remained the responsibility of OMNR. Forest industry participates in the process, but OMNR leads it, and conducts the extensive public consultation program associated with aerial spraying. Ontario does not have a provincial forest protection agency supported by industry and government, as exists in Quebec (SOPFIM) and New Brunswick (FPL). Aerial spraying programs normally occur in more than one management unit. With OMNR leading the process, it's able to provide scientific leadership and overall coordination of the program. Forest industry, which probably does not relish public consultation regarding pesticide programs, is able to leave that role to OMNR specialists.

A second impact of the CFSA has been the establishment of the Forestry Futures Trust. Among other things, this trust provides funding for insect and disease management programs. Revenue for the trust comes from stumpage charges paid by forest industry. The trust is provincial in scope: the money is not tied to a particular management unit, but can be used wherever the problem exists. Previously, special funding was sought annually from Management Board, the central government agency making major decisions on government policy and budget allocations. With the establishment of the Forest Futures Trust, this yearly uncertainty has been removed. Instead, an application is sent to the Forestry Futures Committee. This Committee oversees the Trust and manages the funds. They operate at arm's length from government and forest industry.

Finally, the CFSA has as its purpose the maintenance of long-term forest health. This placement of forest health in the lexicon of the public brings both increased scrutiny of sustainable forest practices, and an increased awareness of the need to maintain healthy, productive forests that are able to meet people's expectations now and into the future.

Climate Change

Global warming, climate change, and greenhouse effect are terms as well known to today's generation as nuclear war was to those who grew up any time since the 1950s to the end of the Cold War. Climate change may indeed be happening now, or imminent. What matters for forest health, though, is the effects of the climate change wave on government policy, and direct effects on major forest disturbances. Climate change may be the flavour of the month, receiving high profile from the media and funding from government. Or, it may be here to stay as a significant determining factor on our ability to thrive on this planet. Heaven help anyone who speaks out as a skeptic. Nonetheless, we must remember our history. In addition to nuclear attack, there have been several issues that seemed sure to be the cause of earth's doom. Included in this list would be acid rain, forest decline, dioxins, rainforest destruction, pesticides, clearcuts, and pit bull attacks. These problems haven't gone away. The problem is they get lots of attention and funding, then fade from prominence, not necessarily after they have been solved. What they do is divert attention away from long-term strategic thinking and planning. And with the thinking goes the funding. In this day of reduced government budgets, the funding gets diverted from existing programs, such as forest health, that are more long-term in their approach. Similarly, invasive species have received high profile recently. This has benefited forest health by increasing its profile. Invasives have illustrated the need for forest health monitoring, trained staff, vigilance, international co-operation, and the need for effect pest management programs and research. When this new program gets replaced by the next wave, it, too, will suffer from lack of political appreciation.

The same risks exist for climate change. Climate change also directly affects forest health. Insects, abiotic disturbances from extreme weather, and fire are three of the most common problems expected to be exacerbated by climate change. Although there's a high degree of uncertainty of which species will do what, some insects are expected to emerge as severe pests, some current pests will disappear or become more severe, and interactions among insects, fire and drought are likely to drive forest succession. Extreme weather events that affect forest health are also predicted, such as drought, snow damage, blowdown, and ice storms. Enhanced forest health monitoring, effective pest management strategies, succession models, and adequate wood supply models are going to be needed more than ever should climate change proceed as predicted. Currently, though, in Ontario the emphasis from government is on reducing carbon emissions or increasing sequestration. It is not on studying or detecting the effects of climate change.

We can also expect increased need for protection programs if insect problems worsen. Connected to this is the question of carbon credits. Analyses are already underway to determine the amount of carbon that can be sequestered by controlling insect outbreaks. The premise is that reducing insect attack keeps trees alive and growing, storing carbon in the forest sink. The saved carbon can then be traded or sold to offset industrial emissions targets. Carbon credits themselves may be an incentive for conducting spray programs to maintain tree growth and survival.

Forest Certification

Forest certification has arisen from pressure to manage forests sustainbly. Some of this is being driven by overall trends in the market: people in general are concerned about sustainable forestry. Certified forest products are one way of demonstrating this requirement. Some environmental groups have used demonstrations, threatened boycotts, and bad press, to convince retailers to source their wood products from forest companies that manage according to set standards. Adhering to principles that ensure sustainability can only be good for forest health (especially since the definition of sustainable is tied to long-term forest health). The issue, though, is in putting this into practice.

Ontario has recently announced it will seek certification from the FSC for forest products produced from Crown land. The implications of this for forest health are unknown. What is known is that FSC opposes the use of pesticides. It has nothing to do with sustainability. There is no evidence whatsoever that pesticide use as practiced today in forestry adversely affects forest sustainability. Ontario has already received acceptance of its pesticide programs under a class environmental assessment of forest management practices. The Forest Stewardship Council, through setting of standards for certification using a closed process, will be setting de facto policy for forest companies and forest management. The public is not represented at the table. Interest groups are. Government is not. It's a back door approach to determining what is an acceptable forest management practice. The Forest Stewardship Council operates internationally, by establishing local standards. Auditors then create checklists. For example, the draft standard for the Great Lakes St. Lawrence Forest states that herbicides should only be used for silviculturally challenging species such as red and white pine. This makes no sense from a silvicultural view. You don't use herbicide based on the species being regenerated, but on the site conditions, desired future forest condition, and competition levels from other plants. The draft auditor's checklist goes further. It basically says "use of herbicides, yes or no", with no being a failure. The FSC's principles also violate some long-held principles of forest insect management. It outright opposes the use of biological controls. This would make it impossible to release parasites to augment natural populations. The use of *B.t.* would be disallowed, and classical biological control for invasive species would not be permissible.

The whole concept of certification has implications for conflict between government and forest companies. When interventions must occur in the public interest, it may affect a company's certification. The FSC does not permit introductions of exotics. The fungus

Entomophaga maimaiga, which appears to have great potential for reducing gypsy moth impacts, could not be introduced. Likewise, where the Crown owns the land as is the case in Ontario, there are often competing users. For example, a conifer-based forest company with FSC certification may have undertaken responsibility for managing a forest unit. The aspen from the unit goes to other companies. If an insect problem threatens the aspen resource, the Crown may wish to conduct a spray program. Such a program may violate the FSC certification, but not conducting it could result in reduced wood supply for the other companies. The same holds true if the Crown needs to prevent spread of an insect problem from a certified forest to another area. Such are the hazards of accepting philosophical principles, such as "no use of pesticides" instead of science-based principles of managing sustainably.

Conclusion

The forest management landscape is continually changing, driven by new information, new issues, public pressure, and political decisions. Some of the changes are positive for forest health. New legislation such as the *Crown Forest Sustainability Act* has catapulted forest health to the primary objective of forest management policy. Climate change will recognize the need for reliable long-term forest health monitoring data.

Other changes are less than positive, such as certification efforts that ignore science, exclude the public in favour of interest groups, and hamper effective forest health management. The forest though, is amazingly resilient, repeatedly demonstrating its ability to recover from misdirected decisions. Forest managers and forest health specialists need to do likewise.

WORKSHOP 1.3

FUTURE OF DIRECT CONTROL IN WORKING FORESTS

MODERATOR:

A. Retnakaran, *Canadian Forest Service, Sault Ste. Marie, Ontario*

Moderator Summary: Control of forest insects in Canada has undergone profound changes during the last few decades and emphasis has shifted from the most economically efficient pest control strategy to control with minimal impact on non-target species. Progressively we have moved away from organochlorines, carbamates and organophosphates to biorationals, *B.t.* and baculoviruses. In this workshop we would like to highlight four methods of control and how they are being fine-tuned to increase efficiency without jeopardizing environmental acceptance.

Development of Tebufenozide (Mimic®), a Non-Steroidal Ecdysone Agonist, as a Pest Control Agent for Forest Insects

A. Retnakaran, B. Tomkins, M. Primavera, T. Ladd, Q. Feng, R. Palli and **B. Arif**

Canadian Forest Service, Sault Ste. Marie, Ontario

Tebufenozide (Mimic®) is an ecdysone agonist that acts at the molecular level in larvae and induces an incomplete, precocious molt that is lethal. Day 0 sixth instar larvae of the spruce budworm, *Choristoneura fumiferana*, upon ingestion, stop feeding and go into a precocious molt that is incomplete and stay frozen in this developmental state and eventually die. Similar to ecdysone, it binds to the receptor complex and transactivates the expression of a sequence of genes. After this event, however, this agonist persists and prevents further development. Its mode of action, lepidopteran specificity and a possible resistance mechanism will be described.

Blocking Juvenile Hormone Synthesis in Forest Insects: Exploring Novel Approaches to Pest Management

M. Cusson and **C. Béliveau,** *Canadian Forest Service, Sainte-Foy, Quebec*

The disruption of juvenile hormone (JH) functions in insects has long been viewed as a promising strategy for the development of environmentally safe, insect–specific pest control products. One of the conceptual approaches currently being explored involves the artificial lowering of JH levels in the target insect, using products that either promote its degradation or block its biosynthesis. This presentation will focus on the latter strategy as JH biosynthesis is the variable that most strongly impacts on JH titers. More specifically, our current work on the characterization of a JH biosynthetic enzyme that may be targeted for inhibition will be highlighted.

Bacillus thuringiensis Genes and their Application

J.L. Gringorten, K. van Frankenhuyzen and **A.S.D. Pang**
Canadian Forest Service, Sault Ste. Marie, Ontario

To date, more than 70 distinct δ-endotoxin genes from many strains of *Bacillus thuringiensis* (*B.t.*) have been isolated that code for insecticidal proteins (Crickmore 2000). These genes are on plasmids, rendering them readily transmissible among *B.t.* strains through conjugation and very amenable to genetic engineering and insertion into plants. In forestry, the use of transgenic trees is still experimental, and foliage protection relies mainly on aerial spraying of commercial *B.t.* products, particularly in regions where use of synthetic chemicals has been discontinued. There is a need to make these spray programs more cost effective, and at the same time, deal with the risk of resistance development in the target insect population. To achieve this, novel genes that code for proteins with high insecticidal activity must be sought. Both routine screening of natural *B.t.* strains and their cloned gene products and genetic manipulation to obtain mutants with increased activity and stability have produced very promising results. Cry9Ca endotoxin was found to be much more potent against spruce budworm (*Choristoneura fumiferana*) than the commercial *B.t.* strain presently in use (van Frankenhuyzen et al. 1997) and a Cry2A mutant showed strikingly higher potency against gypsy moth (*Lymantria dispar*) (unpublished). Experiments involving site–directed mutagenesis and domain–swapping between genes and determination of the tertiary structure of endotoxin proteins have yielded a wealth of information about *B.t.* mode of action and specificity regions (Schnepf et al. 1998). It has set the stage for developing an arsenal of bioengineered gene products with improved efficacy and selective specificity. The alternate use of different genes, or their combined use, is one means to reduce the risk of resistance development, but the effectiveness of this strategy is dependent on prior determination that the endotoxin proteins do not compete exclusively for the same receptors in the insect midgut.

Besides the genes that express δ-endotoxins, many *B.t.* strains contain genes that produce virulence factors that may contribute to insecticidal activity. These include proteases, chitinases, phospholipases, the vegetative insecticidal proteins (Vips) and β-exotoxins (ATP analogues). The potential of chitinases as synergists of endotoxin activity, either applied in combination with endotoxins or engineered as fusion proteins, is receiving increasing attention, but little research has been carried out on other hydrolytic enzymes. Finally, there is revived interest in engineering insect baculoviruses with a *B.t.* gene to increase their virulence while preserving their capacity to cause epizootics.

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Molecular Modifications of Baculoviruses for the Control of Forest Insect Pests

Q. Feng, R. Palli, T. Ladd, B. Arif and **A. Retnakaran**
Canadian Forest Service, Sault Ste. Marie, Ontario

Entomopathogenic viruses are attractive alternatives to chemical pesticides because they are host specific with little or no adverse effect on the environment. Various degrees of success have been achieved in the use of wild-type viruses in controlling forest insects but because of their slow action the pest insects often cause extensive defoliation before they die of the infection. We have developed techniques to produce recombinant baculoviruses that kill the insects faster. In this presentation we will report the construction and insecticidal activity of a recombinant baculovirus expressing *Choristoneura* hormone receptor 3 that was cloned from the spruce budworm.

WORKSHOP 1.4

BIOLOGICAL CONTROL IN PEST MANAGEMENT: NOVEL APPLICATIONS AND CONCERNS

MODERATORS:

D.C. Allen, *State University of New York, Syracuse, New York*
R.C. Reardon, *US Forest Service, Morgantown, West Virginia*
D. Dahlsten, *University of California, Berkeley, California*

Moderator Summary: Vincent Nealis indicated in his presentation that the Canadian Forest Service (CFS) has taken the historical lead in classical biological control of forest insects in Canada since the 1940s. Several successes, built on domestic research, international collaboration and scientific innovation, can be claimed. These successes, however, have not strengthened the CFS program nor assured its sustainability because of changing priorities and diminished resources needed to continue development of biological options. A major problem is organizational; forestry takes place on provincial crown lands and most research is accomplished in federal labs or at universities using federal funds. The focus on biological control has also been diminished by the formation of the Forest Pest Institute in 1976 and reorganization of the former Forest Insect and Disease Survey into Forest Health Units. Additionally, the CFS contract with CABI–Bioscience (formerly IIBC) in Delmont, Switzerland has ended, which makes it difficult to secure biological control material. Biological control is not a priority within CFS and successes have been due to the perseverance of individual scientists. The scientific community believes that biological control is best organized at the national level, because this field requires diverse knowledge, this approach to dealing with forest pests has potential for ecosystem level management (exotics invade ecosystems, not countries), and it is a regulatory issue that requires international cooperation.

The Eastern Hemlock is a valuable component of several forest and urban ecosystems in the eastern United States. However, Mark McClure said the invasive hemlock woolly adelgid, *Adelges tsugae* Annand, has caused significant hemlock mortality in many areas along the eastern seaboard. The adelgid is now distributed from Massachusetts south to northern North Carolina and as far west as south-central Pennsylvania and eastern West Virginia. Two predators were introduced from Japan, an orabatid mite, *Diapterobates humeralis* Hermann, which feeds on the waxy material surrounding the adelgid eggs causing dessication, and a coccinelid, *Pseudoscymnus tsugae* Sasaji and McClure. The latter has good predatory characteristics. It has become established at a number of sites in several states and to date over 500 000 individuals have been released in the United States.

Donald Dahlsten's presentation pointed out that classical biological control is the long-term answer for controlling exotic pests. Presently, neither the United States nor Canada train an adequate number of people for this discipline, both countries lack adequate capabilities in the area of insect taxonomy and neither country has sufficient rearing facilities. The introduction of potential forest pests is not going to stop and could very well increase substantially due to the expansion of world trade. There is a critical need for training to accommodate all stages of biological control research and application. Classical biological control in North America is at a crisis, and this situation will continue in the absence of adequate financial support.

Biological Control of Forest Insects by the Canadian Forest Service: Does Success Mean Sustainability?

V.G. Nealis, *Canadian Forest Service, Victoria, British Columbia*

The federal Canadian Forest Service (CFS) has taken the historical lead in classical biological control of forest insects in Canada since the 1940s. Several successes, built on domestic research, international collaboration, and scientific innovation, can be claimed. These successes, however, have not necessarily strengthened the CFS program as changing priorities and diminished resources create a gap in our ability to identify and respond to the need for continued development of biological control options.

Current Status of Biological Control Efforts Against Hemlock Woolly Adelgid (*Adelges tsugae* Annand)

M.S. McClure, *the Connecticut Agricultural Experiment Station, Windsor, Connecticut*

The hemlock woolly adelgid (HWA) (*Adelges tsugae*), is a harmless inhabitant of several hemlock (*Tsuga*) species in Asia. In the eastern United States, however, HWA kills eastern (*T. canadensis*) and Carolina (*T. caroliniana*) hemlock by sucking cell fluids from the young twigs and probably by injecting a toxic saliva during feeding. Populations of HWA on ornamental hemlocks can be controlled with chemical pesticides. In the forest, however, biological control offers the best hope.

In Japan, a coccinellid beetle (*Pseudoscymnus tsugae*) and an oribatid mite (*Diapterobates humeralis*) help control HWA. My research team in Connecticut determined that while the mite is a poor biological control candidate due to its inherent low fecundity, *P. tsugae* is an excellent candidate. *Pseudoscymnus tsugae* can be mass reared in controlled laboratory conditions on living adelgids, it can produce three or more generations each year, it strongly prefers to feed on HWA, its larvae and adults attack all adelgid life stages, its life cycle is synchronized perfectly with that of HWA, it has a high searching efficiency and dispersal ability, and it adapts to a wide range of climatic conditions.

Since 1995 my research team has released more than 160 000 adults of *P. tsugae* in Connecticut, New Jersey and Virginia to evaluate predator dispersal and impacts on HWA. Wherever *P. tsugae* performance could be evaluated, HWA densities were 47-87% less on release trees than on non-release ones after only 5 months.

In 1997, I donated a starter colony of *P. tsugae* to the Phillip Alampi Beneficial Insect Laboratory in New Jersey. Since then they have reared >500 000 beetles for release in 10 eastern states. *Pseudoscymnus tsugae* has established and overwintered successfully at release sites. However, mild winters between 1995 and 1999 favored HWA survival, and together with severe drought in 1999, significantly reduced hemlock health and hampered biological control efforts. January 2000 featured sub-zero (F) temperatures on several occasions in the north which killed more than 90% of HWA. This, together with a cool, rainy spring and summer in 2000, allowed hemlocks to recover and flourish, which may have enhanced the effectiveness of *P. tsugae* during 2000.

Three other coccinellids (*Scymnus sinuanodulus, S. camptodromus,* and *S. ningshanensis*) were imported from China for study in quarantine by Dr. Michael Montgomery's research team in Connecticut. A derodontid beetle (*Laricobius nigrinus*) commonly associated with HWA in western North America, has been imported to Virginia for study by Dr. Scott Salom's research team.

In just a few years we have made good progress in finding and studying potential biological control agents for HWA. *Pseudoscymnus tsugae* clearly possesses many important qualities of a successful biological control agent for HWA and results in the field have been encouraging. However, additional studies are needed to substantiate that P. tsugae will help control HWA and to justify the additional effort required to rear enough beetles for release throughout the HWA-infested area. Also, because several natural enemies working together may be needed to ultimately control HWA, further studies on known enemies and further exploration for others are also needed.

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WORKSHOP 1.5

DENDROCHRONOLOGY AND INSECT IMPACTS ON PRODUCTIVITY

MODERATOR:
R. Alfaro, *Canadian Forest Service, Victoria, British Columbia*

Moderator Summary: This workshop centered on the uses of dendrochronology in assessing ecological impacts of insects. Tree rings maintain a record of the disturbance history for a locality, and are therefore very useful as indicators of ecosystem function. Tree rings can help in establishing the baseline or reference level for past insect outbreak frequency and intensity. Comparing historic outbreak frequency and intensity with present patterns reveals if ecosystems are functioning at normal levels. A forest undergoing a regular disturbance regime is said to be in a healthy state.

Spatio-temporal Dynamics of Eastern Spruce Budworm Outbreaks and Its Impact on the Productivity of Black Spruce Forest

H. Morin and **Y. Jardon,** *Université du Québec à Chicoutimi, Chicoutimi, Québec*

Dendrochronology has been broadly used to study the chronology of many insect outbreaks. In this presentation, we want to focus on two contributions of dendrochronology to the study of eastern spruce budworm outbreaks, namely the dynamics of outbreaks in space and time, and the impact on the growth of the boreal black spruce forest. A network of new chronologies in the southern parts of Quebec and in the boreal black spruce forest shows that for a vast territory, outbreaks occur at a very regular interval. There is a remarkable shift between the 19th and the 20th century in the chronologies. In the 20th century, the impact in each stand was more important, the synchronism between the sites more evident, and the diffusion more rapid in a given stand and the entire territory. However, each outbreak presents its own diffusion pattern. Stem analysis of dominant trees from pure boreal black spruce stands revealed that from 3% to 37% of the potential volume was lost during the last budworm outbreak due to growth reduction caused by defoliation. Young stands were less affected but no other evident correlation could be found with the amount of reduction. These studies shed some new light on a better management of the boreal forest.

Periodicity of Two-Year Cycle Spruce Budworm Outbreaks in Central British Columbia: a Dendro-Ecological Analysis

R. Alfaro and **Q-B. Zhang,** *Canadian Forest Service, Victoria, British Columbia*

An outbreak of the 2-year cycle budworm (*Choristoneura biennis* Freeman) has caused defoliation damage to interior spruce (*Picea engelmannii* Parry ¥ P. glauca (Moench)) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests of north central British Columbia for more than 10 years, and was still continuing in 1999. A sample of 429 increment cores from spruce, subalpine fir and lodgepole pine (*Pinus contorta* var. latifolia Engelm.) was collected in areas of chronic defoliation, and used in a dendro–ecological study. The objective was to develop accurately dated ring-width chronologies of each species and, by comparing growth rates of the budworm host tree species (spruce and fir) with those of the nonhost pine, to determine the past history of budworm outbreaks in this region. This history would help in estimation of the potential duration and severity of the current outbreak in the region. Four periods of decade-long reduced growth attributable to budworm defoliation were identified in the increment cores. These occurred in the mid-1890s to the early 1900s, the mid-1920s to the mid-1930s, the 1950s to the early 1960s, and the late 1980s to 1999. Outbreaks recurred approximately every 32 years. The reduced growth period, indicative of past outbreaks, consisted of a growth reduction phase lasting 7 to 11 years in which rings generally exhibited a pattern of alternating wide and narrow rings (a saw-tooth pattern). This pattern was attributed to the biennial nature of the life cycle of this budworm, in which severe damage is caused every other year. The growth reduction phase was followed by a growth recovery phase lasting three to five years in which ring-width gradually returned to pre-outbreak levels. Thus, the entire growth loss period could last from 10 to 16 years, and cause an average annual loss in radial increment from 16%–21%. The 32-year cycle of outbreak recurrence was attributed to changes in forest structure in which the forest evolves from a non-susceptible to a susceptible state as the proportion of subalpine fir present in the upper canopy increases relative to the spruce component. A 2-year cycle budworm outbreak will selectively remove the subalpine fir component, returning the forest to a less susceptible state. It was concluded that the 2-year cycle budworm is an important disturbance agent of northern British Columbia forests causing significant growth loss.

A 250-Year Record of Spruce Bark Beetle Outbreak History on the Kenai Peninsula, Alaska

E. Berg, *Kenai National Wildlife Refuge, Soldotna, Alaska*

Spruce bark beetles have killed most of the mature white and Sitka/Lutz spruce on the Kenai Peninsula, thinning canopies and releasing growth in survivors. Tree-ring evidence of canopy thinning in 17 stands indicates regional bark beetle outbreaks occurred in the 1810s–1820s, 1870s–1880s, and 1970s. The outbreaks of the 1970s and 1990s are strongly associated with drought stress, as warmer summers have increased evapotranspiration and hence tree susceptibility to beetle infestation. We compare past outbreaks with reconstructed summer temperatures and find that at least two warm summers are required to initiate an outbreak.

White Tree-Rings in Trembling Aspen (*Populus tremuloides* Michx.) as an Indicator of Past Insect Defoliation

E.H. Hogg, *Canadian Forest Service, Edmonton, Alberta*

Recent studies of trembling aspen have shown that abnormally pale-colored (white) tree-rings were often produced during years when outbreaks of forest tent caterpillar (Malacosoma disstria Hübner) were recorded. These white tree-rings are characterized by low density due to an apparent thinning of cell walls in the xylem. In a recent study, white tree-rings were produced experimentally in young aspen following severe, artificial defoliation. It appears that white rings can provide a useful tool for reconstructing insect defoliation histories of individual aspen stems, but the technique requires further validation to determine the limits of its applicability over a wider range of conditions.

WORKSHOP 2.1

HAZARD AND RISK RATING SYSTEMS

MODERATORS:
L. Maclauchlan, *British Columbia Ministry of Forests, Kamloops, British Columbia*
T. Shore, *Canadian Forest Service, Victoria, British Columbia*

Moderator Summary: This workshop will explore various hazard and risk rating systems and their development, strengths, weaknesses and application. The development and evaluation of susceptibility (hazard) and risk rating systems for the mountain pine beetle in British Columbia, as well as current research towards developing a system for the Douglas-fir beetle, will be discussed. In comparison, the southern pine beetle hazard rating system in North Carolina will be reviewed. Hazard and risk rating systems, both in operation and being developed, will be discussed for three defoliator species: the Nantucket pine tip moth in the southern United States, the western hemlock looper, and the western spruce budworm in British Columbia.

Developing Hazard Rating Systems for the Mountain Pine Beetle and the Douglas-fir Beetle

T. Shore, *Canadian Forest Service, Victoria, British Columbia*

In recent years we have developed and evaluated susceptibility (hazard) and risk rating systems for the mountain pine beetle (Shore and Safranyik 1992; Shore et al. 2000). We have also conducted research towards developing a system for the Douglas-fir beetle (Shore et al. 1999). Discussion will focus on the differences between the two beetles in terms of tree and stand susceptibility as well as beetle attack behavior, and how this can be captured in hazard and risk rating systems for these two damaging insects.

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Hazard and Risk Assessment for the Nantucket Pine Tip Moth (*Rhyaciona frustrana* [Comstock]) in Intensively Managed Stands

C.W. Berisford, J.T. Nowak and **C. Asaro,** *University of Georgia, Athens, Georgia*

The Nantucket pine tip moth is the most common insect pest of loblolly pine (*Pinus taeda* L.) plantations in the southern United States. Tip moth larvae feed in terminal buds and growing shoots of seedlings and saplings and may cause growth reduction, loss of form and a decrease in wood quality. Damage is proportional to the populations within the shoots and attacks by 5–10 larvae may kill up to 25 cm of a shoot. Depending on location, the moth may have from two to five generations annually. The tip moth has become more important as management intensity (and therefore cost) has increased. In some cases it appears that intensive management exacerbates tip moth damage and larger trees are more frequently attacked. Additionally, intensive management may increase the instability of populations, resulting in increased amplitude of normal population fluctuations and "boom or bust" cycles not previously documented in stands with less intensive management.

Some areas traditionally suffer more consistent and severe damage than others, and it therefore seems logical to develop hazard rating systems to identify sites where heavy damage is likely to occur. Although factors associated with high hazard sites have been identified for some areas (Hood et al. 1988; White et al. 1984), site factors which are consistently associated with high populations have not been identified for much of the southern pine region. Results from attempts to develop hazard rating criteria based on stand characteristics, soil chemistry and soil physical properties for intensively managed stands in the Georgia coastal plain have not been promising.

Until hazard rating techniques are developed, it appears that there may be a good chance for estimating immediate risk in lieu of hazard for individual plantations by using pheromone traps. Preliminary data show that there is strong correlation among trap catches of males, adult population estimates and subsequent damage (percentage of infested shoots). Improvements in the interpretation of pheromone trap catches by standardizing traps and lures plus adjusting for decreased male longevity (and therefore lower catches) in hot weather provide more realistic population estimates. Estimates of risk can be made prior to optimum dates for chemical control (Fettig et al. 2000) within a generation, which will permit control efforts to be concentrated on those stands likely to suffer the most damage.

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Hazard Rating and Outbreak Prediction of *Lambdina fiscellaria lugubrosa* in British Columbia

N. Borecky and **I.S. Otvos,** *Pacific Forestry Centre, Victoria, British Columbia*

The western hemlock looper, (*Lambdina fiscellaria lugubrosa*), is a serious defoliating pest in western North America. In British Columbia, there have been 14 distinct outbreaks, increasing in duration and severity over the past 87 years. Outbreaks tend to occur in coastal And interior western hemlock biogeoclimatic zones and generally last from one to five years. During the 1990–1995 outbreak, this pest was responsible for approximately 63 000 ha of tree stand mortality in the Province. Early monitoring suggests that another outbreak may be imminent.

This project entails two components of prediction: 1) spatial susceptibility or hazard rating, and 2) forecasting outbreak timing. The hazard rating system being developed uses Geographic Information System (GIS) analysis of forest cover information to model stand conditions which have historically been susceptible to outbreaks of western hemlock looper. Logistical regression techniques are employed to produce a model probability surface explaining the likelihood of an area to be attacked based upon age and proportional stand composition of western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*). Forest stand data is derived from the Province of British Columbia's Forest Information and Planning database, combined with FC-1 (digital forest cover). Sampling measures take into account spatial autocorrelation and multicollinearity amongst variables of interest, in addition to compensating for the original defoliation aerial survey's estimated ground error. Stands with higher proportions of cedar and western hemlock are more likely to harbor the loci of defoliation events. In addition, stands generally over 120 years of age are considered high hazard areas with regards to the initiation of looper outbreaks.

At present, an analysis of pheromone trap counts and weather variation is being examined to produce an accurate method of forecasting the timing of impending outbreaks. It is anticipated that variation from long-term weather trends may provide a proxy indication of population trends. The use of counts of larval density preceding and during outbreaks will also be explored.

Results of both hazard rating and outbreak predictions are expected to aid forest managers in dealing with outbreaks of western hemlock looper in an effective manner through direct control measures, alternate harvest/conservation planning, or modified silvicultural practices.

Building a Hazard Rating System for Western Spruce Budworm

L. Maclauchlan, *British Columbia Ministry of Forests, Kamloops, British Columbia*

Western spruce budworm (*Choristoneura occidentalis*) periodically reaches outbreak proportions in British Columbia, causing varying degrees of damage to trees and stands. Within the Kamloops Forest Region, budworm is a particular problem and forest managers needed a tool to better manage susceptible Douglas-fir stands.

Key elements in a hazard rating for western spruce budworm include: the historic occurrence of budworm; biogeoclimatic zones impacted most frequently and severely; range and location of susceptible stands (species, age, density, structure); and, population dynamics of the insect. The final product will give managers an idea of the potential impact that budworm may have in stands of specific density and stand structure, and what the differences in outbreak duration will mean in terms of tree and stand impacts.

Analysis of almost 100 years of historical incidence data revealed that 57% of recorded budworm activity occurred within the Interior Douglas-fir (IDF), 32% within the Interior cedar-hemlock (ICH) and minor amounts within other ecosystems. However, the duration of outbreaks, in terms of consecutive years of defoliation, was much shorter in the ICH, averaging only one-two years. Within the IDF, outbreaks lasted longer, particularly in the driest and hottest subzones of this ecosystem (IDFxh). Of the total area affected by budworm in the past 100 years, 94.3% (1.4 million ha) received one to three consecutive years of defoliation, 5.5% (83 187 ha) received 4–6 consecutive years of defoliation, and less than 1% received over seven consecutive years of defoliation.

Due to past management practices, stand structure was extremely variable across the range of budworm activity. Four stand types were described and impacts quantified in each. Within each of the four stand types, trees were divided into four layers. Layer one included dominant, overstory trees, layer two included sub- or co-dominant trees, layer three included suppressed or intermediate trees, and layer 4 was made up of two age classes of small understory trees. In all stand types, layer three incurred the highest mortality and topkill.

This type of analysis will present possibilities for future management of these forest types.

WORKSHOP 2.2

PROFESSIONAL ETHICS: FOREST ENTOMOLOGY AND BEYOND

MODERATORS:
B. Strom, *US Forest Service, Pineville, Louisiana*
L.K. Rieske-Kinney, *University of Kentucky, Lexington, Kentucky*

Public-Private Partnerships: Conflict of Interest, Conflict of Conscience, or Symbiosis

L.K. Rieske-Kinney, *University of Kentucky, Lexington, Kentucky*
B. Strom, *US Forest Service, Pineville, Louisiana*
R. Harrison, *University of Alberta, Edmonton, Alberta*
K.M. Clancy, *US Forest Service, Flagstaff, Arizona*
J.R. Spence and **J. Welchman,** *University of Alberta, Edmonton, Alberta*

Joint efforts among government, university and private enterprises are common in natural resources fields. Public-private partnerships are a natural response to declining public resources and for addressing the administrative and marketing concerns for products designed for environmental management. While increasing emphasis has been placed on the development of cooperative ventures, comparatively little has been done to educate individuals about the ethical dimensions of such ventures.

United States legislation emphasizing the development of public-private partnerships has successfully accelerated transfer of scientific discoveries into the marketplace, and allowed for the establishment of cooperative research agreements between public and private entities. Consequences of this success include the entanglement of university research with private industry and a blurring of boundaries between academic and corporate interests. Scientific tradition calls for openness and free exchange of ideas; proprietary interests often call for restricted access to research information and products. Pressures that arise may include conflicts of interest, effort, and conscience. Any or all of these can reduce the quality of research and delay or prohibit their publication.

Most research universities have an industry liaison office that facilitates technology transfer by helping establish and monitor industry/university partnerships. These offices offer expertise in forming partnerships to develop research products for the marketplace, while ensuring that public interests are protected. Such partnerships may take the form of grants, contracts, joint ventures, etc. Ethical responsibilities of the Industry Liaison Office include managing conflicts of interest and ownership and use of intellectual property. Balancing a university's need for private funding and expertise with the obligation to best serve public interests is critical to the success of joint ventures.

Research administrators and journal editors can promote ethical behavior of professional scientists. Public agencies and professional societies have Codes of Ethics and/or Conduct that stress reporting research results openly, honestly, with full recognition to contributors, and with full disclosure of any potential conflicts of interest. Administrators should be cognizant of these and establish enforceable policies that reflect ethical considerations. Editors are the gatekeepers of scientific information exchange, and may effect ethical decision-making through proactive use of their status.

Despite the challenges, public-private partnerships often succeed in producing fruitful projects that would be impossible without the partnership. A large scale, long-term research study that examines ecological responses to forest management in Alberta has successfully incorporated industry, government, and university concerns into a common project. Careful interactive planning that identifies common objectives while maintaining an open and honest dialogue among participants has been the key to the project's success.

In forming public-private partnerships, it is imperative to recognize that each member has his or her own background, viewpoint, and goals that may form a unique set of acceptable ethical behaviors and expected outcomes. Recognizing these differences and maintaining open lines of communication throughout the process are essential steps in minimizing conflicts and maximizing the benefits of public-private partnerships.

Development of Environmental Research Collaborations with Industry: an Ounce of Prevention is Worth a Pound of Cure

J.R. Spence, *University of Alberta, Edmonton, Alberta*
W.J.A. Volney, *Canadian Forest Service, Edmonton, Alberta*

We review the development of the EMEND project (Ecosystem Management by Emulating Natural Disturbance), a large-scale wildfire versus harvest comparison located in Northwestern Alberta. Key to the success of this project has been the active involvement of industrial foresters from the start. We used formal structures to ensure that they had formative input into the development of the science behind EMEND. In such an environment, scientists can achieve their research goals while at the same time facilitate a very clear understanding of what research can and cannot do to meet the challenges faced by industry. Communication reduces potential conflict that can result from insufficient understanding of mutual goals.

WORKSHOP 2.3

LINKING RESEARCH ON BIOLOGICAL PROCESSES TO POPULATION DYNAMIC STUDIES

MODERATORS:
J. Régnière, *Canadian Forest Service, Sainte-Foy, Quebec*
V.G. Nealis, *Canadian Forest Service, Victoria, British Columbia*

Moderator Summary: Many entomologists are involved in large-scale, long-term experiments or observations of forest insect ecology or population dynamics. These workers measure basic biological quantities like population density, survival, reproduction, and movement, and attempt to relate variations in these basic measurements to their causes: environmental factors, natural enemies, or host plants interactions. Other entomologists are involved in the examination of specific processes, often in hypothesis-testing or modeling frameworks where detail is of the essence. Then, they attempt to infer the consequences of their findings on the overall ecology or population dynamics of the creatures studied. There is a gap here: long-term series of observations that can be very vague as to the exact workings of the interactions identified as probable causes, and details on specific interactions are often isolated from their general system-wide context and are difficult to put into an overall perspective. What methods are available to us to bridge this gap? One approach is to develop more accurate methods of analyzing and teasing out the finer details from the results of our large-scale/long-term population-level observations. Another approach is to place results of process-specific experiments in their broader context through some form of modeling. This workshop consisted of a collection of papers outlining individuals efforts at bridging this gap with one or the other of these approaches.

Measurement and Interpretation of Mortality Factors in Insect Survivorship Studies

T. Royama, *Canadian Forest Service, Fredericton, New Brunswick*

I have developed a practical method to evaluate insect survivorship and the effects of major factors that determine it, with a view to providing solutions to certain problems in survivorship studies. The mortality rate due to either parasitism or disease (including those hosts that are parasitized as well as diseased) is evaluated by frequent sampling in the field and rearing each batch of samples in the laboratory for a short period of time. Comparing this rate with the field mortality rate, directly evaluated by sampling, determines the mortality rate other than parasitism and disease, e.g., predation.

Mortality and Natality in Collapsing Spruce Budworm Outbreaks: Results of Long-Term Survivorship Studies in Ontario And Quebec

J. Régnière, *Canadian Forest Service, Sainte-Foy, Quebec*
V.G. Nealis, *Canadian Forest Service, Victoria, British Columbia*

The results of a long-term study (1983–1998) of spruce budworm population dynamics during the outbreak decline phase (in Ontario and Quebec) are being analyzed. The patterns of variation of mortality and natality in these collapsing outbreaks reveal the major mechanisms involved. A new method developed by T. Royama is also quite useful in separating the contributions of parasitoids, diseases and predators to overall survival. Our study contrasts the early decline of three outbreak populations from causes other than stand death, with the decline of a population in a stand where tree mortality reached very high levels.

Modeling a Density-Dependent Ecological Relationship between Jack Pine Budworm, *Choristoneura pinus*, and Its Host Tree

V.G. Nealis, *Canadian Forest Service, Victoria, British Columbia*
S. Magnusen, *Canadian Forest Service, Victoria, British Columbia*

Conifer-feeding budworms in the genus *Choristoneura* form intimate ecological relationships with their host trees. The influence of this trophic interaction on population dynamics of the budworm can be elucidated through process-oriented modeling. The jack pine budworm, *C. pinus*, shares many life history and ecological characteristics with the related eastern spruce budworm, *C. fumiferana*. Unlike the extensive and persistent outbreaks of the spruce budworm, however, outbreaks of the jack pine budworm tend to be spatially patchy and relatively short-lived. Our model focuses on the ecological relationship between the insect and its host plant to understand the possible mechanisms behind these differences in population patterns. A combined experimental and survey approach to population ecology of the jack pine budworm first quantified the relationship between local larval survival and the abundance of pollen cones on the host tree. Newly emerged budworms disperse in the spring to locate feeding sites. During most of this dispersal period, neither developing vegetative shoots or previous-year needles are available as food sources. Only pollen cones can be exploited. Consequently, losses to the jack pine budworm population and associated rates of change in population density are a direct function of the abundance of pollen cones in the stand. To quantify the reciprocal effect of budworm density on the local abundance of pollen cones, a 7-year time series of observations of defoliation levels and frequency trees producing pollen cones was obtained from a network of 180 permanent sample plots in Ontario, Canada. A subset of these plots was defoliated by jack pine budworm between 1992 and 1996. Our analysis involved developing an index of a tree's propensity to produce pollen cones in any year given its location, age, and previous history of pollen cone production. This propensity was compared for defoliated and undefoliated plots and showed that severe defoliation by the jack pine budworm reduced the propensity of the tree to produce pollen cones in the subsequent year. This reciprocal density-dependent relationship between budworm density and pollen cone density forms the basis for a process-oriented population dynamic model of the jack pine budworm.

Population Dynamics of Browntail Moth in North America

J.S. Elkinton, D. Parry and **G. Boettner,** *University of Massachusetts, Amherst, Massachusetts*

The browntail moth *Euproctis chrysorrhoea*, was introduced to North America near Boston from Europe in 1897. It became an important defoliator of many tree species throughout New England and was also a human health hazard due to severe skin rashes caused by urticating hairs from the larvae. Beginning around 1915, however, browntail populations receded gradually to coastal enclaves at the tip of Cape Cod and to islands in Casco Bay in Maine, where high densities have persisted ever since. Until now no studies have explained why it declined and why it persists in coastal enclaves. We present evidence that the cause of the decline was the generalist tachinid parasitoid *Compsilura concinnata*, which was introduced to North America in 1906 to control gypsy moths. Analysis of historical data revealed high levels of parasitism of browntail moth by this species, but low levels in coastal areas. We confirm this pattern experimentally by creating artificial browntail populations at both inland and coastal locations on Cape Cod.

Modeling the Impacts of Temperature on the Population Dynamics of the Mountain Pine Beetle

B.J. Bentz and **J.A. Logan,** *US Forest Service, Logan, Utah*
J.A. Powell and **E. Hanks,** *Utah State University, Logan, Utah*

Synchrony is an important aspect of many insect life histories. For the mountain pine beetle, appropriately timed and synchronous emergence are both required for successful reproduction. Although many insect species use diapause to maintain synchrony, nondiapausing species such as the mountain pine beetle are under direct temperature control wherein the interaction between developmental rate parameters and seasonal temperature regimes appear to maintain an adaptive seasonality. Model simulations provide an avenue to predict regions of stable voltinism, based on annual temperature regimes, and hence successful temperature-based population dynamics.

WORKSHOP 2.4

RESTORATION ECOLOGY: INCORPORATING INSECTS

MODERATORS:
D.L. Six, *University of Montana, Missoula, Montana*
K.M. Baker, *University of California, Berkeley, California*

Considering Insect Responses and Biodiversity in Forest Restoration Efforts

D.L. Six, *University of Montana, Missoula, Montana*

As many North American forest ecosystems become degraded through poor management practices, altered natural disturbance regimes, and invasion by exotics, there is an increasing interest in restoration. Insects and other arthropods can be important considerations in restoration efforts. Many restoration treatments decrease populations of insects that have the potential to cause economic damage; however, they also may affect insect populations in a manner contrary to restoration objectives. Additionally, due to their diverse roles in forested ecosystems and sensitivity to change, insects and other arthropods may provide useful metrics for assessing the efficacy and effects of restoration treatments.

Ponderosa Pine Restoration Ecology: Paradigm Shift or Uneven-Aged Management Repackaged?

M.R. Wagner, *Northern Arizona University, Flagstaff, Arizona*

Restoration ecology is a developing discipline within the field of ecology. As with any new discipline, restoration ecology has evolved over the past decade. Restoration ecology as applied to ponderosa pine forests in the Southwest is a well-established approach to forest management. In this paper I describe ponderosa pine restoration concepts and practices. Limitations associated with attempting to recreate forest conditions that existed during pre-European settlement are outlined. Finally, I discuss the need to compare restoration ecology with other forest management options such as uneven-aged management before widespread adoption of this new approach to ecosystem management.

Forest Soil Microarthropod Responses to Precribed Fire and Stand Structure Alteration in California's Southern Cascade Range

M.A. Camann, K.L. Lamoncha and **N. Plant,** *Humboldt State University, Arcata, California*
N. Rappaport, *US Forest Service, Berkeley, California*

Prescribed fire is an important tool for forest management. Little is known, however, about its effects upon forest soil and litter microarthropods, including the Collembola and the acarine Oribatei. Oribatid mites frequently dominate forest soil fauna, and both collembolans and oribatids perform important functions in soil ecosystems, particularly detritus fragmentation, microbial assemblage regulation, and organic nutrient mobilization. Despite their importance in soil ecosystems, microarthropod assemblages in montane forest soils of the western US are poorly studied. Little is known about their assemblage organization, responses to prescribed fire and other forest management prescriptions, and resilience to disturbance.

We studied responses of forest soil Collembola and Acari, particularly oribatid mites, to prescribed fire in eastside ponderosa pine forests of the southern Cascade range. We compared microarthropod population and assemblage organization responses to prescribed fire in undisturbed forest stands (Research Natural Areas), in stands that had been selectively logged to retain old growth structural characteristics, and in stands logged to minimize old growth structure. Low intensity prescribed fire was applied during autumn of the year following timber removal, and microarthropod sampling began in spring of the following year (1998).

Prescribed fire altered habitat characteristics of forest soil and litter. Litter thickness was significantly reduced in the burned split plots, but litter consumption explained less than 10% of the variation in microarthropod abundance and less than 19% of the population decline of any individual oribatid population. Variation in Collembolan species richness was significantly correlated with litter thickness reduction, however. Most microarthropod populations declined following prescribed fire. Oribatei losses accounted for two-thirds of the acarine decline. Individual collembola and oribatid species responded differently to prescribed fire, with a few populations increasing in the burned split plots but most declining. Low intensity fire significantly altered microarthropod assemblage organization, reducing species richness and diversity, modifying dominance relationships, and altering community composition profiles. Several oribatid species were apparent indicators of fire effects upon forest soil fauna.

Our results also suggested that microarthropod responses to prescribed fire were intensified by stand alteration and especially by removal of old growth structural character. Decline in microarthropod abundance, species richness and diversity, and loss of equilibrium dominance relationships was greatest in the low structural diversity plots.

Prioritizing Restoration in Forests Adversely Affected by an Exotic Pest

K.M. Baker and **K.L. O'Hara,** *University of California, Berkeley, California*

Exotic forest pests have resulted in severe decline of many forest ecosystems of North America in the past 100 years. The arrival and establishment of new forest pests appears inevitable given our highly mobile society; thus, many previous efforts in control of pest populations and damage reduction have targeted the spread phase of the pest, when it is increasing in population size and expanding into new territory.

We plan to utilize individual tree and whole-stand vigor, as well as stand characteristics, such as species composition and vertical stratification of the trees, to predict the influence of exotic pests on the tree component of forest ecosystems. By using stand reconstruction techniques, the pest arrival time into the ecosystem can be estimated, and the resulting changes through time can be compared to similar stands that are yet to be invaded by the pest. Individual tree species response, including non-host species, both to the pest and to anticipated restoration treatments, can then be predicted. Other predictions that can be made include changes in species composition and stand structure.

The results will lead to restoration guidelines, which will include silvicultural strategies for preventing pest arrival and reducing the post-arrival influence of the pest. Furthermore, stands can be prioritized for restoration based upon rate of change and stand response. Rate of change can be viewed either on an individual tree basis (such as how fast individual tree mortality occurs from the pest and the effect of the pest on the seed and cone crop) or at the stand level (such as how quickly the pest is moving through the stand, and how long it will be until the host species disappears from the stand). Stands experiencing faster rates of changes would receive higher priority for restoration treatments. Prediction of stand response to treatment will be based on both the stand reconstruction and tree vigor estimates, with higher priority allocated to stands predicted to have a shorter response time. This approach will integrate stand dynamics and exotic pest biology to yield applications for restoration of affected ecosystems.

WORKSHOP 2.5

CONE AND SEED INSECT RESEARCH IN NORTH AMERICA: NEVER HAS SO MUCH BEEN OWED BY SO MANY TO SO FEW

MODERATORS:
P. de Groot, *Canadian Forest Service, Sault Ste. Marie, Ontario*
N. Rappaport, *US Forest Service, Berkeley, California*

Moderator Summary: This workshop consisted of seven presentations on current studies in North America on cone and seed insects. The first three papers provided general overviews for the United States, Mexico and Canada, followed by four papers describing specific research projects.

Nancy Rappaport and Jack Stein indicated that current research in the USA is focused on the two most damaging pests of pine, *Dioryctria* and *Conophthorus*. Research into the control of these pests using semiochemicals and biological control agents is still underway, but at much-reduced levels. Both genera present taxonomic difficulties that impair the ability of resource managers to implement semiochemical-based control programs, so current research is focused on the development of semiochemicals coupled with molecular techniques for prediction of pheromone response.

Jorge Macías-Sámano noted that the most active cone and seed insect research programs are based at the Universidad Michoacana de San Nicolas Hidalgo, Morelia, Michoacan (Adolfo Arturo del Rio Mora) and Universidad Autonoma, Chapingo, Estado de Mexico, Mexico. Both programs are focused on development of semiochemicals for the control of cone beetles in Mexican pines. Several behaviorally active chemicals have been identified, including 4-allylanisole and 2-hexenol. The first female-active semiochemical for cone beetles was recently identified in work by del Rio Mora.

Ward Strong described the main areas of research in Canada, which include: soil dispersal and entomopathic nematode attack of *Strobilomyia neanthracina*; physiology of gall initiation by *Adelges cooleyi*; cone beetle semiochemical cues and management; systemic insecticide orchard soil drenches; mating disruption of *Synanthedon* and *Eucosma*; pheromone trapping and attract-and-kill control of *Contarinia oregonensis*; trapping, damage assessment, and bionomics of *Leptoglossus occidentalis*; environmental monitoring for prediction of spruce cone rust; and spray trials for pine diseases. Jean J. Turgeon, Marc Kenis, and Eckehard G. Brockerhoff presented an analysis of the parasite community attacking cone and seed insects of world conifers. Their analysis was based on the potential influence of the trophic relationships of the host insects as they might structure the parasite community that they support. Some patterns emerged from the analysis, but the analysis was limited by the number and extent of existing studies in the literature.

Anthony Cognato provided a phylogenetic reconstruction of the genus *Conophthorus*, based on both mitochondrial and nuclear DNA sequences, and suggested that speciation in the genus is not driven by host race formation. Instead, speciation in the genus appears to follow a geographic pattern, with ancestral forms originating in Mexico and the southwestern United States. Donald Grosman, William W. Upton, Frank A. McCook and Ronald F. Billings presented the results from their research on control of cone and seed insects with systemic injections. A high-pressure injection system was used to deliver emamectin benzoate and thiomethoxam to loblolly pine cone crops. The technique was successful in controlling damage by cone worms (*Dioryctria amatella*) and seed bugs (*Leptoglossus corculus* and *Tetyra bipunctata*).

Jon Sweeney, Blair Helson, and Garvice Gesner noted that stem and foliar applications of neem failed to control cone and seed insect damage in a spruce seed orchard.

Cone and Seed Insect Research in the United States and Mexico

N. Rappaport and **J. Stein,** *US Forest Service, Berkeley, California*

Current cone and seed insect research in the USA and Mexico is focused largely on the two most damaging genera, *Dioryctria* and *Conophthorus*. Both of these genera are taxonomically refractory, and efforts are underway to elucidate the genetic relationships among populations in different geographic regions and in different hosts. Because neither host association nor morphological characters can reliably predict semiochemical response among many of these taxa, there is a concomitant effort to link pheromone response to genotype so that semiochemical monitoring and control programs can be implemented. New semiochemical delivery systems are under development. In addition to the semiochemical control approach, research is underway to develop biological control (insect pathogens) and insecticidal methods of control for cone and seed insects. New delivery systems appear far more promising for good translocation of insecticides to cone and seed tissues, with resulting better control of cone and seed insect pests.

Cone and Seed Pest Research in Canada

W. Strong, *British Columbia Ministry of Forests, Vernon, British Columbia*

Cone and seed pest research in Canada is carried out by several groups across the nation. This presentation will provide an overview of the main areas of research in Canada, which include: soil dispersal and entomopathic nematode attack of *Strobilomyia neanthracina*; physiology of gall initiation by *Adelges cooleyi*; cone beetle semiochemical cues and management; systemic insecticide orchard soil drenches; mating disruption of *Synanthedon* and *Eucosma*; pheromone trapping and attract-and-kill control of *Contarinia oregonensis*; trapping, damage assessment, and bionomics of *Leptoglossus occidentalis*; environmental monitoring for prediction of spruce cone rust; and spray trials for pine diseases.

Development of Molecular Methods for Predicting Cone Insect Response to Pheromones

A.I. Cognato, *A&M University, College Station, Texas*

Taxonomic uncertainties among *Conophthorus* species limit the ability to develop and implement behavioral chemicals to monitor and control these beetles in integrated pest management programs. Many species are indistinguishable on the basis of morphology. Hence, taxonomists and pest control researchers have been forced to rely on surrogates such as host association and cuticular hydrocarbons to distinguish species. However, preliminary evidence from molecular data does not support the use of these surrogates for making taxonomic determinations. The nominal species *Conophthorus ponderosae* infests thirteen *Pinus* species, but evidence from mitochrondrial DNA sequence clearly suggests that the *C. ponderosae* group is not monophyletic and relationships among individuals may instead correspond to semiochemical phenotypes or geographic proximity. Thus, phylogenetic reconstruction of DNA sequence markers will be used to identify cone beetle taxa. This method will aid the prediction of beetle response to semiochemicals, so that semiochemical-based control strategies can be effectively implemented.

Control of Cone and Seed Insects with Systemic Injections in a Southern Pine Seed Orchard

D.M. Grosman, W.W. Upton, F.A. McCook and **R.F. Billings**
Texas Forest Service, Lufkin, Texas

Three systemic insecticide treatments, emamectin benzoate alone, imidacloprid alone, and a combination of emamectin benzoate and thiamethoxam, were injected one or two times into loblolly pine, *Pinus taeda* L., during a 2-year period in a seed orchard in east Texas. Single injections of treatments containing emamectin benzoate reduced coneworm (*Dioryctria* spp.) damage by 94%–97% during the study period. A second injection after one year did not improve protection. Imidacloprid also significantly reduced coneworm damage in 1999 but not in 2000. Significant reductions in damage from pine seed bugs (*Tetyra bipunctata* and *Leptoglossus corculus*) and an increase in the number of full seeds per cone resulted from imidacloprid and thiamethoxam treatments and to a lesser extent from emamectin benzoate. Yearly injections of imidacloprid or thiamethoxam were required to maintain protection against seed bugs. The best treatment, a single injection of emamectin benzoate plus thiamethoxam, reduced cone and seed losses from insects by 72%.

Stem Injection and Foliar Application of Neem for Control of Seed and Cone Insects in Spruce

J. Sweeney, *Canadian Forest Service, Fredericton, New Brunswick*
B. Helson, *Canadian Forest Service, Sault Ste. Marie, Ontario*
G. Gesner, *Canadian Forest Service, Fredericton, New Brunswick*

Neem seed kernel extracts containing azadirachtin were applied to white spruce using the systemic tree injection tube (STIT) system in 1998 (Fortune AZA 3% EC) and by hydraulic foliar spray in 2000 (Neemix - 4.5% azadiractin at rates of 250 and 500 ppm), either prior to reproductive budburst or when cones were half pendant. Neem extract was also applied to black spruce by stem injection in 1999 (AmVac formulation at 0.8 g/kg tree biomass) when cones were half pendant. No treatment increased seed yields or reduced damage by cone maggots and seed chalcids compared to untreated controls.

Development of Pheromones for Control of Cone Beetles in Mexican Pines

A.A. del Rio Mora, *Universidad Michoacana de San Nicolas de Hidalgo, Michoacan, México*

Various potential interruptants and synergists for pityol were field tested for efficacy in managing *Conophthorus* spp. infesting Mexican pines. Host and beetle combinations included *Conophthorus conicolens* on *Pinus pseudostrobus*, *C. edulis* on *P. cembroides*, *C. michoacanae* on *P. michoacana*, and *C. tecotum* in *P. teocote.* Behavioral chemicals tested included trans-pityol, conophthorin, verbenone, 4-allylanisole, 2-hexenol, and alpha-pinene. Conophthorin served as an effective interruptant for *C. conicolens* on *P. pseudostrobus* and *C. teocotum* on *P. teocote*, while 4-allylanisole served, in general, as a synergist for attraction of male beetles by pityol.

Cone and Seed Insects of World Conifers: Patterns in Species Richness of Parasitoids

J.J. Turgeon, *Canadian Forest Service, Sault Ste. Marie, Ontario*
M. Kenis, *CABI Bioscience Centre, Delemont, Switzerland*
E.G. Brockerhoff, *University of Canterbury, Christchurch, New Zealand*

An updated world list of cone and seed insect parasitoids was generated and used to examine the possible influences of ecological and taxonomic variables of the specialised phytophagous fauna exploiting coniferous seed cones on parasitoid species richness. The seven variables considered were: pattern of habitat exploitation (conophages versus conospermatophages and spermatophages), life cycle (endoconophytics versus exoconophytics), capability of prolonged diapause, cone insect order, cone insect host plant genus (pine versus spruce and fir), and cone insect host specialisation (mono-, oligo-, and polyphagous). The patterns in host-parasitoid interactions observed will be discussed.

WORKSHOP 3.1

HIGH ELEVATION FOREST INSECTS AND THEIR MANAGEMENT

MODERATORS:
J. Wilson, *US Forest Service, Coeur d'Alene, Idaho*
J. Villa-Castillo, *INIFAP, Campo Experimental Clavellinas, Cuidad Guzman, Jalisco State, México*

Moderator Summary: High elevation forests and their associated forest insects can present some interesting management challenges. These forests are often highly prized for their scenic beauty and wildlife values. In many cases the forest species found at these sites are geographically isolated particularly in the west, which means that when an insect outbreak affects habitat for a critical species, management options may be limited. Access can be limited for many sites, providing for many logistical challenges. Forest insects themselves have not been extensively studied at high elevations and in some cases, life cycles can be somewhat different than in lower elevation habitats. In this workshop four presenters discussed selected topics that ranged in area from Mexico to the Northern Rockies in the United States.

Whitebark Pine Forest Health Concerns and Management in the Selkirk Mountains of Northern Idaho

S.J. Kegley, *US Forest Service, Coeur d'Alene, Idaho*

Whitebark pine (*Pinus albicaulis* Engelm.), one of a few tree species that grows in the subalpine community, plays a key role in the survival and distribution of wildlife species, is important for watershed stabilization, and to recreation and esthesis. This important species is rapidly declining through much of the west due to white pine blister rust (*Cronartium ribicola* Fisch.), fire suppression and forest successional processes, and periodic outbreaks of mountain pine beetle (*Dendroctonus ponderosae* Hopkins).

In the Selkirk Mountains of northern Idaho, mountain pine beetle is currently threatening removal of the seed source and other resource values in whitebark pine forests severely impacted by blister rust. Management in these ecosystems is difficult due to limited access, esthetic values, and recreational demands. Prescribed burning and the testing of new tree protectants are planned management activities.

Bark Beetle Management on High Elevation Forest Ecosystems of Mexico and Its Importance in Understanding Short- and Long-Term Dynamics

R. Gutierrez-Rodriguez and **J. Bocanegra-Gallegos**
SEMARNAT, Delegación Jalisco, Guadalajara, Jalisco State, México
J. Villa-Castillo, *INIFAP, Campo Experimental Clavellinas, Ciudad Guzman, Jalisco State, México*

In some high elevation forest ecosystems of central Mexico, tree mortality occurs in remote and rough areas where native bark beetle species perform what is seen to be a natural process strongly associated with stand dynamics. While any sudden increase in tree mortality is attributed to bark beetle population outbreaks in the short term, changes in mortality patterns on stand composition and structure in somewhat pristine forest ecosystems could tell us a lot about long-term dynamics; in particular, the influence of fire, abnormal wet and drought periods, or climate change would be of interest.

Spruce Aphid in the Southwest

A.M. Lynch and **B. Fitzgibbon,** *US Forest Service, Flagstaff, Arizona*

The exotic spruce aphid, *Elatobium abietinum*, is causing heavy defoliation leading to mortality of spruce in both the spruce/fir and mixed conifer types in the southwest. Populations were limited to the White Mountains of Arizona and the city of Santa Fe, New Mexico in the late 1980s. Since 1995, damaging populations have been found in the Pinaleos, San Francisco Peaks, the White Mountains of Arizona, and the Sacramento and Mogollon Mountains in New Mexico. The outbreak in the Pinaleos went from about 15 acres in December of 1999 to the entire host type in the mountain range by the spring of 2000, with moderate to severe defoliation over two-thirds of the type. The population of the endangered Mt. Graham Red Squirrel will be impacted if severe mortality follows this and future outbreaks in the Pinaleos. Management options are being considered.

WORKSHOP 3.2

AERIAL SURVEYS—20TH CENTURY METHODS IN THE 21ST CENTURY

MODERATORS:
T. McConnell, *US Forest Service, Missoula, Montana*
G.M. Howse, *Canadian Forest Service, Sault Ste. Marie, Ontario*

Accuracy of Aerial Sketch-Mapping Estimates of Defoliation

D.A. MacLean, *University of New Brunswick, Fredericton, New Brunswick*
W. MacKinnon, *Canadian Forest Service, Fredericton, New Brunswick*

Aerial sketch-mapping has been used to determine the severity of spruce budworm (*Choristoneura fumiferana*) defoliation for almost 50 years, has been used in hazard rating, and, more recently, in Decision Support Systems (DSS). Accuracy of the method had not been rigorously tested, but has been questioned due to subjectivity of observer ratings, difficulties in detecting defoliated areas and rating the severity of budworm feeding, and in determining the exact locations of the observed defoliation. Aerial sketch-mapping estimates of spruce budworm current defoliation were compared with ground-based estimates for 5–20 trees/plot in 222-325 plots, over 10 years. Overall, 56% of plots were correctly rated in four classes (nil 0–10, light 11–30, moderate 31–70%, and severe 71–100%), with 37% underestimated and 7% overestimated. The predominant error (26%) rated defoliation as nil from the air when it was actually light. Using three defoliation classes (by combining nil-light), 82% of the plots were correctly rated. Defoliation class, weather conditions prior to and during observation flights, and the defoliation class X weather interaction significantly affected results. We conclude that aerial sketch mapping of defoliation is a viable technique for landscape-level surveys, and its use in the Spruce Budworm DSS was described. Further details of the study are available in MacLean and MacKinnon (1996).

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Aerial Surveys for Detection and Damage Assessment of Major Forest Disturbances in Ontario

G.M. Howse, *Canadian Forest Service, Sault Ste. Marie, Ontario*

The first aerial reconnaissance to observe and map spruce budworm defoliation and damage in Canada occurred in July, 1920 in the Lake Timiskaming area of northeastern Ontario using a Curtiss flying boat, type HS-2L powered by a 360 HP Liberty engine, flying at an observation height of 800–1200 metres. Cruising speed of this aircraft was 97–105 km/hour. The aircraft carried three passengers, the pilot and engineer midship, and an observer in the nose. It is now 2001. The question is, are we any better off than in 1920? Current aerial surveys for forest disturbances in Ontario will be described.

Changing of the Guard: the Trials and Tribulations of Taking Over Aerial Surveys from the Federal Government

T. Ebata, *British Columbia Ministry of Forests, Victoria, British Columbia*

In 1996, the responsibility for aerial overview surveys in the province of British Columbia was transferred from the federal government to the province after a restructuring of the Canadian Forest Service. Historically, the Forest Insect and Disease Survey Section of the Canadian Forest Service conducted the annual overview survey, while the British Columbia Ministry of Forests conducted smaller operational aerial surveys. The change in responsibilities meant that the province was now required to map the province's entire forest land base and also continue the detailed aerial surveys with the same number of staff and resources as before.

Taking over the aerial overview required the province to create standardized survey procedures, to find and/or train aerial surveyors, and develop data and reporting standards. This was accomplished through the assistance of the Forest Health Network, the Canadian Forest Service, and British Columbia Ministry of Forests and forest health specialists in branches, regions and districts. In 1999, after suffering through many growing pains, the first province-wide aerial overview was completed by the British Columbia Ministry of Forests, and in 2000, was improved and refined. With the advent of the WWW, the 1999 and 2000 data were immediately available via the Forest Health Web Map (http://142.36.218.240/health/maps/maps.html) and the digital files could be downloaded from the Ministry of Forests' FTP server: (http://www.for.gov.bc.ca/ftp/Branches/Forest_Practices/external/!publish/Aerial_Overview/2000/).

Numerous challenges still remain. One key challenge is maintaining quality control and assurance. Training of contractors and staff and the monitoring of their work is a vital part of maintaining good data quality. A solution that is being implemented this year is the use of a monitoring contractor who will check, mentor and monitor aerial surveyors in regions using less-skilled contractors. Training will be delivered as and when needed, depending on the skill level of the contractors selected. It is recognized that aerial overview survey skills cannot realistically be obtained with a short course, but are honed in the air. Because of our limited pool of skilled surveyors, it is expected that quality will suffer in the short term, but improve with each season.

More information on the Ministry of Forests Aerial Overview Survey program can be obtained from our web site at http://www.for.gov.bc.ca/hfp/forsite/overview/overview.htm

Aerial Surveys in the United States—a New Hey-Day

T.J. McConnell, *US Forest Service, Fort Collins, Colorado*

If aerial sketch mapping survey can be considered a valuable remote sensing method, then ensuring that skilled aerial sketch mappers do the work is a must. Like other more technical remote sensing methods, the human aspect is an important part of the information. Aerial sketch mapping is only as good as the sketch mapper, the flight map and the conditions at the time of the survey.

Recent efforts to assure quality data have begun in the United States due to Forest Health Protection (FHP), a unit of the US Forest Service, and the Forest Health Monitoring Program

(FHM). By asking questions about quality assurance, providing funding for aerial survey programs and helping to implement national reporting standards, FHM has helped create a hey-day for aerial surveys. Hey-Day is a time of highest strength, vigor or prosperity.

All aerial survey programs share the constant challenge of maintaining a cadre of qualified sketch mappers. Whether the program relies on seasoned federal employees, contractors, provincial foresters, state forest health specialists or part time summer help, no program keeps all their qualified sketch mappers for very long. In the past, each program was totally independent of all other programs in the United States. Now, with FHM's support, national, regional and state programs are helping each other to ensure safe, quality programs through training, written guides and seasonal workshops.

As a new customer, FHM, along with FHP, has become proactive by:

1. Funding additional aerial survey work.
2. Bringing aerial survey specialists together to develop reporting standards, so all data can be combined into a national data set.
3. Supporting the training of sketch mappers.

Forest Health Protection directors have:

1. Created a safety and management infrastructure, including regional program unit aviation officers and a national aviation safety manager.
2. Chartered the Aerial Survey Working Group in support of having technical experts work together to:
   a. Help ensure all aerial survey programs are safe and efficient.
   b. Acquire high quality aerial survey data.
   c. Advise and provide recommendations to FHP Washington office, staff directors, state foresters and state cooperators on aerial survey program issues and opportunities.
   d. Share expertise, information and ideas.

The Working Group is made up of not only Forest Service folks, but also state people and occasionally, Canadians.

In the past, Forest Service Insect and Disease units gathered their own information by sketch mapping for their own local uses. Now, along with local uses, there is a national central data management center that maintains all available aerial survey data. All survey data are supposed to come to this center in the standardized GIS (geographic information systems) format that can be combined for a national map or summary. This center is the Forest Health Technology Enterprise Team, located in Fort Collins, Colorado.

WORKSHOP 3.3

IMPACTS OF EXOTIC PESTS ON FOREST ECOSYSTEMS AND WORLD TRADE

MODERATORS:
M. Ostry and **S. Katovich,** *US Forest Service, St. Paul, Minnesota*

Moderator Summary: Introductions of exotic pests of forest trees have had profound effects on forest ecosystems and on world trade of raw wood products. Increased globalization has added to the already long list of established exotic forest pests in North America. The goal of this workshop was to review recent case histories of exotic pests already established and potential arrivals, and to discuss their impacts on the forest resource, management, policy, and international trade. Discussions on the compound effects of multiple exotic pests included issues with hazard trees, losses of wildlife habitat, disruption of trade and the long-term management costs for established exotics. In recent years the rapid increase in the detection of exotic insects and pathogens has reduced our emphasis on research and management of native pests. There is a critical need for more proactive approaches to be taken to assist forest entomologists and pathologists throughout the world in managing pest problems that could otherwise become new arrivals in North America. Increased support for education and exchange programs aimed at international forest pest concerns would greatly assist in the prevention of the global movement of damaging agents.

Butternut Canker and Sudden Oak Death: Current and Potential Threats to Eastern Hardwood Forests

M.E. Ostry and **J. Juzwik,** *US Forest Service, St. Paul, Minnesota*
S.D. Cohen, *US Department of Agriculture–Animal and Plant Health Inspection Service, St. Paul, Minnesota*

Butternut *Juglans cinerea* is being killed throughout its range in North America by the fungus *Sirococcus clavigignenti-juglandacearum*, believed to be an exotic pathogen that can be seedborne, and may also be moved by insects and birds. Butternut is valued for its wood, nuts and contribution to biodiversity and wildlife habitat. The disease has only been known to be present in North America since the early 1960s and its origin remains unknown. The fungus has killed up to 80% of the trees in some states and is threatening its survival as a viable species.

Evidence suggests that disease-resistant trees exist. It is important that the remaining genetic diversity within the species is maintained. Various conservation practices and research projects to restore butternut are underway in the United States and Canada.

Thousands of coastal oaks within seven northern counties of California are dying from a newly described and yet unnamed species of *Phytophthora* that is causing an epidemic among several oak species. The disease known as sudden oak death was first reported in 1995. The fungus has been found to cause cankers on tanoak (*Lithocarpus densiflorus*), coast live oak (*Quercus agrifolia*), Shreve's oak (*Q. parvula* var. *shrevei*) and California black oak (*Q. kellogii*). Of particular concern recently is the discovery that the fungus causes a leaf spot and twig dieback on Rhododendron spp., huckleberry (*Vaccinium ovatum*), bay laurel (*Umbellularia californica*), madrone (*Arbutus menziesii*) and arrowwood (*Viburnum* ¥ *bodnantense*). Since it is not known if this disease could affect oaks elsewhere in North America, there is a danger of the accidental spread of the pathogen on movement of nursery stock of these host plants.

In May 2001, the California Department of Food and Agriculture instituted the oak mortality disease control regulation that prohibits movement of plants, plant parts (except acorns or seed), unprocessed wood and wood products of the above-mentioned hosts, potential carriers of the pathogen. The regulation allows the movement of these plants if the geographic area and plant in question is free of the pathogen. These regulatory measures cover the movement of plant materials within the state of California but do not address interstate movement of plant materials. Currently, there are no federal regulations enacted that regulate interstate movement of plant materials for *Phytophthora* canker of oaks and rhododendrons.

The Threat of *Sirex noctilio* to North America

D.A. Haugen, *US Forest Service, St. Paul, Minnesota*

Sirex noctilio (Hymenoptera: Siricidae) is native to Europe, Asia and northern Africa. It has been introduced into New Zealand (1900), Australia (1952), Uruguay (1980) Argentina (1985), Brazil (1988), South Africa (1994), and Chile (2001). In the southern hemisphere, *S. noctilio* has become a major exotic pest of exotic pine plantations, often causing 50-80% tree mortality in susceptible plantations. Native pines from North America, including *Pinus radiata*, *P. taeda*, *P. banksiana*, *P. ponderosae*, and *P. contorta* have been found to be highly susceptible hosts in the southern hemisphere. If *S. noctilio* becomes established in North America, it would be a major threat to pine plantations.

Sirex noctilio populations can be managed through silvicultural and biological controls. On-time first thinning can greatly reduce the susceptibility of a plantation. An effective biological control agent is available: the parasitic nematode, *Deladenus siricidicola*. This nematode can be mass produced and efficiently inoculated into *S. noctilio* populations. This nematode is highly density-dependent and can regulate *S. noctilio* populations well below economic thresholds. Parasitoids of siricids from North America have also been introduced into Australia to control *S. noctilio*. *Megarhyssa nortoni* and *Rhyssa persuasoria* (Hymenoptera: Ichneumonidae) have provided delayed density-dependent effects. However, the nematode is the key regulating agent. Though silvicultural and biological controls are effective in managing *S. noctilio*, they are costly to implement.

Reducing the risk of establishment of *S. noctilio* in North America is still a viable opportunity. Potential pathways for introduction include logs, green lumber, and solid wood packing material, especially from areas with current outbreaks. Treatment of solid wood packing material for international trade is likely to be the standard in a few years. Enforcement of import regulations for logs and green lumber is also key in preventing the entry of *S. noctilio*. To further reduce the risk of introduction into North America, assistance should be given to significant trade partners that are experiencing outbreaks of *S. noctilio*. The US Forest Service is assisting Brazil in implementing a biological control program to minimize expanding *S. noctilio* populations in southern Brazil. This technology is being shared with Argentina and Uruguay.

Assessing the Impact of Exotic Pests on Management of Michigan Forests

D.G. McCullough, *Michigan State University, East Lansing, Michigan*
R.L. Heyd, *Michigan Department of Natural Resources, Marquette, Michigan*

Many regions of North America are dealing with recent invasions of exotic forest pests. In Michigan, exotic forest insects have had major ecological and economic impacts on important forest cover types. In addition, these pests have profoundly affected forest health management, particularly over the last 15 years. Risks and benefits of programs implemented to eradicate, regulate or control exotic forest pests have varied substantially. Examining how management priorities and practices have evolved to respond to exotic pests can provide useful information for future invasive pest issues.

WORKSHOP 3.4

INSECT/PLANT INTERACTIONS: BRIDGING THE GAP BETWEEN INDIVIDUAL AND POPULATION-LEVEL STUDIES

MODERATOR:
D. Quiring, *University of New Brunswick, Fredericton, New Brunswick*

Moderator Summary: Feeding by herbivorous insects influences forest productivity, and conversely, the structure and nutritional quality of forest plants can influence the dynamics of herbivorous insects. Both the growth rate of trees, which is often related to their suitability to herbivorous insects (Herms and Mattson 1992), as well as forest structure (Ostaff and Quiring 2000), are two aspects of natural resource management commonly manipulated by foresters. Thus, understanding insect-tree interactions is important both for insect and forest ecologists as well as for pest and forest managers.

Many studies have documented the influence of plants on the performance and abundance of herbivorous insects. Yet the role of host plants and forest structure in the dynamics of insects is poorly understood. Previous studies have shown that the influence of host plants on insects often varies with feeding guild (Larsson 1989; Koricheva et al. 1998) but most studies have only looked at individuals, often in the laboratory, and have not evaluated the influence of the host plant on populations of herbivorous insects.

The aim of this workshop was to evaluate the role of host plants on populations of forest defoliators. Individuals were selected to present mostly new, unpublished data from field studies carried out with defoliators of hardwood and of young and old conifer stands. Presenters were asked to compare the relative influence of top-down (e.g., predators, parasitoids and pathogens) and lateral (e.g., competition) forces with bottom-up (e.g., nutritional quality, phenology, forest structure) forces on the dynamics of defoliator populations. They were also asked to provide examples of experimental protocols enabling researchers to bridge the gap between individual and population-level studies of insect-plant interactions.

Workshop participants concluded that bottom-up, lateral and top-down forces influence defoliators in young and old coniferous and deciduous stands. However, the relative influence of these factors varied by system and the type of experimental protocol used. In contrast to much of the literature, this workshop indicated that host plant quality and forest structure may be more important for defoliators of conifers, and that induced defenses may be less important for defoliators of some deciduous trees, than previously thought. Manipulative field experiments are well suited to answer questions regarding the role of the host plant and forest structure on populations of defoliators.

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Seeing the Forest from the Trees: the Role of the Host in the Spatial Dynamics of Conifer Folivores

A.L. Carroll, *Canadian Forest Service, Victoria, British Columbia*

Populations of forest insects are often highly variable in space and time. Although considerable attention has been devoted to the processes that govern temporal dynamics, much less is known of the spatial dynamics of forest defoliators. Despite the apparent uniformity of the mature conifer-dominated landscapes of northern North America, these forests can be generalized as a collection of discrete, relatively even-aged and monocultural habitat patches (i.e., stands). Within these forests, the distribution of herbivorous insect populations will be constrained by the composition and physiognomy of suitable stands.

The hemlock looper (*Lambdina fiscellaria fiscellaria* (Guen.); Lepidoptera: Geometridae)–balsam fir (*Abies balsamea* (L.) Mill.) interaction was used as a model system to determine the role of stand conditions in the spatial dynamics of a conifer-feeding folivore. Although stands of vigorous, fast-growing balsam fir trees produced foliage that was higher in nutritional components and lower in secondary chemicals, hemlock looper survival was optimal in low-vigor stands due to better synchrony between the timing of egg hatch and bud burst. In addition, stand vigor also affected the probability of mortality from natural enemies. For all taxa considered, natural enemies were 2 to 4.5 times more abundant in moderate- to high-vigor stands than in low-vigor stands.

Thus, the suitability of balsam fir stands for hemlock looper populations is determined by the vigor-dependent impacts of bottom-up and top-down trophic interactions. Variability in the vigor of stands within mature conifer forests may determine the spatial dynamics of folivores in mature conifer forests.

The Role of the Host Plant on Population Changes of Herbivores in Young Conifer Stands

D. Ostaff, *Canadian Forest Service, Fredericton, New Brunswick*

A common hypothesis explaining why some species of insects are present only in early stages of succession is that such changes are due to ontological changes in plant physiology associated with plant aging. Physical changes associated with tree development, such as increased stand density or changes in microclimate, could also exert a strong influence on the susceptibility and suitability of the host to herbivores. In young white spruce plantations, spruce bud moth populations decline at crown closure. Life table studies showed that a reduction in larval survival, occurring as the degree of crown closure increased, was the most important factor influencing decreases in intergeneration survival at the beginning of population decline. Fluctuations in egg-to-moth ratio suggested that dispersal behavior and/or realized fecundity of females also contributed to annual changes in population. Manipulative experiments showed that declines were caused by increased first-instar larval mortality, resulting from temporal asynchrony between budburst and egg hatch, and reduced oviposition caused by female preference for open trees. Qualitative survey data suggest that crown closure plays an important role in population fluctuations for many other herbivores on young conifers.

Re-evaluating the Host Tree as a Factor in the Population Dynamics of Hardwood Defoliators

D. Parry, *University of Massachusetts, Amherst, Massachusetts*

Delayed-induced resistance (DIR) in deciduous trees following defoliation has been hypothesized as a potential mechanism underlying population cycles of outbreak folivores. A number of recent reviews have been critical of this idea, concluding that induced resistance is likely only of minor significance in outbreak dynamics. Review of experiments done to date suggests that it may be premature to dismiss DIR as an important component of population dynamics. Many of the experiments have methodological problems or do not accurately emulate natural processes. These factors may have contributed to the equivocal results and the continued controversy surrounding induced response in trees. At least in birch and poplar systems, recent studies, which sought to eliminate problems plaguing earlier research, suggest that the direct effects of induced-resistance on fecundity and/or mortality of insects are relatively small. In a study using mountain birch, Kaitaniemi et al. (1999) found that the induced resistance decreased fecundity by only 11% when natural outbreak populations were manipulated. My studies using experimental outbreaks showed that delayed-induced resistance contributed little to the decline of gypsy moth populations in hybrid poplar, but did reduce forest tent caterpillar fecundity by 22% in trembling aspen. Indirect interactions between defoliators and induced resistance have received less attention. For example, studies examining tritrophic interactions between induced changes in phytochemistry and natural enemies are in their infancy. Thus, the relative roles of top-down and bottom-up factors in the population dynamics of defoliators is a fundamental question that remains unanswered for the vast majority of systems.

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WORKSHOP 3.5

INFORMATION STRATEGIES FOR INVENTORYING AND MONITORING BIOCONTROL AGENTS

MODERATORS:

R. Beard and **A. Mason,** *US Forest Service, Fort Collins, Colorado*

Moderator Summary: Millions of biocontrol agents have been released in the United States and Canada in recent years with the goal of controlling or at least reducing the negative impacts from invasive plants, insects and pathogens. These releases have been conducted by many government agencies, tribes, organizations, and individuals in the United States and Canada.

A significant problem exists in that there are currently no national or international standards for the information we collect about the releases and post-release monitoring of biocontrol agents. Due to this problem, consistent shareable information is not available to land managers, scientists, or the public, to answer the most basic questions about release activities (e.g., Who released it? What biocontrol agent or target? Where released? When released?).

Overview of Current Biocontrol Data/ Forms/Databases: Currently there are two national databases for biocontrol agents in the United States: 1) Releases of Biological Organisms (ROBO), maintained by the USDA Agricultural Research Service (http://www.ars-grin.gov/nigrp/robo.html); and 2) The National Agricultural Pest Information System (NAPIS), maintained by the USDA Animal and Plant Health Inspection Service (http://ceris/purdue.edu/napis/napisug/access.txt). At the state level, the Oregon State Department of Agriculture (ODA) maintains a database with over 11 000 biocontrol release and monitoring records related to control of noxious weeds. In Idaho, the Nez Perce Tribe and the State Department of Agriculture are developing a new database for tracking the release and establishment of biological control agents used in noxious weed control. A very recent effort in the United States was initiated in April, 2001, in Salt Lake City, at a meeting that included managers and scientists from county, state, tribal, university, federal, and other organizations involved in biocontrol activities. Draft national data elements for release and post-release monitoring were developed at the meeting, and they will soon be distributed to appropriate biocontrol agencies and organizations for technical review, and eventual endorsement/sponsorship.

Presentations at this Workshop: Each speaker was asked to address these three questions in their presentation: (1) What type of information about biocontrol agents is provided by your organization through it's current database/data standards?; (2) Who are the users of the information?; and (3) Do you have any recommendations regarding how we could improve the collection, storage, and sharing of information about biocontrol agents?

Conclusions/Recommendations: Invasive plants, insects, and pathogens continue to move across jurisdictional, agency, and international boundaries, as do the biocontrol agents we release to control or minimize their impact. Consistent, credible, shareable information about these biocontrol agents and their targets is essential to scientists, land managers, and the public. National and international information standards can help us address the invasive species issues we face at the local, regional, national, and even global level.

Biocontrol Inventory and Monitoring Information Standards

R. Beard, *US Forest Service, Fort Collins, Colorado*

A meeting was held in April, 2001, in Salt Lake City, Utah, to come to a consensus on the need for biocontrol inventory and monitoring information standards. Meeting participants included: representatives from the Nez Perce Tribe Bio-Control Center in Idaho and from Stillwater County, Montana; the North American Weed Management Association; the US Army Corps of Engineers; the USDA Animal and Plant Inspection Service; the USDI Bureau of Land Management and USDA Forest Service; and state departments of agriculture in California, Idaho, and Montana.

The meeting participants developed and agreed to a draft set of data elements that will guide the collection of standardized information both when biocontrol agents are released and also during post-release monitoring. These data elements were developed for use when collecting information about biocontrol agents—insects and pathogens; and about their targets—non-native invasive plants (includes noxious weeds, both terrestrial and aquatic) as well as non-native invasive forest insects and pathogens.

The proposed data elements are intended to provide common data standards for a broad range of biocontrol specialists including research scientists, weed control managers, government agencies, concerned citizens, commercial groups, special interest groups, lawmakers, and taxa groups. The data elements will provide the most basic information (e.g., what agent, what target, where released, when monitored, who surveyed) using standardized coding and symbols. There are 37 data elements proposed for biocontrol release (13 required, 16 recommended, and 8 optional) and 29 data elements proposed for monitoring (13 required, 11 recommended, and 5 optional).

Participants at the Salt Lake City meeting have agreed to ensure that the data elements receive technical review by appropriate biocontrol specialists in entomology, pathology, weed/plant science, and forestry. After technical review and revision, the participants will seek sponsorhip/endorsement from appropriate organizations with the ultimate goal of making the new standards available by May 2002 for widespread use by all biocontrol practictioners.

General Overview of the Nez Perce Biological Control Center Database

D. Bruno, *Idaho State Department of Agriculture, Boise, Idaho*

Idaho is a US state that borders British Columbia, Canada, and the states of Washington, Oregon, Nevada, Utah, Wyoming, and Montana. Noxious weed control in Idaho is governed by Idaho *Code 22-24,* the noxious weed law, and the noxious weed rule *02.06.22*.

Why is Idaho taking a closer look at tracking biological control agents for noxious weeds? With increased emphasis on Integrated Pest Management (IPM), Idaho is faced with several issues. More private and professional individuals who are not trained in entomology, are being asked to use biological control agents as part of their IPM program. While these agents can be purchased in bulk from a retailer, there is strong pressure from the growing organic farming community to find an alternative to herbicides. Another issue has been limited communication between those using biological control and others with vegetation management responsibility. In addition, if the person doing the releases leaves, the release location information often leaves with the him/her. The current available databases contain incomplete and outdated biological control information, and are in a format difficult to understand. The end result is a lot of frustration and wasted funds.

Approximately 2 years ago, the Nez Perce Biological Control Center proposed a partnership to the Idaho State Department of Agriculture to create a statewide tracking database. The goals were to provide land managers (public and private) with a tool to enhance statewide planning, allow agency coordination, provide research capabilities, and decrease redundancy in release and control efforts. The tribe actively requested input from county, state, federal and university personnel. From this, the need for recording of release and monitoring information and for easy access to statewide information were identified. Two types of users were also identified: the researcher/professional who would be well educated and have research type goals in mind; and the private landowner who was interested in limited investment in tracking the release, but required positive results.

This database has now been designed in Microsoft Access, a program easily obtained by private and public cooperators and compatible with Nez Perce Tribe's geographic information system (GIS). It will store release information with limited required fields for the private landowner, and maintain detailed site, target, and agent information for the research user. Monitoring information will be also be tracked. World Wide Web access to information is an essential component of the database. Password protection will be required for direct database access and specific location information. Online data entry into the database is planned, and general maps will be online for illustration purposes.

Currently, the initial data entry of historic information has been concluded, and the preliminary database structure is under review. Once finalized, the interface will be developed and the interactive mapping site will be developed.

For more information, contact Chris Kuykendall, Director, Nez Perce Biological Control Center, at (208) 843-7392, or chrisk@nezperce.org.

WORKSHOP 4.1

FOREST PEST SURVEY: HISTORY, PURPOSE, AND POLICY

MODERATORS:
B. Schaupp, *US Forest Service, Lakewood, Colorado*
H. Ono, *Alberta Sustainable Resource Development, Edmonton, Alberta*

Moderator Summary: Approximately 20 people attended this session, which began with a thorough and frank presentation on the history and value of forest pest surveys in Canada from the past to the present. (This presentation was given by Edward Kettela of the Canadian Forest Service in Fredericton, New Brunswick, who kindly agreed to stand-in for Tom Sterner, who was unable to attend.) Although the Forest Insect and Disease Survey (FIDS) demonstrated the value and uses of survey information, survey activity and national reporting of pest survey results is no longer coordinated nationally across Canada. With the end of federal responsibility towards FIDS, each province developed its own standards and determined activity level and mapping results from their own survey activity. Several consequences, suggestions, and future needs based on survey information were presented.

Pest conditions in British Columbia for the year 2000 were summarized by Tim Ebata, who provided an example of a current provincial pest survey program. Considerable reliance on contracted workers is necessary to acquire information that is primarily derived from aerial surveys. Predictions for next year were given based on these surveys. Interested parties are directed to the Internet, where this information is posted.

Methods and activity levels from other provinces were mentioned by attendees. Gordon Howse described the history and current situation in Ontario. A close relationship exists between national research and provincial pest management/survey groups. (Note: See Workshop 3.2 for presentations by T. Ebata and G.M. Howse.)

Pest survey activity in Mexico was summarized by Tim McConnell, who indicated that interest in aerial survey is growing there. The US Forest Service provides training in this area both in Mexico and in the USA to help develop this capability. Most aerial survey activity is of an overview type, while special purpose ground surveys are focused on particular problems. Currently, national reporting does not exist. Approximately 1% of the forested land in Mexico is publicly owned.

The US Forest Service's Forest Health Monitoring Program has lead to an increase in survey activity to cover "off-plot" conditions. The Program and its goals were briefly discussed.

The discussion turned to surveys using traps. Pheromones are used to detect or obtain population status for various scolytids, the Douglas-fir tussock moth, and gypsy and nun moths in Canada and the United States. The topic then shifted to trapping to detect or delimit exotic organisms. This effort once again illustrates how vital and scarce are taxonomic resources.

Mary Ellen Dix described an interagency pilot test in the United States for the rapid detection of exotic pests. This effort parallels and uses some of the methods developed and used in Canada, particularly by Lee Humble. Additional tactics, techniques, and overseas research are needed to improve this effort.

History of Forest Pest Surveys in Canada

T.E. Sterner, *Canadian Forest Service, Fredericton, New Brunswick*
(Presented by E.G. Kettela, Canadian Forest Service, Fredericton, New Brunswick)

The first forest insect survey was conducted in eastern Canada in 1936 and by the mid-1940s the federal government was conducting an annual national survey. The forest disease survey was initiated in 1951 and in 1962 the two surveys were united as the Forest Insect and Disease Survey (FIDS) within the Canadian Forest Service (CFS). The Forest Insect and Disease Survey conducted regional surveys and published regional and national conditions reports until 1995. At its height, FIDS had approximately 105 staff who maintained close working relationships with provincial forest management agencies, many of whom participated in collaborative survey activities. As a result of a federal government-wide review in 1994–95, forest pest surveys were deemed to no longer be within the federal mandate of activities but to reside within provincial jurisdiction, similar to forest inventories. Decades of survey data now reside in the CFS Forest Health and Biodiversity Data Base and the invaluable reference collections are still actively maintained. Currently there is no nationally coordinated nor reported forest pest survey. It is suggested that the Forest Pest Management Forum consider taking on the role of publishing an annual national summary of provincial pest survey activities.

WORKSHOP 4.2

EDUCATING RESOURCE MANAGERS AND THE GENERAL PUBLIC

MODERATORS:
R.L. Livingston, *Idaho Department of Lands, Coeur d'Alene, Idaho*
E.G. Hebertson, *US Forest Service, Ogden, Utah*

Moderator Summary: Staffan Lindgren (University of Northern British Columbia, Prince George, British Columbia) and Michael Wagner (Northern Arizona University, Flagstaff, Arizona) presented innovative approaches their schools have developed for incorporating forest health training into forest resource management programs. Although the structure of both programs is unique, each utilizes an interdisciplinary curriculum from which forest health concepts are taught. Traditional entomology courses have been revised with each program giving greater emphasis to the role of insects and disease in forest ecosystems. Students also learn from a variety of field-based experiences, management exercises and special projects. While some workshop participants expressed concern that students may no longer graduate with sufficient knowledge for managing specific insect agents, others felt that these approaches would better equip students to address the complexity of forest health issues and variety of challenges lands managers must now face.

Elizabeth Hebertson discussed the Intermountain Region, Forest Health Protection strategic education plan and several methods to enhance educational programs. The goals of the strategic plan are to improve the transfer of information to technical customers and expand public education efforts. Specific methods include developing a marketing plan to identify the educational needs of various audiences, produce informative publications on forest health topics, make personal contacts with the media to facilitate more accurate reporting, look for opportunities to coordinate forest management interest groups and encourage diverse interests to find common ground, develop training and aids for teachers and students at all levels, and utilize new technologies to make training more effective.

Reaching Out, Enhancing Education Efforts

E.G. Hebertson, *US Forest Service, Ogden, Utah*

Education is a primary emphasis area of the USDA Forest Service, State and Private Forestry, Forest Health, and Forest Health Protection programs. Traditionally, Forest Health Protection offers training and workshops on insect and disease identification, detection surveillance and monitoring to a variety of federal and state natural resource managers. A recent shift in resource needs and values necessitate that courses target an even broader audience. This presentation will discuss several strategies and methods that can make reaching out more effective and enhance all educational efforts.

Management Seminars and Workshops

R.L. Livingston, *Idaho Department of Lands, Coeur d'Alene, Idaho*

Forest insect and disease recognition and management seminars are taught annually, in cooperation with the US Forest Service, to state, federal, industrial and non-industrial forest owners and managers. Two- and three-day workshops incorporating slides, samples, presentations and field trips are very popular. We also provide insect and disease training for loggers (Logger Education to Advance Professionalism) in conjunction with University of Idaho Cooperative Extension training for foresters to meet requirements for certification (Forest Sustainability). All sessions are filled to capacity with a waiting list.

Teaching Forest Entomology to Future Forest Managers

S. Lindgren, *University of Northern British Columbia (UNBC), Prince George, British Columbia*

Forest entomology at UNBC is taught within the context of a one-term integrated forest health course. This format provides both opportunities and challenges, but is logical if the focus is on forest ecosystem processes rather than on organisms. I attempt to provide a general understanding of forest entomology in an ecological context. For students with some field experience, this involves breaking down some misconceptions and challenging some existing paradigms. For example, mere presence of a forest health agent is often thought to necessitate immediate action, and there is a prevailing paradigm that bark beetle outbreaks automatically lead to forest fires in the absence of harvesting.

Northern Arizona University School of Forestry Model for Training Forest Managers: Changing with the Times

M.R. Wagner, *Northern Arizona University, Flagstaff, Arizona*

Northern Arizona University (NAU) School of Forestry has trained forest managers for over 40 years using a team-taught integrated curriculum approach. A key component of our program is a capstone experience where students prepare a detailed management plan as part of their undergraduate requirement. Technological change, a more contentious society, and changing career opportunities have necessitated a constantly changing approach to training forest managers. Northern Arizona University is responding to these changes by creating new emphasis areas; developing writing and speaking across the curriculum; and developing distance-learning courses. The training of forest managers within universities and in-service will certainly continue to change and this will produce foresters better able to manage resources within the context of society.

WORKSHOP 4.3

URBAN FOREST PEST MANAGEMENT

MODERATORS:
S. Wilkins, *Department of Parks and Recreation, City of Calgary, Calgary, Alberta*
R.L. McIntosh, *Saskatchewan Environment and Resource Management, Prince Albert, Saskatchewan*

Moderator Summary: The esthetic, environmental and social value of urban forests is unquestioned. However, high individual value and species diversity, preference for old and senescent individuals, and adverse environmental conditions make urban forests one of the most challenging ecosystems in terms of pest management. However, values at risk are often not met with sufficient financial and public support.

The overall focus of this workshop was three-fold:

1. To discuss issues and challenges encountered in delivering pest management in the urban forest and urban/forest interface;

2. Review past and current status of research and development of the knowledge base; and

3. Explore initiatives to integrate research and scientific knowledge into operational Integrated Pest Management (IPM) programs to aid development of planning programs and long-term proactive management strategies.

The first speaker described building an IPM infrastructure in an urban setting. Four building blocks were identified: communications, developing partnerships, addressing local issues and concerns, and quantification through cost-benefit analysis. To demonstrate this process, three major projects were described: Dutch elm disease (DED), IPM, and the Urban Forest Effects Model. Dutch elm disease management in Calgary includes surveillance, pruning, sanitation, monitoring and public education. Other aspects involve advisory groups, fundraising, and political lobbying. Integrated Pest Management is a knowledge-based integrated approach to prevent and manage pests. Management options are contingent on human health and safety issues and ecological, social and economic acceptability. The Urban Forest Effects Model quantifies urban forest structure and environmental benefits. This is achieved through detailed forest cover inventory, assessing levels of carbon storage and sequestration, measuring air pollution deposition, and energy conservation.

The second presentation provided an historical view of urban pest management research in Manitoba. With the introduction of DED in 1975, the research focused on elm protection and reducing fungal reservoirs. First, an effective pruning program was developed; later, the emphasis was on native elm bark beetle (*Hylurgopinus rufipes*) population management. Cypermethrin was examined as a replacement for chlorpyrifos with only moderate success. Other initiatives include: evaluation of Siberian elm as a disease reservoir and habitat for beetle populations, and the use of monosodium methanearsenate (MSMA) killed trap trees. Mark-recapture studies into *H. rufipes* dispersal revealed beetles are able to fly 100 m and some were trapped over 1 km from the emergence point. These results are significant in planning and deployment of buffer zones.

The third speaker described the spread of DED in Saskatchewan since 1991. Dutch elm disease management in Saskatchewan integrates surveillance, sampling and detection, pruning, sanitation, population reduction, and reforestation. Continued use of chlorpyrifos is uncertain in the face of increasing societal desire to reduce chemical insecticide use. Semiochemicals provide an ecologically benign means for beetle management. The smaller European elm bark beetle (*Scolytus multistriatus*) pheromone has been identified but is not effective for *H. rufipes*. Knowledge of the chemical ecology of *H. rufipes* is lacking and there is a need to elucidate host-selection behavior. Research aims to develop a bait through identifying qualitative and quantitative chemical constituents of susceptible elm volatiles. Antennal response to host and non-host volatiles will be determined using gas chromatographic electroantennographic detection (GC-EAD) techniques. Candidate compounds will be tested in laboratory and field bioassays to determine bioactivity.

The session was brought to a close with a review of ways to adapt IPM approaches used in large-scale forestry for application to urban forest pest management—in particular, in areas where there is a high proportion of urban/forest interface. The use of hazard and risk rating systems and enhanced monitoring and management methods using semiochemicals were discussed. Efforts have been made in the municipalities and Parks and Recreation to monitor and quantify pest problems, help deployment of resources, and aid the development of long-term proactive management strategies.

Chemical Ecology of the Native Elm Bark Beetle *Hylurgopinus Rufipes* [Coleoptera: Scolytidae]: an Ecological Approach to Beetle Management

R.L. McIntosh and **M. Pryznyk**
Saskatchewan Environment and Resource Management, Prince Albert, Saskatchewan
G. Gries, *Simon Fraser University, Burnaby, British Columbia*

Dutch elm disease (DED) (*Ophiostoma ulmi*), vectored by two Scolytid beetles (Coleoptera: Scolytidae), has caused extensive mortality in wild and urban elms throughout North America. Dutch elm disease was first confirmed in Regina, Saskatchewan in 1981, and considered eradicated. In 1991, the disease re-emerged and since then has claimed, on average, 1 000 elms per year. Despite exhaustive efforts to manage the disease, there is no known cure.

Dutch elm disease management in Saskatchewan comprises a synthesis of administrative and operational components. Administrative components include legislation and quarantine, public awareness, and cost-sharing programs. Operations integrate surveillance, sampling and detection, pruning, sanitation, population reduction, and reforestation action. Basal application of chlorpyrifos, used to control overwintering beetle populations, is a significant part of DED management. However, re-evaluation of organophosphate use by the Canadian Pest Management Regulatory Agency might lead to the removal of chlorpyrifos from the market. In view of public desire to reduce chemical insecticide use and the fact that urban forest managers may be left with no effective tool for managing beetle populations, alternative methods must be investigated.

In this paper, we propose to explore an ecologically benign alternative focusing on semiochemical-based manipulation of beetle populations. Semiochemicals provide an ecologically benign means for beetle management. A pheromone lure, containing 4-methyl-3-heptanol, (-)a-multistriatin, and the host-terpene (-)a-cubebene, exists for the smaller European elm bark beetle (*Scolytus multistriatus*) (Pearce et al. 1975). However, this lure is not effective for *H. rufipes* and there is evidence that host-selection is mediated by host compounds. There has been only one study into host kairomones used by *H. rufipes* (Millar et al. 1986). Significant gaps in the knowledge of the chemical ecology of *H. rufipes* exist and clearly more work is needed to elucidate what mediates host selection behavior.

Working hypotheses for the proposed research were based on manipulating the following:

1. Chemical ecology mediating feeding response.
   - *H. rufipes* are attracted to compounds found in flushing foliage and fresh twig material, or these materials later in the season.

2. Chemical ecology mediating host-selection for brood development.
   - Beetles are attracted to host volatiles emitted from stressed or moribund elm.
   - Blends of attractive compounds can be used to increase trap catches.

3. Putative repellency using non-host species.
   - Susceptible elm trees might be protected using non-host compounds.

Qualitative and quantitative chemical constituents of susceptible elm volatiles will be identified. Host and non-host twigs, foliage and bark will be collected over time and aerated in chambers. Poropak Q will be utilized for volatiles collected, they will be eluted with pentane and subsequently identified using gas chromatography. Antennal response to host and non-host volatiles will be determined using coupled gas chromatographic electroantennographic detection (GC-EAD) techniques. Candidate compounds, and proportioned blends, will be tested in laboratory and field bioassays to determine bioactivity.

In addition to enhanced monitoring, trapping, and population management activities, this research will increase our knowledge of insect-host interaction. Opportunities may arise for the development of a repellent formulation using non-host volatiles to deter attack by *H. rufipes*.

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Recent Research into the Management of Elm Bark Beetles in Urban Forests in Manitoba

R. Westwood, *University of Winnipeg, Winnipeg, Manitoba*

During the 1990s most of the urban tree insect pest research in Manitoba concentrated on development of more effective tools to manage the native elm bark beetle (*Hylurgopinus rufipes*), the vector of the Dutch elm disease (DED) pathogen *Ophiostoma ulmi*. The research has been concentrated in four broad areas. The first has focused on the role Siberian elm (*Ulmus pumilla*) occupies in maintaining reservoirs of DED fungus and the potential for elm bark beetles to utilize Siberian elm as viable alternate hosts to American elm (*Ulmus americana*). Research by H.J. Holliday and others at the University of Manitoba in Winnipeg, Manitoba, has shown that Siberian elms harbor sufficient breeding beetles during the summer to make them significant reservoirs for DED, and that they should be included in programs that manage DED in American elm stands. As overwintering sites, Siberian elm of equal dbh (diameter breast height) to American elm harbor approximately half the number of beetles, and beetles preferred to overwinter in American elm if both species of trees were in close proximity.

The second area of investigation has examined methods of lowering elm bark beetle populations through the use of trap tree techniques. Research has shown that monosodium methane arsenate (MSMA) proved very effective in attracting breeding bark beetles to treated trees and subsequently drying trees to the point of killing beetle broods prior to adult emergence. Less than 1% of adult beetles emerged from treated trees and the procedure was effective in attracting beetles and preventing colonization of nearby and adjacent trees (Pines and Westwood 1996).

Another area of interest has been a search for alternate synthetic insecticides to the presently registered insecticide chlorpyrifos for suppression of over-wintering bark beetles. A combination of research projects looked at both the field and laboratory environmental fate of chlorpyrifos and cypermethrin in tree bark and cambium, in soil and in leaf litter to establish efficacy levels for elm bark beetle control. Our results indicated residues of chlorpyrifos could be found in elm bark and leaf litter up to 800 days post treatment, while cypermethrin residues were non-detectable by 500 days. Chlorpyrifos residues in elm bark provided in excess of 95% beetle mortality at 800 days post application, while cypermethrin efficacy dropped below 80% by 500 days post application.

Our current research endeavors to focus on the movement of native elm bark beetles in both spring and fall from wild forest stands into managed urban forests. A series of mark-recapture projects are underway to examine beetle movement and behavior to design more effective community buffer zone protection programs. While these studies are ongoing, results to date indicate that bark beetles may move significant distances very quickly when seeking host trees. This finding is contradictory to present thought which suggests bark beetle dispersal is restricted within elm stands and that elm bark beetles may be reluctant to move large distances in seeking elm hosts.

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Managing "Forest" Pests in Urban Areas: Some Experiences in South-Central British Columbia

I.M. Wilson, *Phero Tech Inc., Vernon, British Columbia*

Forest pests such as bark beetles or defoliators can be particularly damaging in the urban forest, where the loss of even a few high-value trees may be significant. In the Okanagan valley of south-central British Columbia, practices such as fire suppression and urban encroachment seem to have exacerbated the problem. Certain areas have experienced chronic problems, and reactive management approaches have been costly and have only offered short-term relief. A more proactive approach was initiated in the central Okanagan in 1999 to develop longer-term strategies for urban forest health problems. Tools developed primarily for use in industrial forests, such as hazard and risk rating, pheromone monitoring, and silvicultural techniques, were adapted to the smaller scale of the urban forest and combined into an overall management plan. It is hoped that this strategy will help to mitigate or prevent future pest outbreaks.

WORKSHOP 4.4

SPATIAL DYNAMICS OF FOREST DEFOLIATOR POPULATIONS

MODERATOR:
A.M. Liebhold, *US Forest Service, Morgantown, West Virginia*

Moderator Summary: Forest insects, especially foliage-feeding insects, have served as model systems for pioneering research in population ecology. Important methods that were first explored using data from forest defoliators include: Morris's life table analysis with spruce budworm; Varley and Gradwell's stage-specific population models of winter moth populations; and Anderson and May's classical model of insect/pathogen dynamics using larch budmoth data. In keeping with this tradition, foliage-feeding insects are currently being used by several groups as model systems for exploring new concepts of spatial dynamics. In this session, participants described several different projects that are using data on defoliator problems to explore space-time problems.

The first speaker, David Gray, described his recent work on understanding how habitat characteristics are related to historical patterns of defoliation by the spruce budworm in Quebec. His work has focused on the use of spatially constrained correspondence analysis which relates multivariate properties of yearly defoliation levels with multivariate habitat properties such as forest type, slope, aspect, and climate. A key element of this statistical method is that it adjusts for spatial dependence in data, and he found that doing so substantially affected conclusions about which habitat variables are associated with defoliation frequencies.

Jean-Noël Candau spoke about his research in Ontario with Rich Fleming, which also focuses on relating spruce budworm defoliation to habitat variables such as climate, slope, aspect, etc. In contrast to David's use of correspondence analysis, Jean-Noël has adopted regression trees for quantifying these relationships. While this method is computationally intense, it imposes no assumptions of linearity, normality, etc. to the data. These analyses indicate that the geographical range of defoliation is primarily explained by forest type, and then secondarily related to climate.

Barry Lyons described his work in developing statistical models for predicting defoliation (as maps) from pheromone trap counts interpolated from a network of traps. These models have used logistic regression to predict probabilities of defoliation in each map pixel. He has found that addition of lagged values of trap capture as independent variables increased the predictive power of these models, presumably because it adjusts for the temporal position in the current outbreak.

Jens Roland discussed some of the work he and Subhash Lele have been doing in applying spatially explicit population models to the dynamics of forest tent caterpillar populations. These models capture direct and delayed density-dependent processes and can incorporate geographical variation in model parameters due to variation in forest fragmentation, climate, etc. Models are fit using a technique called "estimating functions" that Subhash has explored with other data in the past. They have plans to use an expanded model to evaluate the role of dispersal in explaining outbreak dynamics.

Mikko Peltonen described some of the work that he, Sandy Liebhold, and Ottar Bjornstad have been doing in comparing patterns of spatial synchrony of various forest insect populations. They assembled a collection of time series of defoliation maps for seven different species and applied a technique, spatial covariance functions, to quantify spatial synchrony as a function of lag distance. They found that all seven species shared rather similar patterns of synchrony as a function of distance even though some species were very good dispersers and some were poor at dispersing. They interpret these results to indicate that the ubiquity of spatial synchrony in forest insect populations is more likely the result of a Moran effect (spatially synchronous weather effects) rather than the result of synchronization via dispersal among populations.

Space: Not Just a New Frontier; or, Why Changing the Species Composition Doesn't Reduce the Pest Hazard

D. Gray, *Canadian Forest Service, Fredericton, New Brunswick*

A common question in forest research and management can be rephrased in a generic way by asking: "What is the relationship between the environmental variables across my landscape (climate, forest composition, edaphic conditions, etc.), and the occurrence and/or severity of pest outbreaks across that same landscape?" In effect, we are asking this question when we develop hazard and risk rating systems (or vulnerability and susceptibility rating systems), or when we develop decision support systems. After identification of the significant environmental variables, there usually follows the assumption that a modification of these environmental variables will lower the probability of an outbreak (hazard or susceptibility), and/or lower the anticipated damage in the event of an outbreak (risk or vulnerability). However, we may not always be properly identifying the environmental variables that truly influence the occurrence and severity of pest outbreak, or accurately quantifying their real influence.

The problem arises because of inherent spatial structuring that exists within the communities of our landscape. Spatial structuring occurs for a variety of reasons. Large scale geomorphologic processes and climatic gradients will create gradients and patches in environmental variables (Legendre 1993). Contagious biotic processes such as reproduction will create a smaller scale spatial pattern in the biotic environmental variables. Similarly, observations of pest occurrence and severity may also have a spatial structure due to a number of unquantified factors such as migration, mating behavior, predation, etc. Any degree of similarity between the environmental variables and pest occurrence/severity in their spatial structures will cause the influence of the environmental variables on pest occurrence/severity to be overestimated as a result of a spurious correlation. Spatial structures such as trends will also result in positive autocorrelation over (at least) short distances and regression and correlation tests will be more liberal than we intend.

A multivariate technique of constrained ordination derived by Braak (1988) will be discussed with an example to illustrate why modifications to forest composition may not always result in our anticipated reduction of pest occurrence or severity.

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Landscape Scale Dynamics of Spruce Budworm Defoliation in Ontario. Analysis of Large-Scale Data From 1967-1998 in Relation to Bioclimatic Variables

J-N. Candau, *Ontario Forest Research Institute, Sault Ste. Marie, Ontario*
R.A. Fleming, *Canadian Forest Service, Sault Ste. Marie, Ontario*

We relate the spatiotemporal dynamics of large-scale defoliation by spruce budworm in Ontario to bioclimatic variables which describe local vegetation, climate and elevation. A model of the presence/absence of defoliation shows that the northern and southern boundaries of defoliation are related to the proportion of balsam fir and white spruce in the local forest. Between these boundaries, the presence/absence of defoliation appears to depend on the maximum winter temperature and the minimum temperature in May. A model of the frequency of defoliation indicates that high frequencies were generally associated with low June precipitation and relatively low minimum temperatures. In several instances, the results of the regression tree models corroborate independent observations and results published in the past.

The Use of Logistic Regressions to Predict Spruce Budworm, *Choristoneura fumiferana*, Defoliation Based on Historical Defoliation and Pheromone Trap Data

D.B. Lyons, *Canadian Forest Service, Sault Ste. Marie, Ontario*
A.M. Liebhold, *US Forest Service, Morgantown, West Virginia*
G.C. Jones, *Canadian Forest Service, Sault Ste. Marie, Ontario*

The spruce budworm, *Choristoneura fumiferana*, is the most destructive insect in the boreal forest of Canada. This defoliator has a transcontinental distribution occurring from Newfoundland to British Columbia wherein it feeds on foliage of *Picea* spp. and *Abies* spp. The species also occurs in the northernmost tier of states in the northeastern United States. The species undergoes catastrophic changes in density, and the period of these outbreaks may be approximately 35 years. A network of pheromone traps has been deployed annually since the mid-1980s throughout most of the distribution of the insect to detect changes in densities of male moths. In Ontario, the defoliation cased by this pest has been aerially mapped since 1941. Logistic regression techniques have been used to construct predictive models of budworm defoliation probabilities for Ontario. Variables included in predictive models include frequency of historical defoliation, pheromone trap captures and previous defoliation. A model combining all three variables resulted in high concordance values. Validation of the models is provided.

Statistical Modeling of Forest Tent Caterpillar Populations in Dynamics in Time and Space

J. Roland, S. Lele and **B. van Hezewijk,** *University of Alberta, Edmonton, Alberta*

We fit population models with direct and lagged density terms to spatial population data from 130 high-density and collapsing populations of forest tent caterpillar. We include the effects of covariates such as degree of forest fragmentation on these parameters. Intrinsic growth is affected positively by forest continuity; more forest is associated with greater growth, and is most strongly affected by local forest structure. Direct density dependence is stronger (more negative) in fragmented forests, suggesting an effect of fragmentation on factors such as competition or dispersal. Lagged density-dependent effects are poorly estimated, due to the limited time series in only the collapse phase.

What Causes Spatial Synchrony Of Forest Insect Outbreaks?

M. Peltonen, *Academy of Finland and US Forest Service, Morgantown, West Virginia*

Spatial synchrony (i.e., simultaneous population fluctuation over large areas) seems to be almost a universal characteristic in forest insect dynamics. The most commonly suggested mechanisms to explain synchrony include regional stochasticity and dispersal. According to a theory known as the Moran effect, populations with similar intrinsic linear dynamics will be synchronized if they are affected by common density-independent factors, such as regional weather anomalies. On the other hand, dispersal may induce synchrony by linking segregated populations. Since both mechanisms can produce identical patterns of synchrony, it is difficult to identify the ultimate cause of synchrony among specific populations. Confronting the theoretical framework with observational data still remains one of the great challenges in the quest to understand population processes.

In the present study, synchrony was investigated in spatiotemporal outbreak data of six forest insect species with varying life history traits, dispersal abilities, and geographical ranges: the spruce budworm (*Choristoneura fumiferana*), the western spruce budworm (*C. occidentalis*), the larch bud moth (*Zeiraphera diniana*), the forest tent caterpillar (*Malacosoma disstria*), the mountain pine beetle (*Dendroctonus ponderosae*), and the gypsy moth (*Lymantria dispar*). A recently developed statistical method (the nonparametric covariance function) was used for quantifying the magnitude and spatial range of synchrony in outbreak data and corresponding weather time series. The aim was to relate observed variation in outbreak synchrony with corresponding variation in dispersal capability and spatial synchrony in weather data. The results suggested that regional stochasticity is probably the dominant process causing spatial synchrony in the outbreaks of these species at the landscape scale. In general, the decrease of synchrony with increasing distance (i.e., the spatial covariance function) was much steeper in outbreak data than in weather data. This pattern could not be explained by Moran effect, since the theory predicts spatial covariance functions of population and weather data to be parallel. One of the core assumptions of Moran's theorem is that all populations have identical linear intrinsic dynamics. Simulations allowing heterogeneous, spatially autocorrelated local dynamics resulted in a spatial covariance function resembling those observed in outbreak data. The extent of spatial variance of the local dynamics in natural populations and further exploration of how this affects spatial synchrony, remains to be determined.

WORKSHOP 4.5

ARTHROPOD DIVERSITY AND COARSE WOODY MATERIAL

MODERATORS:
J. Hammond, *Canadian Forest Service, Edmonton, Alberta*
C.G. Niwa, *US Forest Service, Corvallis, Oregon*

Moderator Summary: Following formal presentations, workshop discussion centered around three main themes: Coarse woody material (CWM) work currently being conducted by workshop participants, classification of CWM and management of CWM.

Current studies included: snag creation using bark beetle pheromones in western Oregon, effects of fire and thinning on downed CWM in California ponderosa pine forests, surveys of CWM arthropods in northern California late successional reserves, responses of arthropods to the addition and deletion of CWM in Alberta and in Georgia, studies of saproxylic arthropod assemblages at the EMEND (Ecological Management by Emulating Natural Disturbance) site in northern Alberta, and responses of beetles to a severe windstorm and silvicultural practices in northern Minnesota.

Classification of CWM is a major obstacle to assessing habitat conditions that are suitable for arthropod colonization and utilization. Established methods developed for fuels inventory or wildlife use are not always meaningful or representative of the characteristics that arthropods respond to. For instance, new CWM with intact bark and branches with needles may have it's heartwood decayed due to pathogens; or conversely, CWM that by outside appearance looks older, may still be solid inside. Methods other than visual inspection may be necessary, such as coring CWM to determine decay condition. In addition, inspection of CWM at a finer scale many be necessary in studying some arthropods. For example, ants have been found to utilize even small twigs, a size that would not be included in typical CWM surveys; and the occurrence of some arthropod species are linked to specific CWM inhabiting fungi, a resource that is not commonly measured.

There are efforts by Forest Health Protection personnel in Oregon to provide resource managers with guidelines for managing standing and down CWM. Available literature is being used to provide educated guesses on the amount, size, species, etc. of CWM that is necessary to maintain ecosystem functions. The premise is to sustain a continual flow of CWM throughout the development of a stand. The amount and type of CWM is based on historic records and is tied to plant association

Creation and Utilization of Snags by Arthropods in Mixed-Conifer Forests

C.G. Niwa, *US Forest Service, Corvallis, Oregon*
D.W. Ross, *Oregon State University, Corvallis, Oregon*

This paper describes two snag studies: the use of bark beetle semiochemicals to produce snags for wildlife habitat; and the capture of arthropods crawling up snags in managed and unmanaged stands.

Many techniques have been developed to create snags from living trees, the most common of which is topping with chainsaws or dynamite. Tree-baiting with bark beetle aggregation pheromones is potentially a more efficient and less hazardous method of creating snags. This technique would keep trees structurally intact and immediately initiate the same succession of fungi and insects that commonly occur in snags resulting from natural processes. A possible limitation of this approach is the lack of control over attacks on adjacent unbaited trees. The amount of unwanted, spill-over tree mortality depends on the density of the local beetle population and stand conditions. Pheromone baits for the Douglas-fir beetle were applied alone and in combination with the antiaggregation pheromone, MCH to determine if the number of beetle attacked trees could be regulated. The application of MCH was successful in limiting the number of unbaited trees that were mass-attacked, while allowing infestation of the baited trees. However, after 1 year, fewer of the baited trees had died on the plots treated with MCH than on the plots without MCH. A lower dose of MCH may have resulted in higher rates of mortality to baited trees while still protecting unbaited trees. Using pheromones effectively to create snags will require modifying treatments based on expected beetle population densities.

Commercial thinning of overstocked stands has been recognized as an effective tool for reducing the hazard of wildfire, increasing stand productivity, improving wildlife habitat and as a means for hastening the transition to old-growth conditions. However, opening the forest canopy often increases exposure to solar radiation and wind, generally increasing temperatures, decreasing relative humidity and accelerating the drying of coarse woody material. For deadwood-inhabiting organisms sensitive to fluctuations in microclimate, this change could be profound. During 2000, arthropods were trapped on snags and live trees in six stands of late successional old growth and on adjacent sites of similar structure, but thinned 10-20 years earlier. Funnel traps (Hanula and New 1996) were monitored for six 2-week periods from 22 May through 10 October. Preliminary results for spiders, ants, beetles, springtails and mites showed no statistical differences in abundance between thinned and unthinned stands for snags. Significantly more ants utilized live trees in thinned than in unthinned stands, possibly responding to increased temperatures and prey availability. Species level taxonomic identification will be conducted to determine effects on community structure and diversity.

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Arthropods and Large Woody Debris in Pine Forests of the Southern United States

J. Hanula, S. Horn and **D. Wade,** *United States Forest Service, Athens, Georgia*

The interrelationship between arthropods and large woody debris in southern pine forest has not received much attention. A 5-year study was conducted on the Osceola National Forest in Florida to determine if woody debris was important to arthropods that did not feed on it. Forty-four arthropods from nine different orders were captured in higher numbers in traps near logs when compared to traps along a drift fence of equal length. In other studies, woody debris was removed annually from 9 ha plots and compared to undisturbed controls. Overall abundance of arthropods on live tree boles was reduced by removal. Woodroaches, an important prey of an endangered woodpecker, were more abundant in snags than in logs. However, the two habitats were approximately equal in importance because log volumes were much higher. These studies show that large woody material in southern forests is an important habitat for arthropods and its removal may affect higher order predators not directly dependent on it for food.

Ants and Woody Debris in Sub-Boreal Conifer Forests

S. Lindgren, *University of Northern British Columbia, Prince George, British Columbia*

This paper describes preliminary and planned research on the role of ants relative to woody debris in these northern ecosystems. Preliminary surveys revealed that a majority of ant species found in sub-boreal forests in central British Columbia utilize woody debris for nesting. Size and integrity are important for some species, e.g., *Camponotus herculeanus*, which use large, relatively intact logs and stumps or heart-rotted standing trees, while other species show little preference.

WORKSHOP 5.1

APPLICATION OF BEHAVORIAL CHEMICALS TO INTEGRATED FOREST PEST MANAGEMENT

MODERATORS:
Bark Beetle Section – **R.F. Billings,** *Texas Forest Service, Lufkin, Texas*
Defoliator Section – **J. Wenz,** *US Forest Service, Sonora, California*

Moderator Summary – Bark Beetle Section: The bark beetle session focused on current and potential approaches to bark beetle management with emphasis on behavioral chemicals for survey and control.

Moderator Summary – Defoliator Section: The four defoliator presentations summarized below illustrate the operational use of behavioral chemicals in forest pest management systems. The uses range from mating disruption for the Douglas-fir tussock moth in the west and the gypsy moth in the east to monitoring population trends for western budworms and the tussock moth. These examples reflect the successful development and application of applied forest entomological research. Future needs for defoliator-related behavioral chemicals are considered on an ongoing basis by the Western North American Defoliator Working Group.

Research on the Chemical Ecology Interactions between Bark Beetles and Their Predators in South Mexico

J.E. Macías-Sámano, *El Colegio de la Frontera Sur, Chiapas, México*

We expect to find differences in response to semiochemicals of *Dendroctonus frontalis* and *Ips grandicollis* populations and their predators in South Mexico, from those already reported in the southern United States. In a very simple approach, we challenged local populations of these two bark beetle species with commercially available pheromones. Qualitatively, we compared insect responses to these compounds with those responding to local pheromone sources. We did not find significant differences in responses. Even though qualitative analysis is debatable given our experimental design, we conclude that responses by *D. frontalis* to commercial pheromones are very low.

Updates on Semiochemical Regulatory Issues

S. Burke, *Phero Tech. Inc., Delta, British Columbia*

a) Status of MCH Bubble Cap registration: US Environmental Protection Agency (EPA) registration is firmly in place. The product cannot be used against Douglas-fir beetle in California. State level registrations are renewed on an annual basis for Idaho, Montana, Oregon and Washington. Canadian registration is being explored with the Pest Management Regulatory Agency (PMRA), but it is uncertain if the product will be registered for 2002.

b) Verbenone Pouch: An amended registration was submitted in March 2001. Of issue were actives versus contaminants, the nature of inert release matrix and Worker Protection

Safety language on the label. As of May 2001, Phero Tech has not received a response from EPA except to acknowledge receipt of the package.

c) Straight Chain Lepidoptera Pheromones versus other semiochemicals: The USA and Canada have relaxed the data requirements for Straight Chain Lepodoptera Pheromones (SCLPs). Significant changes are focused on residue analysis (especially food crops) and environmental degradation and fate. There has been no additional relaxation for registration of other pheromones for the last few years. An exemption from Experimental Permits for test areas in forestry not exceeding 100 ha is now in place in both countries; however, both SCLPs and other pheromones must be contained in macro release devices and not exceed 375g AI/ha. The EPA seems to have a better handle on non-pheromone semiochemicals (e.g., kairomones and allomones) and can be approached regarding the 100 ha exemption rule. The PMRA seems far less familiar and thus more hesitant to entertain such exemptions. In the future it is hoped that both EPA and PMRA will amend biochemical pesticide regulatory requirements so that non-pheromone semiochemicals data requirements and exemptions are relaxed as well. Two SCLPs mating disruption products were recently registered in the USA and Canada through a concurrent, coordinated application (3M/Bedoukian).

d) USA/Canada Harmonization:
For pheromone registration, most of the data requirements have been harmonized. The major remaining difference is that Canada officially asks for efficacy data whereas the USA does not. Note, however, that the USA reserves the right to ask for efficacy data and often exercises this right. The Environmental Protection Agency's interest in efficacy seems more acute when products are likely to be used on public lands.

e) OECD Countries:
Participating countries are Austria, Australia, Belgium, Canada, Finland, France, Germany, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Spain, Sweden, and the United States. There is a general attempt to harmonize semiochemical registration requirements in all these countries. The USA is the example the others are looking at. Currently some, but very few, OECD countries require registration for monitoring traps so this isn't a big issue. Most OECD countries have a flatter tier testing hierarchy with some Tier II tests (much more involved and expensive) elevated to a Tier I level. These additional Tier I testing requirements will add significant cost to registrations. Also, many tests in the USA are considered CR—conditionally required. This means that the potential registrant will not need to do the test unless the registering officer makes the request. In most OECD countries, many CR tests are required (R). The registrant must undertake the test unless a waiver is applied for and granted. Registrants generally find the latter situation overkill and fraught with uncertainties and unnecessary efforts.

f) Biopesticide Industry Alliance (BPIA):
The BPIA has been in existence for the last couple of years. Most member companies are involved in registering microbials. However, they include semiochemicals and may replace (assimilate) the American Semiochemical Manufacturer's Association, which was instrumental in getting the relaxations for SCLPs. A significant thrust of the BPIA is self regulation to avoid snake oil promoters and steer regulatory bodies away from them. Another trust is voluntary quality control compliance through checks by independent, third party checkers.

Southern Pine Beetle Outbreaks in the Southern United States and Central America: Current Status and Potential for Behavioral Chemical Applications

R. F. Billings, *Texas Forest Service, Lufkin, Texas*

Populations of the southern pine beetle (SPB), *Dendroctonus frontalis*, have reached outbreak levels in 2000 and 2001 in the southeastern United States and in Belize, Guatemala, Honduras, Nicaragua, and El Salvador. Control measures to date vary from country to country, but the more successful ones consist of mechanical methods to disrupt pheromone production and halt infestation expansion (cut-and-leave and cut-and-remove). The actual and potential uses of synthetic behavioral chemicals for survey and control of SPB in North and Central America were discussed. The SPB prediction system, which involves predictions of SPB trends based on early-season pheromone trap catches of SPB and a major predator (*Thanasimus dubius*) has successfully been implemented annually in 14 southern states since 1986. In 2001, this system correctly forecasted the SPB outbreaks that occurred east of the Mississippi River and the low SPB populations in Louisiana, Texas, Oklahoma, and Arkansas. This prediction system is being expanded in 2001 to also include Delaware, Kentucky, and Ohio. Annual predictions are now available on the Internet. The Verbenone Pouch was registered by the Environmental Protection Agency in 1999 for SPB control, but has seen little operational use to date. An improved gel formulation of verbenone is currently being field tested and awaits EPA registration. Verbenone was found to inhibit trap catches of SPB in Honduras. However, cut-and-leave remains the most recommended control for SPB infestations in Central America, based on 20 years of excellent results with this tactic in Honduras. Cut-and-leave, in effect a mechanical manipulation of SPB semiochemicals to halt infestation spread, has been successfully introduced and implemented in Nicaragua recently to address a severe SPB outbreak.

Pheromone Monitoring of Western Budworms

C.G. Niwa, G.E. Daterman and **C. Sartwell (retired),** *US Forest Service, Corvallis, Oregon*
J. Wenz, *US Forest Service, Sonora, California*

A pheromone monitoring system was developed to predict subsequent defoliation by the western spruce budworm, *Choristoneura occidentallis*. Half-gallon milk carton sticky traps were baited with a 92:8 mixture of E-11 and Z-11 tetradecenal. Lures were extremely weak, containing about 0.035 micrograms of synthetic pheromone, so that traps would not saturate at moderate to high population levels. Seven areas, each approximately 8 000 ha in size, were monitored using 27 traps per area. Traps were deployed in early July when budworm larvae were pupating, and were retrieved in late August. The following year, 81 trees were rated for defoliation in each of the study areas. The number of male moths caught in summer are highly correlated with defoliation occurring the next year, r = 97%. Pheromone trapping is one component of an operational survey system used in the pacific northwest United States (US Forest Service, Region 6; Department of the Interior (USDI) Bureau of Indian Affairs (BIA); States of Oregon and Washington; and on private lands) to monitor areas where management activities are being considered due to timber, wildlife habitat, or other resource concerns. When insecticide treatment is under consideration, pheromone trapping helps to refine analysis unit boundaries by further defining outbreak areas.

Pheromone baited traps were used to determine the distribution and relative abundance of *C. carnana*, *C. retiniana* and *C. lambertiana subretiniana* in the central Sierra Nevada of California. Pheromone components of all three species have been identified and provide powerful attractant sources for detection monitoring. The two fir-feeding species, *C. carnana* and *C. retiniana*, were trapped in white, red and Douglas-fir dominated stands, while *C. l. subretiniana* was captured in Jeffrey and lodgepole pine stands. Douglas-fir and white fir have been identified as principal hosts of *C. carnana* (Harvey 1985). However, in the central Sierra Nevada, this species was trapped in very low numbers in both white and red fir stands, and was only abundant in predominately Douglas-fir stands. *Choristoneura retiniana* was most abundant in white fir stands, followed by red fir and Douglas-fir. *Choristoneura l. subretiniana* was consistently recovered in greater numbers in lodgepole pine compared to Jeffrey pine stands. Pheromone trapping in different host types provides important baseline data on *Choristoneura* spp. that is useful in the future protection of forest resources in this region.

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Using Mating Disruption to Manage Gypsy Moth, *Lymantria dispar* (L.): a Review

R.C. Reardon, *US Forest Service, Morgantown, West Virginia*

The gypsy moth, *Lymantria dispar* (L.), is a serious defoliator of broadleaved forests in eastern North America. Historically, populations of this insect pest have undergone periodic outbreaks to extremely high densities that resulted in widespread defoliation to an average of one million forested hectares per year. The current option for suppressing potentially defoliating populations is the use of insecticides, primarily *Bacillus thuringiensis kurstaki*, Gypchek and diflubenzuron.

The identification and production of the synthetic gypsy moth sex pheromone or disparlure provided the opportunity to implement a prevention strategy by managing sparse gypsy moth populations using mating disruption. The gypsy moth is not an ideal candidate for mating disruption due to its high fecundity. In addition, males are highly polygamous, and natural distribution patterns of adult females are not random but clumped or aggregated. Good characteristics of the gypsy moth for mating disruption include flightless females, low mating success of females at sparse densities, limited dispersal of the majority of males beyond a few hundred meters, and one generation per year.

Since 1971, many attempts have been made to use mating disruption to manage populations of the gypsy moth. In general, these results (1971 to 1989) were inconsistent in terms of efficacy and formulation performance, and disparlure release profiles were not monitored during the treatment year. In 1990, a Gypsy Moth Mating Disruption Working Group was formed with multi-agency representation (e.g., US Forest Service, Agricultural Research Service, Animal and Plant Health Inspection Service, US Environmental Protection Agency, Hercon Environmental Co.). Through cooperative research and development efforts, the working group conducted field and laboratory studies to solve problems associated with the use of mating disruption to manage sparse-density gypsy moth populations. This coordinated effort resulted in mating disruption being used on approximately 500 ha per year in the early 1990s to 90 000 ha in 2001.

The plastic flake formulation Disrupt II (Hercon Environmental) is the only slow-release formulation registered by the US Environmental Protection Agency and used operationally to manage low-density populations of the gypsy moth. Formulation costs are approximately \$20/ha for the flakes and the active ingredient is \$22/ha for a 76 g AI per ha dose.

Status of Douglas-fir Tussock Moth Mating Disruption

I. Ragenovich, *US Forest Service, Portland, Oregon*

A Douglas-fir tussock moth (DFTM) (*Orgyia pseudotsugata*) outbreak is currently occurring in Oregon, Washington and Idaho. This outbreak offers an opportunity to continue development of DFTM pheromone as a tool for mating disruption. Research over the last 15 years has demonstrated that the DFTM pheromone (z/6/heneciosen-11-one) can be used to effectively disrupt mating and is, therefore, a potential management tool for this insect. These studies were done on small (0.3–16 ha) plots and tested at various dose rates. Results achieved from 74–81% reduction in egg masses (Daterman 2000, personal communication). Previous formulations used in experimental plots, such as the Conrail fibers, are no longer available.

Some questions that remain and are worthy of discussion include:

1. Is this technology effective on larger acreages that would be used in operational projects?

2. What are the best management opportunities for the use of this tool?

3. What dispenser and application equipment are available, or need to be developed?

4. DFTM is a very minor market, and there are a number of difficulties regarding both formulation development (interest of companies), and registration (cost). These obstacles are also true for other minor pest management tools. How can these be addressed and allow managers the options of these tools?

The pheromone must be able to elute from the carrier for the duration of the tussock moth flight period, approximately 60 days. It is a 21 carbon chain molecule. Two formulations, the Hercon Disrupt DFTM flake (modified from the Hercon flake used for gypsy moth disparlure) and a 3M Microencapsulated DFTM (a microencapsulated bead), will be tested. In the spring of 2001, elution rate tests on both products were set up under both controlled greenhouse and field conditions. Efficacy tests are planned for Idaho, and possibly north central Washington during the fall of 2001. Treatment plots will be a minimum of 50 acres in size, and treated at a rate of 30 grams/ha. Effectiveness of treatment will be determined by percent reduction in fertile egg masses.

Pheromone Monitoring of Douglas-fir Tussock Moth Populations

J. Wenz, *US Forest Service, Sonora, California*
G. Daterman, *US Forest Service, Corvallis, Oregon*
K. Sheehan, *US Forest Service, Portland, Oregon*

Douglas-fir tussock moth (DFTM) populations can increase to outbreak levels abruptly with little warning. The DFTM pheromone has been used since 1979 in a monitoring effort to predict outbreaks and provide adequate time for environmental analyses, decision making and efficacious suppression where warranted. This early warning system involves a network of plots consisting of five, one-half gallon milk carton delta-shaped traps baited with one component (Z-6-heneicosen-11-one) of the DFTM pheromone, per plot. Approximately 750 plots are maintained annually throughout the western USA. Thirteen DFTM outbreaks have occurred since 1979. The system has proven effective. Analysis indicates that the early warning system provided a 1 to 3 year early warning for seven of the nine outbreaks for which adequate data was available. Recommendations to improve system implementation and operation include: (1) maintaining plots, evenly distributed throughout the host type, at a density of about 1 plot per 3 000 acres; and (2) prompt initiation of follow-up pupal, egg mass and larval ground sampling in areas of management concern when trap catches exceed threshold levels.

WORKSHOP 5.2

THE MOUNTAIN PINE BEETLE IN NORTH AMERICA: STATUS, TRENDS AND MANAGEMENT

MODERATORS:
L. Safranyik, *Canadian Forest Service, Victoria, British Columbia*
B. Bentz, *US Forest Service, Logan, Utah*

Moderator Summary: The main objectives of this workshop were to review 1) recent trends in mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) infestations in Canada and the United States; 2) phenology in relation to geographic distribution, climate, host–insect interactions, and seasonality; and 3) approaches to management, including assessment of effectiveness of management programs.

Tree mortality caused by MPB populations has been increasing in both the United States and Canada since the early 1990s. The MPB continues to be the most damaging forest agent in British Columbia, with lodgepole pine infestations currently extending over 280 000 hectares. In the United States, populations are building in the lodgepole pine type in Idaho and Montana, and ponderosa pine in Colorado, South Dakota and Wyoming. Increased activity has also been observed in the five needle pines, including high elevation whitebark pine and limber pine, and lower elevation sugar pine. Local variation by tree species in both the onset and rate of increase in infestation has been observed in some areas. The apparent synchronous cycling of MPB populations over much of the geographical range may be a consequence of the so called Moran effect which states that if populations are under regulation by the same endogenous factors, synchronous cycling of populations will occur over broad areas provided climatic factors are correlated.

In a review of MPB phenology, it was hypothesized that a univoltine lifecycle with the attack period occurring during mid- to late summer offers optimum survival because broods will overwinter in the most cold hardy stage and attack occurs during the period of decreasing host resistance. Synchronous emergence, which increases the chances of successful mass attack, is mediated through different thresholds of development for the various brood stages. Mountain pine beetle populations are capable of maintaining a univoltine lifecycle with synchronous emergence times over a very broad latitudinal and elevational distribution, encompassing a wide range of temperature regimes. Recent research suggests that regional variation in development time may enable MPB populations to sustain a univoltine lifecycle, and hence population success, throughout its range. Simulations of a MPB phenology model suggest that increased temperatures of 2.5ºC, as predicted by general circulation models for a CO_2 doubling scenario, could result in an increase in univoltine lifecycles at higher elevations and northerly latitudes, areas where either fractional or semivoltine lifecycles have been the norm. Current MPB outbreaks in high elevation stands of whitebark pine could be the initial signs of this phenomena.

Approaches to MPB management were reviewed from the early years and contrasted with current practice. The main differences are the relatively recent development and use of hazard/risk rating systems and decision support tools that enable managers to select the best strategies and tactics to reduce losses. As well, effective silvicultural methods of control, such as shorter rotations in high hazard areas, forming age and species mosaics, and spacing mature trees to create unfavourable climatic conditions for the beetle, are being used increasingly where suitable. Attractant semiochemicals are used routinely for flight monitoring, while research continues on interruptive aggregation semiochemicals and non-host tree volatiles for protecting high value trees and stands. An interesting approach, involving a stand level model of MPB dynamics combined with a Spatially Explicit Landscape Event Simulator (SELES), was presented to assess the effectiveness of operational management programs by the British Columbia Ministry of Forests in the Kamloops Forest District. The approach allowed assessment of control effectiveness in terms of number of trees killed in relation to no control and various other management scenarios.

Current Status of Mountain Pine Beetle Populations in the United States

S.J. Kegley, *US Forest Service, Coeur d'Alene, Idaho*

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is the most destructive bark beetle in western North America. Hundreds of thousands of trees are killed annually in the western United States. In Region 1 (Montana, Northern Idaho), populations have increased over the past 3 years to 708 300 trees killed on 149 200 acres in 2000. Lodgepole pine is the major tree species affected. Beetle populations have also been increasing in Region 2 (Colorado, South Dakota, Wyoming) since 1995. Over 326 000 trees (mainly ponderosa pine) were killed in 2000. In Region 3 (Arizona, New Mexico), mountain pine beetle infestations increased from 195 acres in 1999 to 810 acres in 2000. In Region 4 (Southern Idaho, Utah, Nevada) mountain pine beetle populations have increased over the past 3 years to 43 000 trees (mostly lodgepole pine) killed in 2000. Impact is most severe to recreation and fisheries resources. In Region 5 (California), mortality has increased in sugar pine, especially following fire injury, and remains chronic in lodgepole pine. Beetle populations decreased slightly in Region 6 (Oregon, Washington), to 106 447 acres infested with an average of 2.9 trees per acre killed in 2000. There have been significant decreases in mortality of western white pine and ponderosa pine there with increases in whitebark pine, sugar pine, and lodgepole pine mortality. In Regions 1, 2, 4, and 6, there have been recent increases in high elevation whitebark pine and limber pine mortality due to mountain pine beetle activity in association with other agents.

Seasonality in the Mountain Pine Beetle: Causes and Effects on Abundance

L. Safranyik, *Canadian Forest Service, Victoria, British Columbia*

The mountain pine beetle (MPB) occurs from northern Mexico north to central British Columbia (latitude 56N) and from the Pacific Ocean in the west to North Dakota, covering a broad range of climatic conditions. Yet, throughout much of its distributional range, MPB has a one-year life cycle with the attack period occurring during the period from mid- to late summer. Areas where the most severe outbreaks occur are characterised by a univoltine life cycle. At higher elevations and near the northern limit of the beetle's range, often more than 1 year is required to complete the life cycle and the average minimum winter temperatures are lower than the maximum super cooling ability of the most cold hardy brood stage, the mature larvae. South of about latitude 40N, often 2 generations are produced per year, with emergence and flight periods during mid- to late spring and mid- to late summer. The question arises, why should a univoltine life cycle with attack period occurring during the later half of summer be advantageous for the beetle?

The clues to the answer lay in the following statements: 1) under a given set of environmental conditions, optimum phenology is that which offers the highest probability of brood survival; 2) two of the most important factors of mortality are those occurring during host colonization, due to host resistance, and during the period of dormancy.

Host resistance in lodgepole pine increases from the beginning of growth in the spring to a maximum during early July and then declines during the later part of summer. Thus, attack during the later part of summer would increase the chance of host colonization. Cold hardiness varies among brood stages. Eggs are the least cold hardy, followed by pupae, adults and larvae. Among larvae, the large (third and fourth instar) larvae are the most cold hardy. Therefore, broods overwintering as large larvae have the greatest probability of survival during the winter. A consequence of host colonization during mid- to late summer is that broods are usually in larval stages prior to the onset of cold weather in the fall. Definitive work by Barbara Bentz, Jesse Logan and colleagues have demonstrated that differential development thresholds for the various brood stages tend to result in overwintering in the most cold-hardy stages. In areas with very cold winters, and common occurrence of unseasonably cold weather, the greater mortality of the least cold-hardy brood stages tends to result in further reductions in the variance of life stage distribution.

In areas where more than one generation is produced per year, necessarily there are two or more attack periods, at least one of which will occur during the late-spring period when host resistance is increasing. Moreover, because temperatures are increasing and are relatively high in comparison with development thresholds, the age distribution of broods is expected to have greater variance. This should result in reduced synchrony of emergence and attack success. Simulation modeling of the phenology of MPB using synthetic climate scenarios indicated that variation in the length of the life cycle was least when maximum temperature during the growing season was near the optimum (24°C). At this climate regime, peak emergence was on Julian day 208 and varied less than 5 days.

It is concluded that for MPB, univoltine development with emergence during mid- to late summer tends to ensure maximum brood survival during the dormant season, and the greatest success in host colonization.

Mountain Pine Beetle Population Distribution: Influences of an Adaptive Seasonality

B.J. Bentz and **J.A. Logan,** *US Forest Service, Logan, Utah*
J.A. Powell, *Utah State University, Logan, Utah*

Mountain pine beetles are widely distributed across western North America, and are found feeding in at least 12 native species of *Pinus*. Recent results suggest genetically based latitudinal differences among widely distributed populations. Development time of populations in central Idaho was significantly faster and adults were significantly smaller than beetles from a population in southern Utah (Bentz et al. 2001). Development time is an important aspect of maintaining an appropriate seasonality. For the mountain pine beetle, appropriately timed and synchronous emergence are both required for seasonality maintenance. Model results suggest that an adaptive seasonality for this nondiapausing insect is a consequence of the interaction between developmental parameters and seasonal temperatures (Logan and Bentz 1999; Jenkins et al. n.d.). Model simulations using temperatures from the current lodgepole pine distribution indicate regions of adaptive seasonality, and thus habitats, in which mountain pine beetle populations are successful. Based on seasonality maintenance concepts, the impact of global warming on population success will differ among regions. Some areas which are currently adaptive could become maladaptive, while in regions which are currently not favorable for mountain pine beetle population success, temperatures could rise just enough to produce a univoltine lifecycle where fractional lifecycles previously existed.

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Managing Stands to Reduce Mountain Pine Beetle-Caused Mortality in the Western United States

K. Gibson, *US Forest Service, Missoula, Montana*

Mountain pine beetle (*Dendroctonus pondersosae* Hopkins) is arguably the most significant and damaging insect pest of coniferous forests in western North America. In the Northern Region alone, over the past 20 years, in excess of 3 million acres of host type (more than 90% of which was lodgepole pine) have been infested. More than one-quarter billion trees have been killed. Peaking at nearly 2.5 million acres in 1981, beetle populations declined during the 1980s. Infested acres began to increase in the early 1990s, as hundreds of thousands of acres of lodgepole pine began to reach overmaturity. In 2000, almost 150 000 acres were once again infested in western Montana and northern Idaho, and populations are increasing in many parts of the beetle's range.

In the 1970s, research entomologists in the western United States and Canada recognized that stands infested by mountain pine beetles shared common characteristics. This led to development of hazard rating systems that helped identify host stands most likely to experience beetle outbreaks. Soon benefits of preventive, rather than suppressive, actions were realized. Demonstrations illustrated the effectiveness of silviculturally managed host stands to prevent population buildups, thereby reducing beetle-caused mortality. Into the 1980s, hazard reduction through sanitation thinnings were implemented in lodgepole and ponderosa pine stands threatened by mountain pine beetles; these became effective alternatives to salvage of beetle-infested trees, or stand regeneration. To date, combinations of sanitation/salvage, regeneration and basal area reductions are used as site and stand conditions allow, and management objectives warrant.

In the mid-1980s, semiochemicals affecting mountain pine beetle behavior were identified, synthesized, and became commercially available. Their use made manipulating beetle populations to our advantage more feasible, and silvicutural management of stands to reduce beetle-caused losses even more effective. Attractant pheromones are commonly used. Anti-aggregants are being tested and hold promise. The latter may find wide applicability—especially in areas too sensitive for traditional management activities, such as recreational and high-elevation sites.

Mountain Pine Beetle in British Columbia

P.M. Hall, *British Columbia Ministry of Forests, Victoria, British Columbia*

Mountain pine beetle, *Dendroctonus ponderosae* Hopk., has an extensive history in British Columbia; it was first recognized as the major forest insect in the province in 1913 by J. M. Swaine, who conducted the first survey of forest insects in the province (Swaine 1914). Mountain pine beetle continues to be the most damaging forest insect in British Columbia. Large outbreaks occurred in the province in the late 1970s (the Flathead outbreak) and in the early to late 1980s (the Chilcotin outbreak). Both of these infestations extended over several hundred thousand hectares, causing high levels of tree mortality in mature and overmature pine stands.

An endemic level of infestation exists between large outbreaks; there are approximately 50 000 ha of infestation active in lodgepole pine, *Pinus contorta* Dougl., stands throughout the province in any given, non-outbreak, year. This is likely a reflection of the continued presence of large areas of susceptible host in areas with a moderate to high climatic hazard.

Mountain pine beetle infestations in British Columbia currently extend over 280 000 ha. While infestations exist in many or most of the susceptible type in the province, the largest outbreak, encompassing over 190 000 ha, exists in the west-central area of the province—including infestations in the Prince Rupert, Prince George and Cariboo Forest Regions. Other forest regions in the province are also experiencing increases in mountain pine beetle activity. Outside of the province, approximately 800 infested trees have been detected in national parks on the border between British Columbia and Alberta. Overall, normal summer temperatures, mild winter temperatures for the past 2 years, and large amounts of susceptible host indicate a continued spread and intensification of the mountain pine beetle infestations in the province. While infestations may well intensify in many areas, a further spread of approximately 30% in area is anticipated without management.

Management efforts are being directed to areas of infestation where significant reductions in further damage can be achieved. While it is unlikely that future outbreaks can be avoided through aggressive management, it is the philosophy of the province that inter-outbreak periods can be prolonged and that eventual outbreak intensities and impacts can be reduced through prompt, appropriate action.

Current management actions depend on the proper implementation of the following activities: aerial overview surveys; specific operational level surveys in priority areas; detailed ground assessments; directed harvesting to areas of current attack; and, single tree treatments, where warranted.

The provincial strategy is based on the elements of bark beetle/host interactions and the appropriate application of proven effective strategies and tactics at the local level. The strategy is designed to concentrate limited resources where management can have an impact and identify situations where it is not possible to have an impact on the course of infestations and tree mortality.

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Landscape Modeling of Management Scenarios for the Mountain Pine Beetle (*Dendroctonus ponderosae*): a Case Study

T. Shore, B. Riel and **L. Safranyik,** *Canadian Forest Service, Victoria, British Columbia*
A. Fall, *Simon Fraser University, Burnaby, British Columbia*

The Canadian Forest Service has developed a population dynamics model (Safranyik et al. 1999) for the mountain pine beetle. We have also, more recently, developed a stand-based infestation and impact model for this bark beetle. In the past year we have integrated our stand-based model with the Spatially Explicit Landscape Event Simulator (SELES) (Fall and Fall 1996) which handles dispersing beetles and tracking resultant infestations across the landscape. Recently, a project was initiated by the British Columbia Ministry of Forests that provided an opportunity to utilize this modeling approach to examine the effect of various management scenarios on tree mortality. Results are presented.

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WORKSHOP 5.3

SHORT ROTATION FOREST ENTOMOLOGY

MODERATOR:

T.E. Nebeker, *Mississippi State University, Mississippi State, Mississippi*

Moderator Summary: The intent of this workshop was to identify, quantify and qualify long-standing and established issues associated with the culture of short rotation wood crops. The workshop gave us a glimpse of some of the issues and future issues that needs to be addressed in our research and management efforts. The group was sensitized to these issues and challenges.

Trees species involved in the presentations included cottonwood, *Populus deltoides* (clones), hybrid cottonwood (*P. trichocarpa* ¥ *P. deltoids* and *P. deltoids* ¥ *P. nigra*), loblolly pine (*Pinus taeda*), sweetgum (*Liquidambar styraciflua*) and sycamore (*Platanus occidentalis*). In most cases, trees were under intensive management including fertigation (trees being watered, fertilized and in some cases, insecticides being applied through drip irrigation systems). Of particular interest were insect and pathogen associations as well as new insect associations related to these intensive cultural practices.

For the first time, information was presented that documents the impact that naturally fluctuating populations of the defoliator *Chrysomela scripta*, cottonwood leaf beetle (CLB), has on the growth of cottonwood. After 3 years, where four *Populus* clones are being followed in a long-term impact study at Iowa State University, the difference in above-ground volume loss ranged from 50% to 73%. Hence, information on the real economic impact of this species is being developed. An initial model for monitoring spring emergence of over-wintering CLB adults and subsequent life stages was also presented. The goal was to utilize this model in the timing of management tactics, if necessary.

As the culture of these short rotation woody crops intensifies, so does the potential of new associations. For example, a root-feeding aphid has been discovered causing mortality to hybrid poplars during their first growing season. This is the first documented case of mortality to hybrid poplars caused by root aphids. They may also be implicated in the reduction of growth of older trees in the area where the root-feeding aphids were discovered. This is being further investigated.

In an exciting but controversial area of potential, gene stacking, insect resistance and herbicide tolerance were discussed. The effects of the Cry3A gene and a herbicide-ready gene were presented, which in turn stimulated a great deal of discussion. This is a critical break-through, and future biotech advances are envisioned; at the same time, we are gaining understanding of the associated bark beetle pathogens on host (pine) defensive systems. These are model examples of the need to extend our efforts in understanding host/insect microorganism/environmental interactions—especially if we want to understand the mechanisms that may lead to a real break-though in our management approaches, and find solutions to long-standing pest problems.

Cottonwood Fiber Farm Pest Management: Emphasis on Cottonwood Leaf Beetle and New Insect Associations

T.E. Nebeker and **M.D. Warriner,** *Mississippi State University, Mississippi State, Mississippi*
E.R. Hart, *Iowa State University, Ames, Iowa*

Chrysomela scripta F. (CLB) is one of the most important economic pests of *Populus*. Accurate determination of when CLB are present in the field could greatly aid in the efficient management of this herbivore. To address this problem, we have compiled data regarding the developmental rate of the CLB to test associated models of development. Utilizing our models, there are 118–138 day degrees (DD) degree centigrade required prior to adult emergence in the spring with a December 1 starting date for DD accumulation. Presences of other life stages can also be predicted utilizing the DD model. Timing of pest management activities may be improved by utilizing DD models.

Reporting here for the first time is the presence of a root-feeding aphid on hybrid poplar. Root feeding was severe enough in the spring of the year to cause mortality in new plantings. The aphid is in the genus *Pemphigus*. The species has not been determined because winged adults have not been found on the roots. *Pemphigus populitransversus* and *P. nortoni* were found on the leaves of associated trees; however, the root host for *nortoni* is unknown. The secondary root host for *P. populitransversus* are Crucifereae. They have not been reported from roots of *Populus*.

Transgenic Hybrid Poplars Exhibit High Levels of Resistance to Chrysomelid Beetles under Field Conditions

R. Meilan, C. Ma, S. DiFazio, P. Payne, T. Agens, L. Miller and **S. Strauss,**
Oregon State University, Corvallis, Oregon

Insect pests often have significant impacts on growth of poplar plantations. We have field-tested hybrid cottonwood (*Populus trichocarpa* ¥ *P. deltoides* and *P. deltoides* ¥ *P. nigra*) lines that were transformed with a rebuilt *Cry3A Bacillus thuringiensis (B.t.)* toxin gene. This gene imparts resistance to the primary insect pest of poplars in the USA, the cottonwood leaf beetle *(Chrysomela scripta* F.*)*. Nearly all of the transgenic lines were virtually free of feeding damage under natural insect pressure east of the Cascade Mountains, whereas the non-transgenic lines sustained significant levels of defoliation. As a consequence, the non-transgenic plants grew an average of 13% less than did the transgenic lines in their first growing season. We are now testing other *B.t.* transgenes in an effort to develop a resistance management plan.

Arthropod Pests in a South Carolina Short Rotation Woody Crop Plantation

D.R. Coyle, *US Forest Service, New Ellenton, South Carolina*

The Short Rotation Woody Crops Cooperative Research Program established a 21-ha tree plantation in spring 2000. Its purpose is to examine fundamental controls of tree growth and productivity, including nutrient balance and allocation, water use efficiency, and the effects of varying irrigation and fertilization levels. The plantation consisted of two cottonwood clones, loblolly pine, sweetgum, and sycamore trees. Several pest problems arose during the first growing season: cottonwood leafcurl mite, cottonwood leaf beetle, and poplar tentmakers in *Populus*; weevil species and Nantucket pine tip moth in loblolly pine; and minor insect pests on sweetgum and sycamore. Cultural and chemical treatments were applied with varying success in 2000, and a more intensive pest management plan is being implemented in 2001.

Cottonwood Leaf Beetle Defoliation Impact on Populus Growth and Above-Ground Volume in a Short Rotation Woody Crop Plantation

D.R. Coyle, *US Forest Service, New Ellenton, South Carolina*
J.D. McMillin, *US Forest Service, Rapid City, South Dakota*
R.B. Hall and **E.R. Hart,** *Iowa State University, Ames, Iowa*

Impact of cottonwood leaf beetle (*Chrysomela scripta* F.) defoliation on four plantation-grown *Populus* clones was examined over three growing seasons. We used a split-plot design with two treatments: protected (by insecticides) and unprotected. Defoliation was reduced significantly on protected trees each year. Tree height and diameter at 1 m were measured annually after leaf fall; above-ground volume was calculated. All parameters increased significantly in protected plots and varied among clones. Defoliation varied among clones and resulted in 50% to 73% above-ground volume loss. Defoliation also resulted in increased lateral branching and forked terminals on unprotected trees.

Loblolly Pine Response to *Ophiostoma minus*

K.D. Klepzig, *US Forest Service, Pineville, Louisiana*

We investigated the responses of loblolly pine grown at SETRES (Southeast Tree Research and Education Site) (a randomized complete block design—control, irrigation, irrigation plus fertilization, fertilization) to mass wounding and inoculation with *Ophiostoma minus*. We measured 24 hour oleoresin flow 1 day before, and 1, 15 and 105 days after inoculation. At 1 day post–treatment, resin flow was reduced in wounded and wounded and inoculated trees. At 105 days post-treatment, wounded and inoculated trees produced significantly higher resin flows than control or wounded-only trees. This may indicate an induced response to fungal inoculation. Irrigated and irrigated plus fertilized trees produced the highest observed resin flows.

WORKSHOP 5.4

WHY AREN'T MORE DECISION SUPPORT SYSTEMS FOR INSECT MANAGEMENT ACTUALLY BEING USED?

MODERATORS:
D.A. MacLean, *University of New Brunswick, Fredericton, New Brunswick*
R. Coulson, *Texas A&M University, College Station, Texas*

Moderator Summary: To some extent, the title of this workshop was a misnomer, in that all four speakers tended to emphasize characteristics necessary for success of pest management decision support systems (DSS). A more appropriate title for the workshop might have been "What do you have to do to get DSS used?" The four speakers included an equal mix of Americans and Canadians, and of government and university representatives. Presenters included Wayne MacKinnon (Canadian Forest Service), Eric Smith (USDA Forest Service), David MacLean (University of New Brunswick), and Robert Coulson (Texas A&M University). One theme that emerged was that the original vision for computer-aided decision support preceded the tools needed to accomplish the task. However, both the tools and databases are now catching up with that vision.

Specific DSS presented as examples included the Spruce Budworm DSS, FASIMS (Fire Ant Spatial Information Management System), and current efforts to use natural disturbance as a template for helping to set forest landscape objectives for species, age class, and patch sizes, and to define appropriate silviculture and harvest treatments consistent with natural disturbance.

The following topics were discussed as important elements of successful DSS:

- Decision Support Systems should address a real and serious problem to engender user support
- the need to be clear on who is the decision maker and who are the potential users
- necessity for early and often input from intended users during development
- development of good working relationships/partnerships with end-user clients
- requirement for significant levels of funding and commitment to the development project
- DSS should be useful, reliable (correct), efficient, accessible, and geospatial
- DSS applications should mesh with operational procedures, which may change over time
- importance of aiming for something that works, not the ideal perfect model
- DSS should clearly demonstrate incremental benefits to the intended users
- need for a strong basis in scientific relationships, and to add value to raw insect population or defoliation data
- black box systems will not be used, so it is important that the underlying science, assumptions and limitations be clear
- DSS should include clear depiction of the consequences of no action as one decision
- technology transfer to end-users is critical; detailed workshops with hands-on training exercises and a low student:instructor ratio (3:1) work well
- complete and thorough documentation is necessary for user reference
- be flexible enough to work in multiple jurisdictions and adapt to new planning frameworks
- from an agency perspective, DSS must be maintained (software and hardware), contemporary, and economical
- internet delivery of information is emerging, and this facilitates implementation for multiple sites
- long-term maintenance and care and feeding of DSS is a serious problem that has not yet been satisfactorily addressed in most cases, but is critical.

Spruce Budworm DSS: Making It an Operational Reality

W. MacKinnon, K. Porter, K. Beaton and **M. Budd**
Canadian Forest Service, Fredericton, New Brunswick
D.A. MacLean, *University of New Brunswick, Fredericton, New Brunswick*

The Spruce Budworm Decision Support System (SBWDSS) is based on a geographic information system (GIS) that assists land managers in pest management and forest restructuring decision-making, by quantifying the marginal timber supply benefits of actions taken during spruce budworm outbreaks. Experience in implementing the SBWDSS for all forest in New Brunswick, and for test areas in four other provinces, will be described. For DSS acceptance and usefulness, it is essential to involve stakeholders and end-user clients at the early stages of design and development. The DSS should not be a black box but rather a system that meshes with existing operational procedures with an easy-to-use interface. For any relatively complex system, repeated explanation and demonstration, training workshops with a student/instructor ratio of about 3:1, and clear step-by-step documentation are necessary for gaining acceptance and a smooth transfer of the technology to users. We must constantly bear in mind that DSS stands for decision-support not decision-making system.

Decision Support Systems: Where are the Users?

E.L. Smith, *US Forest Service, Fort Collins, Colorado*

For many years, presentations on Decision Support Systems (DSS), real and proposed, have been made at meetings similar to this. Decision Support Systems for forest protection applications have been difficult to build, but even more difficult to get used. Why has it been so hard to get systems used that seem to have potential to improve decisions? What follows are my observations, which are based on American public forestry, and may not apply to Canadian forestry.

The whole decision process is divided into three parts: framing the decision and alternatives, analyzing the alternatives, and choosing the decision. The emphasis in American public forestry has shifted from timber extraction, economic efficiency, and providing a domestic timber supply to protection of ecological values, restoration of ecosystems and endangered species, and providing recreation opportunities. Decision Support System tools in the last century tended to focus on alternatives like harvesting timber, insecticide spraying, and providing economic benefits. While these alternatives have not completely disappeared, they are much less popular.

The impetus behind DSS for forest protection came from expanded computing power: the ability to perform complex analyses on large data sets. This focused DSS on the analysis phase of the process. Tools like harvest scheduling algorithms, insect population models, and stand growth and yield projection systems, which once took hours or days to run, now took seconds or minutes. A key source of data came from timber inventories, which focused on common tree species. Today, when public forestry decisions in the USA are often driven by public opinion, silvicultural legislation, and court decisions, an improved ability to perform complex analyses on large data sets is less important. Even when the decision is based on biological issues, the rare events and rare organisms, which often determine the outcome, are often poorly understood or poorly measured and therefore less amenable to analysis.

In a completely quantified system, choosing and implementing a decision alternative would be based on some univariate function, such as the net present value of a discounted cash flow, or a multi-criteria system of constraints and weights. Forestry decisions rarely rely on such procedures, and never have. Significant decisions are made by small or large groups of people: in conference rooms, in judges' chambers, while traveling back home together from a meeting in a pickup or airliner. Decision makers probably know that when this point in the process comes, they better not have to know what mixed integer programming is to understand why Alternative A is better than Alternative B.

Rather than giving up on clearly useful tools, or continuing to believe that users will soon be persuaded that this is what they need, perhaps developers of these systems should expect that no more than a few people are likely to actually operate them. Well-designed systems, which can integrate data and models from various sources and produce meaningful outputs, obviously have a place in our business. But maybe we should drop the decision thing and just think of them as information and analysis systems.

Pest Management DSS: What Decisions, by Whom, for What?

D.A. MacLean, *University of New Brunswick, Fredericton, New Brunswick*

Two distinctly different sets of users could use Decision Support Systems (DSS) for Integrated Forest Pest Management. Pest managers could use support with survey decisions, data interpretation, and planning where, when, and how to conduct treatments. Forest manager support could include scenario analysis of effects of insects on timber and non-timber values, incorporation into timber supply analysis, and optimization of silviculture and harvest treatments to reduce future insect-caused damage. Successful DSS implementation should clearly demonstrate incremental benefits to the intended users, and include extensive support during the technology adoption stage. Decision Support Systems should have a strong basis in scientific relationships, add value to raw insect population or defoliation data, include good documentation, and be flexible enough to work in multiple jurisdictions and adapt to new planning frameworks. These factors were discussed in the context of development of the Spruce Budworm DSS, which has been operationally implemented for all forests in New Brunswick and for test areas in four other provinces. A new emerging area of decision support relating to the natural disturbance paradigm was also discussed, namely using natural disturbance as a template for appropriate forest management. Elements include: 1) helping to set landscape-level objectives for species composition, age class distribution, and patch size distribution based on long-term natural dynamics; and 2) defining appropriate silviculture and harvest treatments through differentiating stand-replacing and gap-replacing disturbance regimes. One of the most critical components of DSS success is early and often input from intended users during development; scientist only development of DSS to help a user community is likely doomed to failure.

Internet Delivery of Smart Maps: the Fire Ant Spatial Information Management System (FASIMS)

R. Coulson and **D. Wunneburger,** *Texas A&M University, College Station, Texas*

Computer-based applications for planning, problem-solving, and decision support have obvious utility in environmental assessment, forest management, and forest protection. Products to facilitate development and delivery of integrated and spatially referenced systems are now available from commercial vendors. This circumstance greatly simplifies the issue of care and maintenance of applications and allows custom systems to be broadcast from a central location for use by a broad clientele. The Fire Ant Spatial information System (FASIMS) is an example of a system developed to provide internet delivery of spatial information. It integrates geographic information systems (GIS), database management, and internet technologies to provide smart maps of survey information.

WORKSHOP 5.5

ECOSYSTEM AND COMMUNITY RESPONSES TO FOREST INSECTS

MODERATOR:
R. Muzika, *University of Missouri, Columbia, Missouri*

Moderator Summary: The focus of forest insect management tends to overshadow an interest in ecological effects of forest outbreaks. Rather, we examine consequences of management activity, not the insect itself. Compounding the problem is the consideration that there are always multiple effects of insect outbreaks. In this session, we provide examples of a variety of forest insect and a breadth of regions and forest types, in order to discuss and understand the varying responses of forests to insects. Potential influences of insect outbreaks that we will focus on include overstory mortality, changing species composition, successional patterns, and nutrient dynamics.

Ecosystem Changing Impact of Southern Pine Beetle and Red Oak Borer in the Southern Region of the US Forest Service

F.L. Oliveria, *US Forest Service, Pineville, Louisianna*

Southern pine beetle, *Dendroctonus frontalis* (Zimmermann), is the number one cause of mortality of southern yellow pines in the United States. During 2000, tens of thousands of acres of pine were killed in the Southern United States. Over 30 000 acres were killed on the Bankhead National Forest in Alabama. The Daniel Boone National Forest in Kentucky lost over 90% of it conifer host type. This impact resulted in fauna and flora change. Combined with the absence of fire in these impacted areas, thousands of acres of the ecosystems, a fire sub-climax existing there for several thousand years, are changing.

Northern red oak, *Quercus rubra* (L.), and black oak, *Quercus velutina* (Lam.), have been silvicultural-favored species in the Ozark and Ouachita Mountains in Arkansas for many decades. Again, without the presence of fire in the landscape, oak regeneration has been minimal and now there are hundreds of thousands of acres of mature oak stands. With the combined effect of drought, oak decline, and abundant host type, the red oak borer, *Enaphalodes rufulus* (Haldeman), and other borer species have been released. There are hundreds of red oak borer attacks per tree. The intense competition for oviposition sites has resulted in the borers laying eggs and larvae developing throughout the trunk and into the primary limbs of the trees. Effects of the drought and first-year feeding of the larvae in the cambium is either girdling or effectively girdling the trees. The impact of the loss of this dominant crown species in the Ozark and Ouachita Mountains is changing the ecosystem over entire watersheds.

Ecosystem to Regional Analyses of Hemlock Woolly Adelgid Outbreaks in Southern New England

D.A. Orwig and **D.R. Foster,** *Harvard University, Petersham, Massachusetts*

Hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand), an introduced aphid-like insect from Asia, is expanding across the northeastern United States through the range of eastern hemlock (*Tsuga canadensis* (L.) Carr.) and has the potential to severely reduce or eliminate this important late-successional species. Chronic infestation and unimpeded migration of HWA has provided an unusual opportunity to examine the impacts of an introduced pest as it spreads. We have developed a multi-faceted research effort that examines stand and community reorganization dynamics, landscape patterns of HWA infestation, hemlock decline and mortality, and ecosystem function changes. Results suggest that HWA is generating profound changes in these forests, including rapid and widespread loss of hemlock and conversion to hardwood-dominated systems, increased cutting, accelerated nitrogen cycling, and altered decomposition.

Responses of Hardwood Forests in the Great Lakes Region to Multiple Disturbances

J.A. *Witter, University of Michigan, Ann Arbor, Michigan*
J.L. Stoyenoff, *University of Michigan, Ann Arbor, Michigan and Dow Gardens, Midland, Michigan*
J.L. Yocum, *University of Michigan, Ann Arbor, Michigan*

The Great Lakes hardwood forest ecosystems have been impacted by many disturbances over time. This presentation discusses our research on several major abiotic and biotic stressors: drought, frost, air pollutants, forest tent caterpillar, gypsy moth, and basswood thrips. Effects range from minor defoliation, crown dieback, and growth reduction to severe stress causing extensive tree mortality. The most serious problems are seen on poor sites, in suppressed and intermediate crown layers, and where multiple disturbances are interacting. Overall, disturbances have acted as a thinning process, leaving remaining trees reasonably healthy. Regeneration may be problematic in some areas heavily impacted by certain disturbances.

Spruce Beetle Outbreaks on Intermountain Region Spruce–Fir Forests

E.G. Hebertson, *US Forest Service, Ogden, Utah*

Since 1986, spruce beetles (*Dendroctonus rufipennis* (Kirby) Coleoptera:Scolytidae) have caused extensive Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) mortality throughout the Intermountain Region. Approximately 1 million trees on 700 000 acres (280 000 ha) of spruce–fir forest have been killed, affecting timber, wildlife, recreation and other resources. The largest outbreaks have occurred on the Manti-LaSal and Dixie National Forests in Utah, resulting in a 90% loss of spruce more than 10 inches in diameter breast height (dbh) (25 cm). In other forests, spruce beetle activity continues to rise.

This presentation will discuss case histories of three outbreaks and relate important ecological, social and managerial issues that have arisen as a result of these outbreaks.

WORKSHOP 6.1

EFFECTS OF FORESTRY PRACTICES ON BIODIVERSITY

MODERATORS:
J.C. Miller, *Oregon State University, Corvallis, Oregon*
J.R. Spence, *University of Alberta, Edmonton, Alberta*

Moderator Summary: Since the Earth Summit of 1992, biodiversity has become a widely accepted indicator of ecosystem integrity. As a result, studies of non-pest arthropod populations and communities conducted in a forestry context are increasingly common and potentially useful for forest managers and policy makers. Given the long-term nature of forestry and the complexity of the poorly understood biological system that underpins it, unexpected changes in biological communities, including species loss, should give us pause. Most systems proposed to certify forestry operations as environmentally sustainable value whole-system properties of forest ecosystems, alongside traditional measures of fiber production. Central among these whole-system properties is biodiversity. These recent developments provide opportunities to expand the domain of forest entomology.

Responses of biota toward which management is not explicitly informed or directed provide the most unbiased assessment of how forestry practices may inadvertently affect biodiversity. Implications of such studies differ from research about rare and endangered species, a topic considered in NAFIWC II. Work on threatened species seeks biological understanding, which can accommodate their needs through improved management and forestall extirpation. Biodiversity studies, like those featured in this NAFIWC, are more like checking the canary in a coal mine. They aim to reveal unintended and undesirable consequences flowing from our approach to management or resulting land use patterns. Taken together, biodiversity studies and work with threatened species provide the background for successful environmental stewardship.

Useful biodiversity studies require certain design features exemplified by the five presentations in this session. First, there is continuing urgent need for taxonomy, inventory and natural history. Although these classical disciplines may seem less flashy than the hypothetico-deductive studies favored by modern grant panels, the biota will not be effectively protected unless we know what species are included, where they occur and what they do. Second, rigorous biodiversity studies require both baseline data about pre-disturbance communities and controls, if we are to attribute changes to our practices with any degree of scientific credibility. Untreated control blocks must be of sufficient size and representative nature to truly reveal what would happen in the absence of the perturbations being considered. Although fundamental to any scientific undertaking, this point has been ignored in some applied biodiversity work. Third, we must give serious attention to how information about various taxa can be melded and developed as indicator tools. Despite caution about use of specific taxa as indicators in the literature, much of which points out deficiencies of using taxon A or B in the way proposed, delaying the development of provisional tools until every taxon is included is simply unworkable. Forests will be harvested and biodiversity will be impacted while we fiddle. We can offer our best guidance now, with the specific proviso that the best will change with further research. Fourth, and perhaps most challenging, we need effective ways to scale up predictions about arthropod biodiversity to the level of whole landscapes. This will require an intimate and presently unavailable understanding of how forest arthropod communities vary with habitat.

Utility of Documenting Lepidoptera Biodiversity for Environmental Assessment

J.C. Miller, *Oregon State University, Corvallis, Oregon*

Lepidoptera function in the dynamics of forested ecosystems by serving as defoliators, decomposers, prey or hosts to carnivores, and pollinators. The biodiversity of Lepidoptera is thus linked into the ecosystem by the influence that various species (groups) have on nutrient cycling, plant population dynamics, and predator-prey population dynamics. The sources of biodiversity of the Lepidoptera can be grouped into vegetation types: conifers, hardwood trees, shrubs, herbs, and grasses.

Inventory of Lepidoptera biodiversity in conifer forests of the Pacific Northwest indicated that a majority of the individual moth abundance and species richness in Lepidoptera can be attributed to hardwood trees and shrubs. Furthermore, various plant communities and land management regimens produce a distinct community of Lepidoptera that is useful for identifying and monitoring dynamics of biodiversity following practices such as timber harvest, fire, grazing, and pesticide applications.

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Effects of Forest Conversion and "Campesino" Forestry on the Ground Beetle Fauna in Central Veracruz, Mexico

E. Montes de Oca, *Instituto de Ecología, Veracruz, México*
J.R. Spence and **G.E. Ball,** *University of Alberta, Edmonton Alberta*

Two volcanic mountains in Veracruz, Cofre de Perote (*Nauhcampaltépetl*, in náhuatl language) in the easternmost part of the Transvolcanic Sierra, and Pico de Orizaba (*Citlaltépetl*), contain temperate forests representing 12% of the total area of the state susceptible to harvesting. The remaining 88% consists of lowland, tropical forests. The geographic position of the Cofre de Perote and pronounced topographic and climatic variations promote a large diversity of forest vegetation and vegetation mosaics. Since colonial times, forest products have been extracted indiscriminately from the Cofre, and despite forest protection and management efforts during the 1930s, exploitation has promoted human colonization and changes in land use in almost the entire Cofre region. At present, plant and animal agricultural practices following forest exploitation contribute to an increase in the heterogeneity of the landscape.

In September 1999, we started a ground beetle sampling following an altitudinal transect in the southeast slope of the Cofre. This and complementary insect collection methods (hand collecting, light trapping) in several transect sites allowed analysis of the effects of anthropogenic factors on the ground-beetle fauna. We also considered the faunal effects of converting high-elevation forests to corn and potato fields, and the importance of keeping forest patches as an integral part of the landscape.

Impact of Harvesting on Native Biodiversity and Ecological Processes

T.T. Work, *University of Alberta, Edmonton, Alberta*

Understanding the relative impact of harvesting on native biodiversity and ecological processes is essential for sustainable management of forests. The EMEND (Ecological Management by Emulating Natural Disturbance) project is a large-scale experiment comparing six levels of forest harvesting with prescribed burning. Between 1998 and 1999, 40 000 litter arthropods from over 200 species were collected. Interactions between forest cover type, understory vegetation, coarse woody debris and harvesting intensity were analyzed using partial Mantel tests to control for spatial differences in experimental plots. Harvesting treatments significantly altered species composition in stands with mixed overstories. Individual species were affected by intensive harvesting only in their non-preferred habitats.

Forest Pest Management Effects on Central Appalachian Macrolepidopterans

J.S. Strazanac and **L. Butler,** *West Virginia University, Morgantown, West Virginia*

Macrolepidoptera are a diverse and abundant component of forest environments. They contribute to forest diversity directly, and they are critically important as food for a wide range of forest animals. Forest pest management can have immediate impact on nontarget macrolepidoptera. The exposed feeding habits of most species make them highly susceptible to broad-spectrum insecticides, and more specific insecticides such as the microbials and IGRs (Insect Growth Regulators) target pests with biologies similar to macrolepidoptera. Recent and current studies document the immediate and more long-term impacts of tebufenozide, diflubenzuron, and *Bacillus thuringiensis* var. *kurstaki* Berliner on macrolepidoptera in forest environments.

The Effects of Forestry and Urbanisation on Ground Beetles (Coleoptera: Carabidae) in Finland

D.J. Kotze, J. Niemelä and **M. Koivula,** *University of Helsinki, Finland*

The total volume of forest wood is increasing practically everywhere in Europe. This is, however, coming at a price. In Finland, for example, increased timber productivity is linked to marshland drainage, monocultural plantations and changes in forestry methods.In turn, these practices change species assemblages significantly, and cause certain forest specialist species to disappear. For example, traditional and modified clear-cutting (groups of trees retained) have the most pronounced effects on carabid species composition because many open habitat species invade these clear-cut areas, and carabid species richness actually increases. However, forest interior species suffer from these harvesting techniques. Alternative harvesting methods, such as thinning and, in particular, cutting small openings, had much less of an effect on the carabid fauna. Site characteristics such as the field layer vegetation, tree density, distance to the nearest potential source habitat, and the presence of spruce mires were important determinants of carabid assemblages in harvested forests.

In the second part of this presentation I will briefly discuss some of the work being done in urban forests in Finland. Rural depopulation means that many people in Finland associate forests with neatly manicured urban forested areas; indeed, managed forests and urban green areas are kept free of rotting and decomposing wood. Many species, however, depend on the existence of these forest elements. An experiment has been started in urban forests in Helsinki to test the effects of fallen trees in worn-out urban stands: fallen trees will be left in these forests and the effects on carabid beetles, trampling intensity and regeneration of forest vegetation will be tested.

Finally, I will discuss results from an international project, called globeNet, aiming to examine whether carabid communities respond in a similar way to urbanisation in different parts of the world. Carabid beetles were collected across an urban-suburban-rural gradient in Bulgaria, Canada and Finland and results indicate significant changes in carabid abundance, species richness and assemblage structure across these gradients.

WORKSHOP 6.2

USE OF ECOPHYSIOLOGY TO ASSESS STAND–SITE–INSECT INTERACTIONS

MODERATORS:
E. Smith, *US Forest Service, Fort Collins, Colorado*
A. McMahan, *Intecs International, Fort Collins, Colorado*

Moderator Summary: Tree- and eco-physiologists continue to make advances in understanding how trees function and how that functioning is related to site and stand conditions. It is necessary for forest entomologists to integrate new insights in tree physiology into their thinking, and perhaps into their field data collection, analysis, and prescriptions. Likewise, it is necessary that ecophysiologists consider insect herbivores if they are to form useful hypotheses, make appropriate observations, and create useful models. In this session, theoretical, applied, and modeling perspectives were presented to link tree physiology processes and insect herbivory.

Tree or stand level growth rates are generally regarded as being indicative of a site's ability to support photosynthetic production. However, not all net available carbon fixed by photosynthesis is allocated to the structural elements—roots, stem, branches, and leaves—that are ordinarily considered as representing growth. The anti-herbivore compounds trees and other plants produce through secondary metabolism constitute an important additional use for fixed carbon. Herms and Mattson (1992) call this: "The dilemma of plants: to grow or defend". Plant genotype, site conditions, plant damage agents, and weather variation all affect the total amount of photosynthate available for growth and defense, and can affect the relative amount allocated to each.

Trees have developed two types of mechanisms to produce secondary defensive compounds. One is to produce constitutive compounds in advance of their need; the other is to wait until the production is induced (in response to wounding, for example). In order to have carbohydrate substrate for secondary metabolism available at the site of induced production, the production site must be in the path of a strong enough source–sink gradient to provide that substrate (Herms and Mattson 1992).

Waring and colleagues (Waring et al. 1980; Larsson et al. 1983; Mitchell et al. 1983) performed a series of studies involving pines, mountain pine beetle (*Dendroctonus ponderosae* Hopkins), and susceptibility which were based on the assumption that photosynthate allocation is hierarchical. They proposed that allocation to defensive oleoresins was lower in the hierarchy than either leaf or stem growth. They produced a vigor index that was based on the notion that the ratio of stem growth to leaf area was indicative of the amount of photosynthate available for oleoresin production. The potential use of this index as a useful output of a simulation model was one of the topics of this session.

A key forest protection application of these ideas has been explored by Lorio and colleagues in a series of studies involving *Pinus taeda*, loblolly pine and *Dendroctonus frontalis* Zimmerman, southern pine beetle (Lorio and Sommers 1986; Lorio 1986, 1993). These studies explore the relationship of tree growth status and oleoresin production within a season's growth cycle, between years, among sites, and among individuals. A related fertilization study showed that contrary to what might be hypothesized from the Waring et al. studies, higher growth from fertilization also resulted in lower oleoresin flows and thus, presumably, a lowered ability to resist bark beetle attack (Wilkens et al. 1998).

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Estimating Stand Vigor with FVS-BGC: a Process-Model Extension of the Forest Vegetation Simulator

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E.L. Smith, *US Forest Service, Fort Collins, Colorado*

The Forest Vegetation Simulator-BGC (Milner et al. n.d.) is a hybrid model, representing a marriage between the United States Department of Agriculture's (USDA) empirically based Forest Vegetation Simulator (FVS) (Crookston 2001), and Stand-BGC (Milner and Coble 1995), a climate-driven process model. The Forest Vegetation Simulator-BGC operates as an extension to FVS, and as such, provides—in addition to the usual FVS growth and mortality estimates—output describing a stand's ecophysiology. Unlike its predecessor FOREST-BGC (Running and Coughlan 1988), FVS-BGC simulates biogeochemical processes on individual tree records; hence, it operates at a spatial scale typical of stand inventories. Furthermore, its linkage with FVS permits the analysis of stand management activities on stand ecophysiology.

The model simulates—on a daily timestep—carbon and water dynamics via the modeling of photosynthesis, respiration, and evapotranspiration. On a yearly timestep, accumulated carbon is allocated to plant tissue pools (leaf, stem, roots). The resultant simulated growth is accumulated for every year within each FVS cycle (the timestep in which FVS grows trees, typically 10 years). At the end of each growth cycle, simulated tree dimensions in FVS are updated using either FVS's or BGC's projected growth estimates, as directed by the user. No matter which model's growth estimates are used across cycle boundaries (FVS or BGC), the FVS-BGC extension provides extensive output describing the within-cycle ecophysiology, including estimates of: 1) daily and yearly rates of photosynthesis, respiration, turnover, and transpiration; 2) amount of carbon allocated to each tree record's leaf, stem, and root pools (including the resultant new dimensions); and 3) leaf areas and crown dimensions of each tree record.

Waring et al. (1980) postulated that tree vigor can be defined as grams of stemwood produced per unit of leaf area, over some time interval. Furthermore, a number of investigators have considered tree vigor as a factor in the susceptibility of pines to attack by bark beetles (Raffa and Berryman 1982; Larsson et al. 1983; Waring and Pitman 1985). Numerous investigators explore the relationship of stand density to stand susceptibility to bark beetle attack (Sartwell and Stevens 1975; Cole and McGregor 1983; Anhold and Jenkins 1987; Olsen et al. 1996), and/or to tree vigor (Mitchell et al. 1983; Kolb et al. 1998). Two conclusions that can be drawn from this body of work are: 1) drought may predispose trees to attack by bark beetles, and 2) thinning may improve tree vigor.

Under a number of hypothesized management, climate, and site scenarios, FVS-BGC is a tool that can be used to analyze tree and stand vigor. We ran FVS-BGC on stands from the Piney Analysis Area, Holy Cross Ranger District, White River National Forest, Colorado. We simulated thinnings to various densities, and simulated varying precipitation regimes. We present results suggesting a quantifiable relationship between stand density, drought, and tree vigor. These results are consistent with other published findings. Further, we suggest that vigor estimates generated by this model may be used as driving variables in other models, such as the numerous pest and disease extensions to FVS.

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Linkages between Tree Stress and Defensive Processes in Southwestern Ponderosa Pine

T.E. Kolb, *Northern Arizona University, Flagstaff, Arizona*

I used results from four studies on southwestern ponderosa pine (*Pinus ponderosa* var. *scopulorum*) to explore linkages between tree stress caused by competition and drought and resin defenses against bark beetles. Two studies that compared tree response to thinning from below (pre-EuroAmerican settlement restoration prescription) two or three years after treatment showed that heavy competition among trees increases tree water stress (lower predawn water potential) and reduces tree growth and early summer resin production after wounding. Similar results occurred in a long-term silvicultural experiment where stand basal area was controlled at different levels over 32 years. In contrast, a different pattern of results occurred for a comparison between a wet *la Nina* year (1995) and a dry *el Nino* year (1996). Compared to the wet year, trees in the dry year had greater water stress, less growth, but higher early summer resin defenses. The results of these studies suggest that: 1) chronic heavy competition stress reduces carbon allocation to both growth and resin production in southwestern ponderosa pine, 2) drought caused by low winter and spring precipitation may increase carbon allocation to resin production in early summer because growth is more limited by water stress than is photosynthesis and resin production, and 3) a trade-off between tree growth and differentiation (resin production) occurs for acute water stress caused by yearly or perhaps seasonal variation in water availability, but not for chronic stress caused by severe tree-to-tree competition.

WORKSHOP 6.3

FOREST INSECT EPIZOOTIOLOGY

MODERATORS:
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J. Elkinton, *University of Massachusetts, Amherst, Massachusetts*

Moderator Summary: Relatively few forest insects reach population levels that result in widespread defoliation. However, periodic outbreaks of endemic species such as the Douglas-fir tussock moth and forest tent caterpillar can have significant impacts on their respective hosts, causing reductions in tree growth and under some conditions, tree mortality. Termination of outbreaks results from a combination of factors that collectively reduce populations to pre-outbreak levels where they may remain for considerable time. One factor contributing to this reduction is disease, which when widespread within a population, is described as an epizootic. Under most circumstances an epizootic occurs several years into an outbreak when a pathogen has become widely distributed in the host population. From a practical standpoint, this delay leads to unacceptable losses in forest stands. Thus a major objective of manipulating pathogens is to disperse these agents much earlier in the outbreak and accelerate its termination. The task seems straightforward: once a suitable pathogen is identified, release it in the target population. Although this approach has worked reasonably well in some cases, e.g., *B.t.* in spruce budworm (Morris et al. 1986) there is a need to increase the number of effective pathogens for forest pests.

To this end, speakers in this workshop were invited to address a variety of issues, including the efficacy of baculovirus products subjected to long-term storage, a requirement for a rapid response to population outbreaks that are periodic in nature. The consensus from several studies is that a virus product can have a shelf-life of 10 years or greater. Aspects of baculovirus biology that ultimately impact their efficacy were also addressed. Often overlooked is the fact that a disease-causing agent such as a virus may consist of several genotypes and in extreme cases several viruses. A wild-type baculovirus isolated from eastern spruce budworm is a well-studied example of the latter. New evidence for vertical transmission within eggs was presented. Additional work is needed to determine the parent to progeny transmission route (Kukan 1999) and the significance of this pathway for epizootics in forest insects. The role of a newly discovered and likely introduced fungal pathogen on an introduced insect species, gypsy moth, was also discussed (Hajek et al. 1995). Recent observations of this interaction have provided us with the perspective of a microbe suppressing a high-density population with the potential of maintaining significant impact on a low-density population, an observation somewhat at odds with current host-pathogen models of disease dynamics. Continued studies of this fungus-insect interaction may lead to a better understanding of natural epizootics and ways of manipulating pathogens to maintain low density insect populations.

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Forest Insect Epizootiology—Vertical Transmission

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Epizootics that occur in insect populations are in part driven by horizontal and vertical transmission of pathogens. Many of the factors, both biotic and abiotic, that drive each of these components have been examined and for some, pathogen-host systems are reasonably well understood. One continually debated aspect of vertical transmission of baculoviruses in lepidopteran hosts is whether virus-infected females simply contaminate the surfaces of their eggs, or in some instances, pass viruses directly within eggs. Here we discuss our evidence for virus transmission within eggs. A baculovirus construct containing GFP (green flourescent protein) was used to identify transmitted virus. Adult insects from groups of larvae infected with a range of virus concentrations were reared to provide eggs. Following submersion in bleach and exposure to Ultraviolet (UV) light, eggs were placed in containers with and without diet. Insects were examined soon after hatching or for a period of days following hatching. Detection of GFP indicated infected individuals. When transmission occurred, rates varied, greater than 80% in some groups to less than 1% in one group. No transmission occurred in other virus-exposed insects. To date, no transmission has been detected in second generation insects (adults reared from groups that had vertical transmission were the source of eggs for the second generation).

Impact of *Entomophaga Maimaiga* on Gypsy Moth Population Dynamics

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Beginning in 1989, epizootics caused by *Entomophaga maimaiga* among gypsy moth populations in North America have completely altered the dynamics of the gypsy moth life system. Earlier work had implicated a link between gypsy moth and its principal predator, the white-footed mouse. Subsequent analyses show that fungal epozootics occur in years of high rainfall even in very low-density populations and that these can prevent outbreaks of gypsy moth from occurring. The ecology of *E. maimaiga* is completely different from that of gypsy moth nucleopolyhedrosis virus, *LdMNPV*, the other major insect pathogen in this life system.

Stability of the Douglas-fir Tussock Moth Viral DNA in Stored TM-Biocontrol-1

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R.C. Reardon, *US Forest Service, Morgantown, West Virginia*
I. Ragenovich, *US Forest Service, Portland, Oregon*

TM-BioControl-1 is a viral insecticide that was produced from 1985 to 1995 by the USDA Forest Service. This product is registered for suppressing outbreaks of Douglas-fir tussock moth, *Orgyia pseudotsugata*. The active ingredient in TM-BioControl-1 is OpNPV, a nuclear polyhedrosis virus that is highly pathogenic to *O. pseudotsugata* larvae. Since its production, the virus has been stored at –10°C.

There are some concerns how storage may have affected the efficacy and stability of the virus. The stability of TM BioControl-1 was assessed by examining the genomic structure of the OpNPV using restriction fragment length polymorphism (RFLP) analysis as a method of visualizing possible changes in the viral DNA. Genomic OpNPV DNA from each product lot of TM BioControl-1 was isolated and compared with the DNA from the strain from which all lots were produced (MEM-75-STANDARD).

DNA samples were digested with three different restriction enzymes (*Bgl* II, *Pst* I and *Sal* I). The digested DNA was separated by agarose gel electrophoresis, Southern blotted, and probed with labeled total genomic OpNPV. The RFLP profiles produced by the three restriction enzymes were identical among all of the samples and the standard DNA. There was no evidence that the viral DNA had degraded during cold storage. The lack of polymorphisms and DNA degradation suggests that the long-term storage of TM BioControl-1 has not adversely affected or altered the quality of the OpNPV genomic DNA in the registered product.

Efficacy of Stored TM-Biocontrol-1

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R.C. Reardon, *US Forest Service, Morgantown, West Virginia*
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Douglas-fir tussock moth nucleopolyhedrovirus (OpNPV) registered under the name of TM-BioControl-1, was produced and stored by the USDA Forest Service for use against outbreaks of Douglas-fir tussock moth (*Orgyia pseudosugata*) (DFTM). Ten lots of TM BioControl-1 were produced between 1985-1995. The product was stored in 17 different package sizes and 4 different processors were involved in the production. Considerable time had elapsed since the production and storage. It was decided by the USDA Forest service to join with our group at Pacific Forestry Centre in British Columbia (B.C.) in a collaborative project to test the shelf life of the stored TM-BioControl-1. More specifically, we tested the effects on efficacy of strain (DFTM from different regions), package size, time in storage and processing by different companies.

Activity standardization bioassays were done to determine the current activity titre (amount of activity/unit wt.). These were conducted using the Goose Lake colony of insects and several field strains. Larvae were reared on artificial diet and newly molted third instar larvae tested. The diet plug inoculation technique was used to administer the virus. Estimates of LD_{50} (lethal dose that kills 50% of the larvae) were calculated using SAS PRO PROBIT.

We compared the efficacy of a fresh sample of OpNPV against four different field strains of DFTM (California, Idaho, Oregon and B.C.) and one laboratory strain (Goose Lake). The 3 field strains from the US (California, Idaho, Oregon) had similar, relatively low LD_{50} values while the B.C. strain had about a 3-fold higher LD_{50}. The three US strains would be more susceptible to TM-BioControl-1 than the B.C. strain.

Because the strain made a difference in LD values, it was necessary to use one strain to compare all TM- BioControl-1 samples to assess lot, package size and processing differences. We used the Goose Lake colony in these experiments. Thirty-nine TM BioControl-1 samples have been tested with the Goose Lake strain, at least 2 from each package size.

Results indicated that package size did not make a difference in efficacy tests. When LD_{50} values and potency ratios were examined for the 10 lots of stored TM-BioControl-1, there was no direct relationship between time in storage and shelf life. Eight of the lots had similar values retaining a potency of 0.7–0.8 and 2 lots had higher LD_{50} values and so lower potency ratios (0.5 and 0.3) but this was not a function of time stored.

When results were examined in view of the different companies processing the stored TM-BioControl-1, there was no direct evidence that any one company made a difference. We concluded that TM BioControl-1 was effectively stored and can still retain most of its potency even after 14 years.

Hazard Rating and Outbreak Prediction of *Lambdina fiscellaria lugubrosa* in British Columbia

N. Borecky and **I.S. Otvos,** *Canadian Forest Service, Victoria, British Columbia*

The western hemlock looper, (*Lambdina fiscellaria lugubrosa*), is a serious defoliating pest in western North America. In British Columbia, there have been 14 distinct outbreaks, increasing in duration and severity over the past 87 years. Outbreaks tend to occur in coastal and interior western hemlock (ICH wk, vk and mw) biogeoclimatic sub-zones and generally last from 1 to 5 years. During the 1990-1995 outbreak, this pest was responsible for approximately 63 000 ha of stand mortality in the province. Early monitoring with pheromone traps suggests that another outbreak may be imminent.

The hazard rating system being developed uses Geographic Information System (GIS) analysis of forest cover information to model stand conditions that have historically been susceptible to outbreaks of western hemlock looper. Logistical regression techniques are employed to produce a model probability surface explaining the likelihood of an area to be attacked based upon age and proportional stand composition of western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*). Forest stand data is derived from the Province of British Columbia's Forest Information and Planning database, combined with FC-1 (digital forest cover). Sampling measures take into account spatial autocorrelation and multicollinearity amongst variables of interest, in addition to compensating for the original defoliation aerial survey's estimated ground error.

An analysis of British Columbia's forest inventory data suggests that stand age and stand proportion of *Tsuga heterophylla* and *Thuja plicata* are positively associated with defoliation by *Lambdina fiscellaria lugubrosa*. In addition, stands generally over 120 years of age are considered high hazard areas with regards to the initiation of western hemlock looper outbreaks.

There are differences in the forest composition between the loci of defoliation events and successive years, with defoliation occurring in less host-specific stands in successive years. Although there are slight differences in age, both initial and subsequent years' defoliation appear to favor older stands when compared to adjacent stands that remain undefoliated. Undefoliated stands adjacent to defoliated stands exhibit significant differences in age and forest composition when compared to stands in valleys which have not sustained defoliation but are also within the same ICH vk, wk, and mw biogeoclimatic sub-zones.

Results of both hazard rating and outbreak predictions are expected to aid forest managers in dealing with outbreaks of western hemlock looper in an effective manner through direct control measures, alternate harvest/conservation planning, or modified silvicultural practices.

Synergistic Relationship between Two Baculoviruses of the Eastern Spruce Budworm: Potential in Pest Management Strategies

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Wild type *Choristoneura fumiferana* nucleopolyhedrovirus was found to contain two distinct viruses, CfMNPV and CfDEFNPV. The first virus has been plaque purified and characterised in various laboratories. The second virus, CfDEFNPV, was deemed defective because it was incapable of infecting the natural larval host by the *per os* route without the help of CfMNPV. However, when injected into the haemolymph, CfDEFNPV caused full infection in larvae and produced normal occlusion bodies. This progeny virus was still incapable of infecting larvae by *per os*. Detailed characterisations by restriction endonuclease analyses, Southern blot hybridisation and polyacrylamide gel electrophoresis of structural proteins have shown that CfMNPV and CfDEFNPV are two distinct viruses and are not variants of the same strain. More recently, genomic sequencing has confirmed this hypothesis.

At this stage, the question was asked on the selective advantage of a defective virus in nature. Clearly, CfDEFNPV requires a helper to cause infection in larvae when delivered per os. Electron microscopic studies on CfMNPV in larvae have revealed that the virus does not have a replication cycle in columnar epithelial cells and can pass through the basal lamina at approximately 2 hours post infection. The CfDEFNPV was also seen to enter columnar epithelial cell but was unable to negotiate the basal lamina. It was concluded that the basal lamina is the barrier preventing CfDEFNPV from reaching cells and tissues where it can replicate and that CfMNPV is needed to pass the basal lamina.

We then decided to investigate the relationship between the two viruses in the natural host. More specifically, we needed to know how much CfMNPV can be diluted and still exert its helping effect on CfDEFNPV. Groups of larvae were given a constant amount (5¥10^4) of CfDEFNPV occlusion bodies along with reducing concentrations of CfMNPV occlusion bodies ranging from 5¥10^4 to 30 occlusion bodies. The 5¥10^4 occlusion bodies represent the LD50 for CfMNPV in early fifth instar spruce budworm larvae. Lower concentrations of CfMNPV occlusion bodies such as 30 or 300 are too low to cause an infection in fifth instar larvae.

After 8 days, viral occlusion bodies were purified from each group, and DNA was extracted and analysed by restriction enzymes. The analysis revealed that insects were infected at all concentrations and that the predominant progeny in all test groups was that of CfMNPV, even though much higher concentrations of CfDEFNPV were in the inoculum. It was concluded that the two viruses appear to exist in a symbiotic-like relationship in larvae. CfMNPV is needed to help CfDEFNPV penetrate the basal lamina and reach cells and tissues where it can initiate infection. Once in susceptible cells, CfDEFNPV appears to synergize CfMNPV so that the predominant progeny is always the latter virus. In this symbiotic-like relationship, CfDEFNPV appears to make certain that at the end of multiplication in larvae, the helper is always present in copious amounts to assure the survival of CfDEFNPV.

WORKSHOP 6.4

TEACHING FOREST ENTOMOLOGY

MODERATORS:
J.A. McLean, *University of British Columbia, Vancouver, British Columbia*
S.J. Seybold, *University of Minnesota, St. Paul, Minnesota*

Moderator Summary: This workshop raised a variety of educational issues related to forest entomology and forest health. The audience/clientele and the institutions offering forest entomology courses in Canada, the United States, and Mexico were presented by John McLean, Steven Seybold, and Jorge Macías-Sámano, respectively. McLean and Seybold also discussed the effect of accreditation guidelines on course content for professional forestry education in Canada and the United States. Comparable guidelines for forest entomology education in Mexico have not been developed. The Internet appears to have impacted forest entomology courses most prominently by preserving images of valuable teaching materials and making lecture and laboratory materials available for review on a 24-hour basis. Course web sites are being developed at numerous institutions (e.g., University of British Columbia, University of Northern British Columbia, Wisconsin State University, Ohio State University, University of Minnesota, University of Wisconsin-Milwaukee, Virginia Polytech and State University, North Carolina State) to serve on-campus as course supplements and off-campus as remote sources of remedial information for practicing foresters. Course web sites from North American institutions have the potential to reach international audiences, and can be particularly valuable in parts of the world where forest entomology instruction is not available. There is also great potential for the Internet to enhance forest entomology education in Mexico: most of the instruction is delivered in person in one state; the one major forest insect compendium available in the Spanish language could be put onto the WWW to reach a wide audience that has access to Internet cafés, but not necessarily to books.

In the US, nearly 50% of courses (20 of 42) that include material on forest entomology are integrated courses—often involving forest pathology and/or fire ecology. About half of these courses are taught by individual instructors. Through a case study at the University of California at Berkeley (UCB), Donald Dahlsten traced the development of forest entomology education from a solo course for forestry undergraduates (1950s-1970s) to its present form as an integrated section of a course called Forest Perturbation, which is team-taught to natural resource undergraduates by Dahlsten, a forest pathologist, and a fire ecologist. The advantages of the forest ecosystem approach to teaching forest protection may be offset by the limited time available for covering the technical issues associated with each sub-discipline. Forestry and resource professionals receiving forest insect biology training in integrated courses will likely have to rely on remedial education provided through web sites and workshops.

Despite the minimal technical content available in some modern forest entomology courses, from the perspective of a British Columbia forest manager, Tim Ebata noted that forestry professionals in his jurisdiction were receiving adequate university preparation and remedial training through insect and disease workshops to allow them to carry out their professional activities. One group that appears to be jeopardized by the current state of forest entomology education is the next generation of forest entomologists, who may not have access to courses with enough technical content needed for scientific proficiency. These students will have to receive their training as teaching assistants or through internships with governmental professional forest entomologists, or, as Dahlsten reported has happened at UCB, organize their own courses or seminars in study groups or with the direction of current forest entomology faculty.

The Status of Education in Forest Entomology in the United States

S.J. Seybold, *University of Minnesota, St. Paul, Minnesota*

Educational opportunities in forest entomology in the United States were reviewed and contrasted with comparable opportunities in Canada and Mexico. Through its accreditation process, the Society of American Foresters (SAF) suggests that the fundamentals of a US forestry education include written and oral communication, mathematics, biological, social and physical sciences, and the humanities. Four general areas of study are requested by SAF and one of those areas (Forest Ecology and Biology) includes forest entomology and forest pathology, which are to be equally weighted with seven other topics such as silviculture (and fire ecology), dendrology, soil science, and forest ecology. An education in forest entomology should include the study of representative forest organisms and the application of integrated pest management. Canada has similar educational guidelines; Mexico does not.

Using the Internet, a state-by-state analysis shows that at least 40 institutions in 32 states offer education related to forest entomology (Table 1). Land Grant universities dominate, but there are also several smaller state institutions that offer some form of forest entomology as a part of their forestry training programs. As a consequence, several US states (e.g., California, Michigan, Washington, and Wisconsin) have multiple institutions that reach forestry audiences with entomological education. At some institutions, forest entomology and shade tree (horticultural) entomology are taught as separate courses (F/S), whereas at other institutions only forest entomology is taught or the two are taught as one course (F). Of the 42 courses taught with at least some forest entomology in them, 22 of the courses are solo courses while 20 of the courses are integrated with forest pathology or fire ecology. Of the 20 integrated courses, 11 are taught by one instructor and nine are taught by two or more instructors.

An e-mail survey of 16 active instructors in forest entomology in the US confirmed that about half of their courses are integrated (Table 2) and that Internet usage varies from extremely heavy (i.e., complete course is on the WWW) to non-existent. Specific comments from these instructors suggest that participation in integrated courses drastically curtails the amount of entomological subject matter covered. However, integrated courses are more representative of the actual forest ecosystem and provide an excellent opportunity to simultaneously contrast insect and disease symptoms and to present realistic management recommendations for both groups of organisms and for prescribed burning. The comments also highlighted the benefits of the Internet in providing a visual archive of teaching materials, ready access to expert systems and models, and a remote repository of information for students and practicing forestry professionals (regionally and internationally).

As an example of a newly developed course in forest entomology, Entomology 4251 (*Forest and Shade Tree Entomology*, Department of Entomology, University of Minnesota, http://www.entomology.umn.edu/classes/ent4251/index.html) is offered for 3 credits during fall semesters with two lectures and one two-hour lab per week for a total of about 30 lectures and approximately 15 labs/semesters. The course attracts undergraduate students from the Forest Resources (FR) major (urban forestry and forest resources management submajors) and the Horticulture major. For FR students, the course represents three of the 128 credits needed for graduation, and these students are required to take either Ent. 4251 or *Diseases of Forest and Shade Trees*. Many FR students take Ent. 4251 because it is listed as a recommended elective for both of the submajors. The course has also attracted graduate students in horticulture and other disciplines. After 3 course offerings, the enrollment has averaged 24 students per semester. Highlights of the course include group exercises during lecture, a written literature review, an oral presentation on an extension topic, and novel laboratory exercises including career opportunities in forest and shade tree entomology, the impact of forest insect management on endangered species, and positive impacts of insects on human values. During the latter exercise, students are given the opportunity to dine on a variety of insect-laden foods (= culinary control).

Table 1. United States institutions offering courses in forest (f) or shade tree (s) entomology

State	Institution
Alabama	Auburn University (F/S)
Arizona	Northern Arizona University (F), integrated (>2)
Arkansas	University of Arkansas, Monticello (F), integrated (1)
California	University of California, Berkeley (F), integrated (3)
	California Polytechnic State University, San Luis Obispo (F), integrated (1)
	Humboldt State University, Arcata (F)
Colorado	Colorado State University (F), integrated (1)
Florida	University of Florida (F)
Georgia	University of Georgia (F)
Idaho	University of Idaho (F), integrated (2)
Illinois	University of Illinois (F)
Indiana	Purdue University (F/S)
Iowa	Iowa State University (F), integrated (2)
Kentucky	University of Kentucky (F/S)
Louisiana	Louisiana State University (F/S), integrated (1?)
Maine	University of Maine (F), integrated (1)
Maryland	University of Maryland (S)
Massachusetts	University of Massachusetts (F/S)
Michigan	University of Michigan, Ann Arbor (F)
	Michigan State Univ., East Lansing (F), integrated (2)
	Michigan Technological University, Houghton (F)
Minnesota	University of Minnesota (F/S)
Mississippi	Mississippi State University (F), integrated (1?)
Missouri	University of Missouri (F), integrated (1?)
Montana	University of Montana (F). Both a stand alone course and an integrated (1) course are offered by same instructor
New York	SUNY Syracuse (F)
North Carolina	North Carolina State University (F/S)
Ohio	Ohio State University, Columbus (F)
Oregon	Oregon State University (F). Both an undergraduate integrated (2) course and a graduate integrated (1) course are offered
Pennsylvania	Penn State University (F/S)
South Carolina	Clemson University (F)
Texas	Austin State University, Nacogdoches (F), integrated (1)
	Texas A&M (F/S)
Utah	Utah State University (F)
Virginia	Virginia Tech (F/S), integrated (3)
Washington	Washington State University, Pullman (F)
	University of Washington, Seattle (F). Both stand alone and integrated (3) courses are offered by same instructor
Wisconsin	University of Wisconsin, Madison (F), integrated (2)
	University of Wisconsin, Stevens Point (F). Both a stand alone and integrated (1) course are offered by same instructor

Note: Courses involving forest entomology instruction integrated with forest pathology or fire ecology are listed as “integrated” with the number of instructors in ( ).

Table 2. Responses of United States forest entomology instructors to an e-mail survey regarding integration of their courses with other forest science disciplines and internet usage

Institution	Solo	Integrated	Internet use
Arizona/NAU		X	"Don't use a web-based format" [0]
Arkansas/UA Monticello		X	Source for student written reports [1]
California/UCB		X	"Use the web from time-to-time" [1]
Georgia/UGA	X		Links provided to students for more detail on certain insect groups [1]
Iowa/ISU		X	Links provided and students required to use the internet as source for writing assignments and term projects [1]
Kentucky/UK	X		Supplemental teaching tool, but not required for assignments [1]
Michigan/MSU		X	Source for research assignments [1]
Minnesota/UMN	X		Source for writing and oral presentation assignments, posting of course announcements and assignments, syllabus, lecture slides, chat room, assignment examples [2]
Montana/UM	X	X	Courses are not web-based [0]
New York/SUNY Syracuse	X		"I do not use the web" [0]
North Carolina/NC State	X		Has a web site and plans to put most of the course on the site [0/1]
Oregon/OSU		X	Syllabus, outline, and lab manual are on the web and available to students [1/2]
Virginia/VPI		X	Has a course web site with everything except the lectures. Links are used as the course textbook [2]
Washington/WSU	X		Has a web site and uses it to teach entire course [2]
Washington/UW	X	X	No response regarding Internet use [0]
Wisconsin UW-Madison		X	Extensive use of the Internet [2]

Question 1: Do you teach a stand alone (solo) forest entomology course or participate in a team- taught course with a pathologist or fire ecologist?

Result 1: 10 of 18 courses are integrated courses

Question 2: Do you use the world wide web to assist or supplement your course in some way?

Result 2: 6 to 7/17 have no internet use [0]
6 to 8/18 supplement the course with internet use [1]
4 to 5/17 have heavy internet use with the course [2]

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Teaching Forest Entomology to Foresters in Canada

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The Canadian Forestry Accreditation Board has accredited seven undergraduate programs in Canada that train professional foresters. Forest Entomology is a required course in the professional foresters curriculum. The seven accredited schools are the University of New Brunswick (UNB), Université de Moncton (UM), Université Laval (UL), Lakehead University (LU), the University of Alberta (U of A), the University of Northern British Columbia (UNBC) and the University of British Columbia (UBC).

Forest Entomology is sometimes taught as a stand-alone course (LU, U of A, UBC), as part of a protection suite of courses with pathology and fire science (UNB, UM, UL) or as part of a forest health suite with pathology (UNBC). In addition to the classroom instruction, forest entomology topics are integrated to field schools and other courses such as silviculture. In western Canada, bark beetles such as the spruce beetle and the mountain pine beetle dominate forest entomology concerns while in the east, defoliators such as the spruce budworm and the pine sawflies receive major attention.

The Internet is used in various ways to supplement courses (ENTONOTES at UNBC, FETCH21 at UBC). FETCH21 (Forest Entomology Textbook Challenge for the 21st century) includes a links section where students can connect to the British Columbia Ministry of Forests Forest Practices Code guidebooks related to forest insects as well as to selected web sites from around the world. They are also encouraged to search on their own. In addition, the hypertext lab manual contains a page on every insect they encounter in the laboratory sessions along with coloured illustrations of the insect life stages and damage symptoms on host trees. In addition, some of the slides from lectures are mounted to aid in course review. FETCH21 is available to all students and will hopefully aid current, past and future students as they encounter insect damage in the field. The only Forest Entomology course that is offered entirely on the web is that of Paul Bell's at Sir Sandford Fleming College in Ontario.

WORKSHOP 6.5

GIS, GPS AND REMOTE SENSING ADVANCES AND APPLICATIONS TO INTEGRATED FOREST PEST MANAGEMENT

MODERATORS:
J. Ellenwood, *US Forest Service, Fort Collins, Colorado*
F.L. Oliveria, *US Forest Service, Pineville, Louisianna*

Moderator Summary: Since the last NAFIWC, digital technology has grown dramatically. What used to be available only on high-end computer systems is now available on the common desktop. Geographic information systems (GIS), global positioning systems (GPS), and remote sensing tools are now accessible to the field specialist to assist in the mapping and analysis of forest health concerns. This session will highlight some key technologies for mapping, monitoring, classification, and analysis of forest health interests.

Digital Aerial Sketchmapping Using a Laptop Computer, GPS and GIS

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During the past 5 years, advancements in laptop computer processing speed and storage capacity have increased greatly. Sketchmapping polygon, line, and point data can now be efficiently collected electronically. The system combines a laptop computer with a capacitive touch sensitive monitor, a global positioning system, geographic information system and remotely sensed imagery. Using Geolink® custom software, we are able to greatly reduce the time between a sketchmapping flight and a digitally-produced map that can be used for ground checking and reports.

Digital Imagery for Mapping Forest Health Concerns

J. Ellenwood, *US Forest Service, Fort Collins, Colorado*

Digital cameras have become more accepted in the consumer marketplace, which makes them more affordable. Airborne video and CIR still-frame digital cameras are being used to map insect damage. The recent availability of the 4-meter Ikonos satellite also allows for the mapping of insect damage. With relatively easy-to-use desktop tools, mosaicking images into a terrain-corrected geo-referenced product is now possible. Field specialists now have the ability to collect and process current imagery and produce accurate maps of forest pest damage in a timely and affordable manner.

Satellite Remote Sensing for Assessing Insect Defoliation Damage in Canada

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Remote sensing involves acquiring information about an object by a sensor that is not in direct contact with the object being investigated. It is a technological tool that is complementary to, rather than being a replacement for, existing aerial and ground survey methods. In Canada, images from remote sensing satellites have been used to detect and map defoliation from a number of insects such as forest tent caterpillar (*Malacosoma disstria* Hubner), eastern spruce budworm (*Choristoneura fumiferana* [Clem.]), eastern hemlock looper (*Lambdina fiscellaria* [Guen.]), and jack pine budworm (*Choristoneura pinus pinus* Freeman). The range of remote sensing applications has included detecting and mapping defoliation, characterizing patterns of disturbance, modeling and predicting outbreak patterns, and providing data to pest management decision support systems. These applications result in information products that support forest management planning, impact studies, and contribute to regional and national reporting.

Insect defoliation affects the morphological and physiological characteristics of trees, and it is these characteristics that govern how trees absorb and reflect light. Successful use of remote sensing for entomological studies requires integrating knowledge of pest, host, and image. Knowledge of insect pest biology and its manifestation of damage can be related to species host phenology, composition, and structure in order to understand its damage impact. In turn, this knowledge is fundamental for remote sensing with respect to defining spectral regions appropriate for damage assessment, determining sensor spatial resolution requirements, identifying the optimum timing for data acquisition, and selecting or developing appropriate image processing methods.

In a review of four past and current studies, one for each of the insect pests listed above, three research issues were identified. First, a remote sensing spectral basis for damage class limits such as light, moderate, and severe, is required to achieve consistent detection and mapping of defoliation severity. Second, the timing of image data acquisition should coincide with the period when spectral changes resulting from defoliation are most observable. Third, the spatial and spectral resolution of the image must be appropriate to the defoliation problem being studied.

Timing of satellite remote sensing is notably one of the most difficult tasks to plan and achieve because of the need for cloud-free conditions during the dates of image acquisition. In future, the likelihood for obtaining cloud-free imagery during the narrow time periods when spectral changes are at their maximum, will increase as the number of suitable sensors increase. The technology to acquire images from airborne sensors is also becoming more widely available. Opportunities to acquire remote sensing images range from high (e.g., sub-meter pixel size) to coarse spatial resolution (e.g., 1 km pixel size), and the number of available sensors is increasing at an unprecedented rate (http://www.ersc.wisc.edu/ERSC/Resources/EOSF.html). Growing competition should help ensure that future prices will be competitive, and that data will be available, especially for those pests whose defoliation damage are best assessed within narrow time periods.

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Using Landsat Data in a Stand Hazard Rating System for Southern Pine Beetle

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There are several published schemes for hazard rating stands for susceptibility to southern pine beetle (*Dendroctonus frontalis*) attack. These rating schemes typically require extensive on-site measurements. In our study, a hazard-rating scheme was created based upon stand data (i.e., total stem and pine density, basal area, and size class) collected at 2000 ground points in four watersheds in the Ouachita Highlands of Arkansas. Correlation analysis was conducted to identify significant associations between the hazard-rating measurements and various remotely sensed data. Multi-variable models were created and compared for accuracy in predicting stand hazard rating classification using these remotely sensed data.

POSTER ABSTRACTS

Peach Bark Beetle: a Potential Threat to Black Cherry in New York

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Black cherry, *Prunus serotina* Ehrh., is our most highly valued northern hardwood, used for veneer and lumber in furniture. Peach bark beetle, *Phloeotribus liminaris*, (Harris) (Coleoptera: Scolytidae) overwinters in healthy standing black cherry and breeds in cherry slash. In response to excavation of overwintering and feeding galleries, black cherry exudes copious amounts of gum in fall and spring. Over time, gum on the bark crystallizes or is washed off, but a gum spot is left on the surface of the sapwood. Over time, these spots are incorporated into the wood and constitute a significant source of degrade. The beetle has not acted as a primary mortality agent, but has been associated with tree death when preceded by repeated heavy insect defoliation. Peach bark beetle is a native insect, and we believe it is univoltine. Heavily infested trees frequently have numbers of foraging clerid adults on the bark and clerid larvae in the galleries. Unusually large populations of peach bark beetle have been present at various locations in the central and southern New York State over the past 3 years.

Predicting Infestation Levels of the Nantucket Pine Tip Moth (*Rhyacionia frustrana*) Using Pheromone Traps

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There is considerable interest in using pheromone trap catches of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), to estimate or predict population density and damage. At 10 sites in the Georgia Piedmont, adult tip moths were monitored throughout the year using pheromone traps while population density and damage for each tip moth generation were determined. Trap catch was predictably higher during the first adult generation compared to subsequent generations, regardless of population density. Within each generation, trap catch was moderately to highly correlated with associated population density or damage levels. Hyperbolic regression models best described these relationships and suggested trap saturation when populations are high. Trap catch during the first adult generation was highly predictive of population density or damage during the subsequent generation. Trap catch during the second adult generation was poor at predicting subsequent density or damage. The models presented herein should be used with caution because they are likely to be region-specific. Validation of these relationships is necessary before widespread application of these models is warranted.

Impacts of the Eastern Spruce Budworm (*Choristoneura fumiferana*) on White Spruce (*Picea glauca*) Plantations in Northern Minnesota

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Minnesota and other Northeastern Area states have had a long history of defoliation by the eastern spruce budworm (SBW). Generally, the host most impacted by this insect has been balsam fir, *Abies balsamea*. However, in the early 1990s SBW began causing growth loss, top-kill, and mortality in increasing numbers of white spruce, *Picea glauca*, plantations in northern Minnesota.

There is very little published information regarding the impact and management of SBW in pure white spruce stands. To assess this impact, we are measuring SBW population densities and defoliation from whole mid-crown branches in selected northern Minnesota white spruce stands that have been divided into treated (thinned) and control (unthinned) plots. Spruce budworm population densities of L1, L2, L3, pupa, and egg mass are measured per whole branch. Surface area and bud density are recorded for each branch. A defoliation rating is assigned using Fettes Method (Fettes 1950). Pre- and post-thinning measurements of basal area, average tree size, age, and other tree and stand characteristics are also being recorded.

Early instar larval dispersal appears to influence SBW population distributions and mortality rates (Morris 1955), and a factor that influences this dispersal is stand density (Morris 1963). Thus, a less dense stand of *P. glauca* might increase dispersal and hence mortality rate. We are testing this hypothesis by measuring dispersal loss of L1 and L2 instars and survivorship from egg to the L3 instar in each plot. Applying results from the stand assessments and the SBW population density and impact, we wish to construct a management tool to assess, predict, and ameliorate the impact of SBW on pure white spruce plantations. One possible management tool is a Density Management Diagram (DMD). Density Management Diagrams are based on the self-thinning rule of plant growth, which states that plant density and plant size are inversely related to one another because of mortality resulting from intraspecific competition (Dean and Jokela 1992; Puettmann et al. 1992; Wilson et al. 1999). A DMD for white spruce in the Lake States would provide a valuable technological tool for correlating tree size-density combinations with increased risk of defoliation, top-killing, or mortality by SBW.

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Success of Pheromone-Induced Attack by Western Balsam Bark Beetle (*Dryocoetes confusus*) and the Defense Response of Fast- and Slow-Growing Subalpine Fir (*Abies lasiocarpa*)

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Western balsam bark beetle (WBBB) typically causes scattered mortality of subalpine fir in infested stands. Results of a study conducted in 1998 showed that WBBB was more likely to attack and establish brood in slower-growing trees. Unsuccessfully attacked trees had moderate radial growth, while fast-growing trees were not attacked. The WBBB may preferentially attack slow-growing trees due to reduced host defenses associated with less vigourous growth. In 1999, a total of 26 fast- and 26 slow-growing subalpine fir trees were pheromone baited at two sites in the interior of British Columbia to test this hypothesis. Although every baited tree was attacked, slow-growing trees were more likely to be successfully attacked than fast-growing trees. Fast-growing trees were more likely to produce resin, and in greater quantities, in response to attack than slow-growing trees. Western balsam bark beetle's reference for low vigor hosts and its frequent inability to induce mass attack on high vigor hosts may in part explain its scattered pattern of mortality.

Resistance of Elms (*Ulmus* Sp.) and Elm Hybrids to Elm Leaf Beetle (*Pyrrhalta luteola*) under Field Conditions in East Central Arizona

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The elm leaf beetle (ELB), *Pyrrhalta luteola*, is an introduced insect that causes considerable defoliation of urban elms throughout their range in the USA. Siberian elm (*Ulmus pumila*) is the most widely planted elm in the high elevation areas of Arizona and especially east-central Arizona. Siberian elm is also highly susceptible to ELB; extensive defoliation and damage occur in Arizona each year.

A cooperative research program was initiated to field test the environmental tolerance and ELB resistance of 28 elm species or hybrids. Based on field screening trials from 1996-2000, several popular hybrids developed for resistance to Dutch elm disease, including "'Regal", "Sapporo", "New Horizon", and "Homestead", are susceptible to ELB. *Ulmus parvifolia, U. japonica, U. wilsoniana*, and hybrids including these parents were generally resistant to ELB. Trials conducted in a greenhouse setting in the summer of 2000 showed a similar trend. Continued testing of these 28 genotypes should allow for the selection of elms that best optimize environmental tolerance and ELB resistance. This work will provide more elm planting options for a region in Arizona that is currently limited to the planting of the environmentally tolerant, but highly ELB-susceptible, Siberian elm.

Allozyme Variation is Associated with Douglas-fir Resistance to Western Spruce Budworm Defoliation

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We investigated the association between genetic variation in inland Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and phenotypic variation in resistance to western spruce budworm (*Choristoneura occidentalis*) defoliation. Douglas-fir seeds collected from 20 putatively resistant and 16 putatively susceptible mature trees that differed in crown damage following heavy budworm outbreaks in Colorado and Arizona were used to assess allozyme variation with electrophoresis techniques. Twenty-five loci were analyzed for variation. Mean number of alleles per polymorphic locus was 2.47 and 2.60 in resistant and susceptible trees, respectively. Susceptible trees had significantly higher allele hetereozygosity (0.214) than resistant trees (0.177). Thus, phenotypically resistant and susceptible trees differed genetically, and susceptibility was associated with higher hetereozygosity and a greater frequency of rare alleles.

The Role of Monoterpenes in Resistance of Douglas-fir to Western Spruce Budworm Defoliation

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We conducted defoliation experiments under greenhouse conditions with 7- to 8-year-old clones of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) to assess the role of monoterpenes as a resistance mechanism to western spruce budworm (*Choristoneura occidentalis*) defoliation. The grafted clones were derived from mature trees that showed resistance or susceptibility to budworm defoliation in the forest. Foliage total monoterpene concentration varied greatly between 2 consecutive years in clones in the greenhouse and in their corresponding mature trees in the forest. Fractional composition of different monoterpenes was similar between years and between clones and mature trees, indicating strong genetic control. In an experiment when the influence of genetic variation in tree budburst phenology on insect feeding was minimized, budworm fitness was greater on clones from resistant versus susceptible trees, and clones from resistant trees had lower total monoterpene concentration. In an experiment when genetic variation in tree budburst phenology was allowed to influence insect feeding, there was no relationship between budworm fitness and foliage total monoterpene concentration. Moreover, total monoterpene concentration was negatively related to foliage nitrogen concentration. We concluded that resistance to budworm defoliation in Douglas-fir is caused by interactions among multiple resistance mechanisms such as foliage monoterpenes and tree budburst phenology.

Phylogenetic Taxonomy and Nomenclatural Changes of Pine Engraver Bark Beetles (Scolytinae: Ipini)

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A dearth of morphological characters has long hindered taxonomy of Ipini genera and *Ips* species groups. Phylogenetic analysis of morphological and nucleotide characters from mitochondrial cytochrome oxidase I, 16S rRNA and nuclear Elongation Factor-1a genes was used to reconstruct a robust tree of most *Ips* and several *Orthotomicus* p*ityogenes* and p*ityokteines* species. Based on monophyletic groups within this tree, Ips is revised, 4 sub genera are named, and the recently described *Pseudips* (includes *mexicanus* and *concinnus*) is supported. *Ips* is monphyletic with the exclusion of the *latidens* group, *mannsfeldi*, and *nobilis*. The *Ips* sub-genera include: (1) *emarginatus, knausi, sexdentatus;* (2) *avulsus, bonanseai, pini, integer, plastographus;* (3) *apache, calligraphus, confusus, cribricollis, grandicollis, hoppingi, lecontei, montanus, paraconfusus;* (4) *amitinus, borealis, cembrae, hunteri, longifolia, perroti, perturbatus, pilifrons, schmutzenhoferi, stebbingi, tridens. Pseudips* is grouped among the other Ipini genera and is characterized by several large contiguous nucleotide synapomorphies of the 16S and EF-1a sequences. These groups are well supported by most of the four data sets and are diagnosed by a combination of morphological characters. The results also suggest that *Orthotomicus* is polyphyletic. The taxonomy of the remaining genera will be addressed in future studies, which will include a dense taxon sample.

Quasi-Synchronous Outbreaks of Forest Tent Caterpillar in Alberta I: Period-Forcing by Non-Linear Perturbation?

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Patterns of defoliation inferred from trembling aspen (*Populus tremuloides* Michx.) ring widths suggest that forest tent caterpillar (*Malacosoma disstria* [Hbn.]) outbreaks are more frequent and nearly chaotic in the aspen parkland region of Alberta. This could be a result of period-forcing via a non-linear perturbing effect of winter weather. Field observations show that winter temperature, while density independent, probably has a stronger impact on egg survival at high density than at low density. Winter cold thus may act as a catastrophic de-synchronizing mechanism (e.g., Berryman 1981) rather than a subtle synchronizing mechanism (e.g., Moran 1953). This may be a key component of tent caterpillar dynamics in Alberta because mid-winter cold-air outbreaks are a normal feature (Colle and Mass 1995; Hartjenstein and Bleck 1991) of Rocky Mountain-induced lee cyclogenesis (Bannon 1992; Davis 1997). To detect the period-forcing effect of winter temperature on western Canadian caterpillar dynamics using time-series analysis, it would be necessary to relax five assumptions inherent in most analytical population models (e.g., Royama 1992): stationarity, temporal independence, symmetry, non-discriminancy, and density-independence of perturbation impacts.

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Quasi-Synchronous Outbreaks of Forest Tent Caterpillar in Alberta II: Population De-Regulation by Forest Fragmentation?

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Patterns of defoliation inferred from trembling aspen (*Populus tremuloides* Michx.) ring widths suggest that decadal outbreaks of forest tent caterpillar (*Malacosoma disstria* [Hbn.]) in the aspen parkland region of Alberta are highly asynchronous within municipalities over sub-decadal time scales. Decadal outbreaks in the aspen parkland are frequently drawn out over an extended period of time to cover widely separated parts of a municipality, but this is not evident in the boreal mixedwood region. Extended parkland outbreaks are sometimes so distended that they take the form of temporally and spatially discrete pairs of pulses. Parkland outbreaks thus appear to be almost twice as frequent, but half as extensive as boreal outbreaks. The breakdown in outbreak synchrony within borderline parkland/boreal municipalities occurs precisely along the boundary between aspen parkland and boreal mixedwood. This is not merely an artifact of higher sensitivity of aspen to decadal drought due to higher moisture deficits in the aspen parkland (Hogg 1997), for the frequency of disturbance within fragmented municipalities of the aspen parkland is sub-decadal and asynchronous. Forest fragmentation in the aspen parkland of Alberta appears to alter the deterministic dynamics of tent caterpillar populations. A similar relationship has been described in Ontario (Roland 1993).

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Harvesting Disturbance Effects on Spruce Beetle (*Dendroctonus rufipennis*) Parasitism

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Spruce beetles are important for ecosystem function in forests, but in Alberta, large populations can kill valuable white spruce trees. Fortunately, beetle populations are regulated by parasitoids, usually in a density dependant manner. However, due to their high trophic position and tight specificity to their hosts, parasitic Hymenoptera are very sensitive to environmental disturbance. Spruce beetle parasitoids were identified and their impact on the host population was assessed pre- and post-treatment in a conifer-dominated forest. Parasitoids were reared using a novel media to determine host instar preferences and host linkages. This study was conducted at the EMEND (Ecological Management by Emulating Natural Disturbance) site located 100 km northwest of Peace River, Alberta. Overall, EMEND is a multi-disciplinary project that aims to examine the responses of stands experimentally manipulated by harvesting strategies as compared to wildfire. This study will enhance our ability to choose harvesting strategies that do not exacerbate spruce beetle outbreaks.

Strategic Planning Systems for Bark Beetles in British Columbia

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British Columbia is experiencing extensive bark beetle outbreaks of all the major pest species including mountain pine, spruce bark, Douglas-fir, and western balsam bark beetles. Funds are limited to address the problems at hand. The allocation of resources must be done in the most efficient and effective manner throughout the province, regions, and forest districts. The systems outlined here address where and how much to treat for each identified beetle management unit (BMU) within a forest district.

The strategic planning system developed is comprised of a spatial database with linked mapping capabilities which is straightforward to use and easy to manipulate with Mircosoft Access software. This system incorporates detailed incidence data, hazard rating, risk rating, constraints to treatments, as well as tracks ground survey and treatment data on a forest cover polygon level. Key performance indicators and target thresholds by beetle management unit are also determined and incorporated into the planning tool, as a way of ensuring responsibility and tracking of beetle management progress.

It is the intention of the province to standardize this approach throughout British Columbia to facilitate the dispersal of forest health funds from treasury board and evaluate districts across a level playing field. Actions have been set out by Branch for each Region to evaluate existing management plans and determine what would be needed to get each district to comply with the system presented.

Basically, the five main functions of the systems developed were to determine where to:

1. Conduct detailed aerial surveys based on hazard rating.

2. Conduct ground surveys based on detailed surveys.

3. Conduct treatments based on ground surveys.

4. Assign responsibilities to individually ranked forest cover polygons of high risk and determine performance measures of each party involved on a yearly basis.

5. Monitor and track all bark beetle efforts over time.

Responses of Sub-Boreal Beetles to a Severe Windstorm Event and Silvicultural Practices in Northeastern Minnesota

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The July 4, 1999 severe windstorm in the Superior National Forest of northeastern Minnesota presented a unique opportunity to explore the effects of wind disturbance and post-wind disturbance practices on the distribution and abundance of epigaeic (Carabidae and Staphylinidae), phloeophagous (Scolytidae), and phloeophagous/xylophagous (Cerambycidae and Buprestidae) beetle species. During the summer of 2000, we established 12 plots stratified into two forest cover types (jack pine and aspen/birch) to compare beetle diversity, abundance and assemblage patterns between the undisturbed, severely wind disturbed (more than 67% tree mortality) and salvage-harvested forests. Within each research plot, we sampled epigaeic beetles using unbaited pitfall traps, and phloeophagous and xylophagous beetles using 6 species of trap-logs, Lindgren funnel traps baited with 8 semiochemicals, and pitfall traps baited with a- and b-pinene and ethanol. We also established permanent vegetation plots to link changes in beetle assemblages with aspects of regeneration such as forest structure and composition. Preliminary results indicate that populations of phloeophagous and xylophagous beetles were not necessarily higher in 1-year-old wind-disturbed forest stands. Instead, trap catches of *Ips* spp. were higher in the undisturbed and salvage-harvested stands. Similar trends were also observed for most cerambycid and burprestid beetle species. Future studies will focus on the jack pine cover type and will include increased replication, sampling of fire-treated stands, and sampling of woody debris to assess beetle colonization patterns and abundance. Results from this long-term multidisciplinary study will be used to understand successional trajectories of sub-boreal biota under various disturbance regimes, and to define forest elements critical to the continuity of beetle species within managed forest stands.

Volcano®: a New, Effective Control Option for the Texas Leaf-Cutting Ant

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The Texas leaf-cutting ant is often a significant problem in newly replanted plantations in east Texas and west central Louisiana. Field trials conducted since 1996 indicate that the Texas leaf-cutting ant is highly attracted to citrus pulp impregnated with sulfluramid insecticide. The bait has proven highly effective in halting ant activity within 2–4 weeks. The Volcano® formulation (Griffin L.L.C) was granted 24C (Special Local Need) registrations in Texas and Louisiana in 1999 and 2000, respectively.

Climate Change Impacts on the Productivity and Health of Aspen

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Trembling aspen (*Populus tremuloides* Michx.) is the most important deciduous tree species in the Canadian boreal forest. Since the 1980s, reduced aspen health has been observed in the southern boreal forest and aspen parkland. Recent, small-scale studies have indicated that the reduced health was caused primarily by climatic factors and defoliation by forest tent caterpillar (*Malacosoma disstria* Hbn.). Climate Change Impacts On The Productivity And Health Of Aspen (CIPHA) is a large-scale study that is examining how climatic variation, insects, and other factors have affected aspen health and productivity over the past 50 years, and includes modeling of how aspen may respond under future scenarios of changing climate and insect outbreaks. It consists of 24 study areas along a regional climate gradient in west-central Canada, extending from the cold, moist boreal forest to the warmer, drier aspen parkland. Trees are assessed for dieback, pest incidence and damage, tree-ring growth, height, diameter, and dominance. White tree rings, indicating past defoliation, are compared with historic insect survey records. Daily climate data are obtained from stations near each study area. Preliminary results indicate that local-scale aspen responses are also operating at the regional scale, including two periods with a 30–60% reduction in growth following episodes of drought and insect defoliation during the 1980s.

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Distribution of Ground Beetles (Carabidae) and Rove Beetles (Staphylinidae) in Burned Stands

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Wildfire creates a mosaic of habitats with a burned forest. It is well known that many beetles are attracted to burned stands, although little work has been done on how they are distributed within these stands. I used pitfall traps to investigate the distribution of ground beetles (Carabidae) and rove beetles (Staphylinidae) between a prescribed aspen burn and conifer burn, and within each of the burned stands. I was then able to attribute some broad characteristics of the burned stands controlling these beetle communities. Preliminary results suggest that many ground beetles have significant cover-type preferences between burned habitats and have a predictable distribution within each burn. Many pyrophilous ground beetles where attracted to areas where the fire was intense and specifically where the entire litter layer was removed.

Ecology and Management of Exotic Forest Insect Pests in the Patagonia Argentina

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Western Andean Patagonia region is planted with 50 000 ha of softwood species, mainly pine trees. These plantations are threatened by insect pests such as the wood wasps *Sirex noctilio* and *Urocerus gigas* and the European pine shoot moth *Rhyacionia buoliana*.

The wood wasp *Sirex noctilio* is the most serious threat to pines in the region. Research studies included pest monitoring using rearing cages, lure-tree patches, sequential samplings and biological control strategies based on the management of the spontaneous egg parasitoid *Ibalia leucospoides* and the recent introduction of the parasitic nematode *Deladenus siricidicola*. The economic impact of the siricid wasp *Urocerus gigas* is also being studied as an alternative host for rearing *I. leucospoides*.

The pine shoot moth *Rhyacionia buoliana* is responsible for severe shoot deformations. Population status, natural enemies and economic incidence of this pest were evaluated on permanent field plots, whereas adult flight was monitored by delta pheromone traps. Several parasitoids were recorded: a braconid larval parasitoid Orgilus obscurator, a pupa ichneumonid parasitoid *Coccygomimus fuscipes* and a native egg parasitoid *Trichogramma* sp. (Trichopgrammatidae). These control agents and the recently introduced *Trichogramma nerudai* are being evaluated in a biological control strategy.

Aleocharine Rove Beetles of the Ancient Sitka Spruce Forest on Vancouver Island and the Impact of Clear-Cutting on Their Diversity and Abundance (Coleoptera: Staphylinidae)

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This is the first comprehensive treatment of aleocharine rove beetles in British Columbia. Forty species are recorded from the ancient Sitka spruce forest of the Carmanah Valley on Vancouver Island. They belong to nine different tribes containing various numbers of species listed in brackets: Myllaenini (1 species), Athetini (20 species), Aleocharini (3 species), Lomechusini (1 species), Oxypodini (5 species), Autalini (1 species), Homalotini (5 species), Hypocyphtini (1 species), and Placusini (3 species). The collections conducted from June through September yielded 1 206 aleocharine beetle specimens captured in 15 Malaise traps and 15 white pan traps. Three collecting zones were targeted in the experiment: forest interior (FI), forest transition (TZ), and 5-year old clear-cut (CC). Most of the specimens were captured in the forest transition zone (n = 739, 61%), followed by the forest interior zone (n = 383, 32%), and only a small number of specimens were recovered from the clear-cut zone (n = 84, 7%). The following number of species were found exclusively in each of the zones: 1 species (forest interior), 10 species (transition zone), and 2 species (clear-cut). Out of 40 recorded species, 17 were totally absent from the clear-cut zone during the entire collecting season. We assume that these species are the most vulnerable and are heavily impacted by the clear-cut treatment.

Suitability of Six Northern Hardwood Species for Larval Development and Host Selection of the Asian Longhorned Beetle (*Anoplophora glabripennis*) (Motschulsky) and Associated Behaviors

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Anoplophora glabripennis is an exotic cerambycid from Asia with a known affinity for maple tree species. Further information regarding the host range of this beetle is needed to develop potential management strategies. Our goal is to evaluate possible susceptible hardwood species and adult female behaviors that influence host selection.

The suitability for female oviposition and larval development on certain hardwood tree species was assessed for eight mating pairs of beetles. A mating pair of beetles was placed in a glass container along with sugar maple twigs and a wood section of the test species for oviposition. No eggs or larvae were found in logs of eastern cottonwood and tulip tree, but were found in oaks, honeylocust and sycamore. A greater number of larvae and eggs were clearly found in sugar maple logs.

Adult behavior was monitored in a four-armed olfactory chamber to determine types and duration of behaviors exhibited by the beetle. Three mating pairs were independently observed and videotaped in the dark for 24 hours, and given sugar maple as a host species. Preliminary results suggest that females mate, twig feed, chew an egg niche, and oviposit in a distinct sucessive order.

Virgin female host-selection behavior was monitored in a four-armed olfactometer when given various hardwood tree species as a host. A female beetle was videotaped for 50 minutes in the dark and all behaviors plus duration were recorded. A choice was made when certain behaviors were witnessed. Preliminary results suggest that maples are preferred to other tested hardwoods.

Differential Gene Expression in the Spruce Terminal Weevil Feeding on Resistant Versus Susceptible Host Trees

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Reproductive maturation and oviposition of the spruce terminal weevil (*Pissodes strobi* Peck) are inhibited by resistant Sitka spruce (*Picea sitchensis* (Bong.) Carr.).

Vitellogenin is an egg yolk protein precursor which is necessary for the maturation of eggs. We describe the molecular cloning and characterization of a fragment of the vitellogenin gene from the spruce terminal weevil. The DNA sequence of this fragment has high identity to vitellogenin sequences from other insects. It hybridizes on Northern blots to a single 6.0 kb mRNA that is expressed only in females, and only after they have started reproductive development. Vitellogenin gene expression is induced by treatment with juvenile hormone, and is differentially regulated in insects feeding on resistant or susceptible trees.

We have observed that ovarian maturation and the expression of the vitellogenin gene is greater in weevils feeding on susceptible trees than in weevils feeding on resistant trees. We have also observed that the levels of ovarian growth and transcription of the vitellogenin gene are reduced in weevils feeding on the severed leaders from resistant trees relative to those feeding on severed leaders from susceptible trees. A force-feeding method was developed to deliver extracts from the bark of leaders into the alimentary canal of the weevils. Weevils given one dose of the aqueous extract from resistant leaders, followed by feeding on sections of laterals from susceptible trees, have exhibited 60% inhibition of oocyte growth and 48% inhibition of transcription of the vitellogenin gene relative to insects given the extract from susceptible leaders. These results indicate that these effects of resistance do not require an intact tree, and experiments using extracts show that the observed effects result from a post-ingestive effect of the bark extract. The use of the vitellogenin gene as a probe may provide a sensitive bioassay for identifying resistance factors.

Outbreak of an Exotic Defoliator: Pine False Webworm [*Acantholyda erythrocephala* (L.)] Research in New York

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An outbreak of the pine false webworm (PFW), *Acantholyda erythrocephala* (L.), began expanding from an epicenter in 1981 and by 1995 resulted in defoliation of more than 5 400 ha of eastern white pine (*Pinus strobus* L.) in two northern New York counties. Our objectives were to monitor PFW population densities, identify vulnerable stand conditions, quantify impacts of defoliation on white pine growth, and characterize natural enemy responses to PFW. Population sampling revealed that PFW densities collapsed to non-damaging levels in all but 3 of 25 stands between 1998 and 2000. Pine false websorm densities greater than 150 webworms/m^2 crown cross-sectional surface area resulted in greater than 60% defoliation. Repeated defoliation reduces mean basal area increment by more than 90%. Pine false webworm population densities in 1998 were positively correlated with stand area. In an investigation of bird predation on PFW, avian species richness and diversity were positively correlated with PFW density. Avian flocking behavior occurred only in stands with high PFW densities and corresponded with the time of PFW larval feeding. Pine false webworm larval density was greater on trees exclosed from birds than exposed trees. Total larval parasitoid (*Homaspis interruptus* (Provancher) and *Olesicampe* sp.) trap catch was positively correlated with PFW density.

An Improved Trap for Large Wood-Boring Insects (Cerambycidae, Buprestidae, Siricidae)

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Commercially available multiple funnel traps have three potential weaknesses for trapping large wood-boring insects: 1) escape by captured insects from the dry collecting cup, 2) low catches of insects that fall outside the trap, and 3) poor visual orientation to the narrow funnel column. To test the importance of these weaknesses, we compared conventional multiple funnel traps to multiple funnel traps with water-filled collecting cups or large bottom funnels, and crossvane traps with a prominent silhouette. The experiment was conducted in a mill yard in the southern interior of British Columbia between July 5–October 2, 2000. Differences in catch among different trap types indicated that two of the three potential weaknesses were important limitations for the capture of most target species. Crossvane traps captured significantly greater numbers of most Cerambycidae and Siricidae, and similar numbers of most Buprestidae, compared to the other traps. Of the two most abundant species, *Xylotrechus longitarsus* Casey was captured in consistently greater numbers in crossvane than in other traps, but *Monochamus scutellatus* (Say) showed little discrimination early in the flight season and much higher captures in crossvane traps late in the season. The change in behavior of *M. scutellatus* may be related to a transition from maturation feeding to searching for oviposition sites.

Influence of Substrate Water on Carabid Pine-Seed Predation

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Seed losses to seed predators in commercial direct-seeding can be substantial. Common post-dispersal seed predators in Northern Sweden are finches, voles and carabid beetles. Various measures are taken to facilitate seedling formation and reduce predation, among which are scarification and micro-site preparation. Among other effects, this alters the capillary properties of the soil. Substrate qualities are known to affect habitat choice by carabid beetles. It has also been shown for rodents that substrate water affects the ability to find buried seeds. In a laboratory experiment, I let adults of the carabid beetle *Pterostichus oblongopunctatus*, one of the most common carabid species in Sweden, choose between Scots pine (*Pinus sylvestris*) seeds on dry sand and moist sand. Observations revealed no preference or aversion to moving about on either substrate, yet only seeds from the moist substrate were eaten. I hypothesise that the observed effect is not caused by the variation in substrate moisture *per se*, but by the variation in seed water content which covaries strongly with substrate water. Probable mechanisms may be increased leakage of volatiles through micro-fissures caused by seed swelling, or formation of volatiles by chemical reactions during water uptake. Further studies may reveal the actual cause.

Are Headwater Streams Important to Forest Ecosystems?: Adult Aquatic Insect Communities in Temporary and Perennial Headwater Streams in Western Oregon

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The riparian areas encompassing headwater streams comprise over 50% of federally managed land in the Pacific Northwest. Forest management practices and their consequences are likely to have direct effects on the abundance and diversity of arthropods in these sensitive habitats, and indirect effects through the foodweb on vertebrates of concern. We examined the effect of stream flow (perennial versus dry-season temporary), and canopy presence on adult insect fauna collected from emergence traps in headwater streams in the conifer forests of western Oregon. Trichoptera and Ephemeroptera emerged in greater numbers in perennial streams, and density and biomass of aquatic insects were higher during the summer in perennial streams than in temporary streams. In contrast, Diptera and Plecoptera emerged in greater numbers from temporary streams, and density and and biomass of all aquatic insects were higher in these streams during the spring. These results are consistent with our hypothesis that the absence of vertebrate predators (fish and giant salamanders) allows insects in temporary streams to flourish, and supports our conclusion that temporary streams are as important as perennial streams in serving as: (1) a potential source of colonization for perennial streams and (2) an important factor in the terrestrial food web as an abundant food source for insectivorous vertebrates. Both temporary and perennial headwater streams flowing through clearcut uplands support higher densities, biomass and richness than forested streams. The proliferation of insects in headwater streams flowing through clearcuts may be attributed to higher levels of insolation, increasing primary production.

Verbenone Interrupts Attraction of Red Turpentine Beetle (*Dendroctonus valens*) to Host Volatiles

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We tested two formulations of verbenone for efficacy in protecting ponderosa pine trees from attack by the red turpentine beetle (*Dendroctonus valens* LeConte): (1) polyethylene bubblecaps filled with 800 mg of neat verbenone, and (2) a sprayable water suspension of microencapsulated verbenone. We baited artificial trees (cardboard cylinders coupled with Lindgren pheromone traps) with host kairomones and the verbenone formulations. Efficacy was measured by numbers of beetles captured in baited traps.

Both release systems significantly reduced trap catch, and there was no significant difference between them. Both systems have promise for use in forest stands, depending on management objectives and land use. Verbenone was an inhibitor for some nontarget insects, especially Coleoptera, and none were consistently attracted to verbenone.

This is the first report of verbenone as an interruptant to host attraction in the red turpentine beetle, and is also the first report of efficacy for a microencapsulated scolytid semiochemical.

Habitat Selection by Douglas-fir Beetles (*Dendroctonus pseudotsugae*) in Fallen Trees Depends on Beetle Condition

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As is the case for many aggregating bark beetles (Scolytidae), Douglas-fir beetles breeding in fallen trees experience strong competition among offspring even at low breeding densities. Nevertheless, Douglas-fir beetles respond positively to aggregation pheromones. One explanation for this paradox is that attraction to successfully breeding conspecifics reduces search costs when breeding habitat is hard to find. Using published data on the energetic cost of flight and the probability of finding habitat, I examined the conditions under which Douglas-fir beetles should accept a given level of crowding rather than continuing to search for a less crowded site. I tested the predictions from this model by examining the fat reserves of Douglas-fir beetles settling at different breeding densities in felled trees. As expected, beetles settling at higher densities had lower fat reserves. These data suggest that aggregation by bark beetles in fallen trees is a conditional strategy that will vary with habitat availability. This also has implications for the effectiveness of pheromone-baited traps.

The Influence of Stand Composition and Stand Structure on the Dispersal of the Striped Ambrosia Beetle [*Trypodendron lineatum* (Olivier) (Coleoptera: Scolytidae)]

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Striped ambrosia beetles, *Trypodendron lineatum*, degrade felled conifers. Few studies have addressed the influence of stand composition and structure on its distribution.

We examined four stand types (deciduous dominated, deciduous dominated with conifer understory, mixed wood, and conifer dominated) and four harvest treatments (10% residual standing trees, 20%, 50%, and uncut controls) as part of the EMEND (Ecological Management by Emulating Natural Disturbance) project in northern Alberta. Habitat availability (abundance of conifers) and abundance (number of conifer stumps) strongly predicted the distribution of *T. lineatum* as measured by baited trap catches. Stand structure had a limited effect on *T. lineatum* comparatively. Residual level had no effect in stand types except conifer-dominated stands, indicating a small effect of structure on dispersal. During the second year following harvest, stand structure had a slightly significant effect as individuals preferred thinned stands across all stand types except deciduous dominated stands. Further evidence that stand structure plays a minor role in *T. lineatum* distribution is that trap catches in cut corridors did not differ from catches in retention strips. However, higher trap catches were associated with denser understory vegetation. This study suggests that habitat availability is more important than physical stand structure in the distribution of *T. lineatum.*

Effects of Wildfire on Oak (*Quercus*) Growth, Foliar Chemistry, and Herbivory

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Fire is a major disturbance factor influencing the formation and maintenance of oak-dominated forests of eastern North America, altering forest stand composition and influencing succession. Fire causes physiological changes, altering photosynthesis and leaf chemistry, and potentially influences growth and susceptibility to herbivory.

The gypsy moth (*Lymantria dispar* L.), is an introduced polyphagous herbivore that devastates oak stands. My objective was to assess the effects of a naturally occurring wildfire on chestnut oak (*Q. prinus* L.) seedling growth, foliar chemistry, and suitability to this herbivore. I sampled chestnut oak seedlings for phytochemical analysis throughout the post-fire growing season, and sampled once to assess suitability for caterpillar performance and for measurement of seedling growth.

Chestnut oak seedlings sampled from burned sites had significantly lower foliar carbohydrate levels, and higher foliar nitrogen and water content, than seedlings sampled from non-burned sites. Seedlings from burned sites had higher tannin levels initially, but later in the season this trend was reversed. Seedlings from burned sites also were smaller, but grew more than their non-burned counterparts. In spite of the differences in leaf chemistry, there were no significant differences in the performance of a generalist herbivore-fed foliage from burned versus non-burned seedlings.

Temporal Response by Predators to Increasing Scolytid Populations following the 1998 Ice Storm in Eastern North America

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The severe ice storm of January 1998 caused extensive damage to forests across north-eastern North America, providing an opportunity to study the population dynamics of a bark beetle pest and its associated predators. Our major objective was to test the hypothesis that stands with high bark beetle populations have higher predator abundance and diversity than stands with low beetle densities.

Population levels of the bark beetle, *Ips pini*, and its associated predators, particularly *Thanasimus dubius* (Coleoptera: Cleridae) were compared between storm-damaged red pine stands and undamaged control stands in eastern Ontario during 1998–2000 using trap logs (1998–2000) and baited Lindgren funnel traps (2000). Our results demonstrated that scolytid populations increased rapidly in the first two seasons, but then declined with decreasing availability of non-resistant brood material. No infestations were observed in standing green trees, even those with only approximately 10 green branches remaining. A significant increase in the abundance and diversity of predator populations also contributed to considerable scolytid mortality. Our results suggest that the likelihood of tree mortality caused by bark beetle outbreaks is low in this region. Responses are compared with recent European and North American studies showing the important regulatory effects of predators on bark beetle outbreaks.

Boreal Spiders as Indicators of Multi-Scale Forest Structure, Disturbance, and Biodiversity

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The maintenance of biodiversity is paraded as the key to sustainable forest management. However, we are largely ignorant of the biodiversity we seek to maintain. In addition, we know very little about the link between biodiversity and forest structure, the tangible key to managing forests.

Through the Ecological Management by Emulating Natural Disturbance (EMEND) experiment situated in the boreal mixedwood forest of northwestern Alberta, industry and research partners are evaluating critical aspects of the natural disturbance paradigm. The central hypothesis of this experiment is that the amount and distribution of residual material left after harvest can emulate the residual left after experimental fire.

The suitability of spiders to act as environmental, ecological and biodiversity indicators is assessed within the context of EMEND. Pre-treatment (1998) and post-treatment results (1999 and 2000) are presented at three structural levels: cover type, treatment, and within treatment. This design assists in gauging environmental and ecological bioindication. Comparing spider diversity to carabid beetle diversity allows for an assessment of spiders to act as biodiversity indicators.

These results will contribute to a basic understanding of boreal forest spider biology and diversity, to an evaluation of the natural disturbance model, and hopefully to the aging socio-political discussion about forest sustainability.

An Evaluation of the Gypsy Moth Pathogen [(*Entomophaga maimaiga*) (Zygomycetes: Entomophthorales)] in Michigan Forests

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The fungal pathogen *Entomophaga maimaiga* has been responsible for significant declines in gypsy moth [(*Lymantria dispar* L.) (Lepidoptera: Lymantriidae)] defoliation in the northeastern USA since 1989. In Michigan, however, the pattern of *E. maimaiga* epizootics has been less consistent since its introduction in 1991. Although *E. maimaiga* is established throughout Michigan, high-density gypsy moth populations and severe defoliation have continued to occur.

We conducted field bioassays in 32 oak-dominated Michigan forests, known to have been previously inoculated with *E. maimaiga*, to assess infection rates of laboratory-reared gypsy moth larvae. We also conducted laboratory bioassays with gypsy moth larvae and soil samples collected from the 32 study sites to determine infection rates under optimal fungal germination conditions. Soil samples were analyzed to quantify the density of *E. maimaiga* resting spores at each site. Additionally, we collected larval cadavers from natural gypsy moth populations at the sites to evaluate the interactions between *E. maimaiga* and nucleopolyhederosis virus (NPV).

Preliminary results from field and laboratory bioassays indicate that *E. maimaiga* azygospore density varied between sites and was correlated with gypsy moth larvae infection rates. Natural gypsy moth population densities also varied between sites and often had larvae killed by *E. maimaiga* and NPV.

Effects of Restoration Thinning Treatments on Water Relations and Photosynthesis of Four Size-Classes of Ponderosa Pine

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We investigated effects of restoration thinning in northern Arizona ponderosa pine forests on leaf water potential and net photosynthetic rate. Treatments were initiated in December 1998 and included an unthinned control, a light thinning, and a heavy thinning. In thinned plots, leave-tree selection was based on presettlement tree evidence. Unthinned controls were densely stocked with pre- and post-settlement trees. Measurements were made on four tree size classes during dry (June) and wet (August) periods.

June predawn water potential was significantly higher in thinned than control treatments. Mid-day water potential was significantly higher in heavily thinned than lightly thinned or control treatments, with no differences at midmorning. August predawn and mid-morning water potentials were significantly lower in lightly thinned than in heavily thinned or control treatments, and mid-day water potential was significantly higher in the control treatment.

Plots of net photosynthetic rate versus vapor pressure deficit suggested that heavy thinning increased photosynthesis compared with the lightly thinned and unthinned control. Tree size did not affect water potential or photosynthetic rate in most cases. These results suggest that previously suppressed ponderosa pines respond quickly to heavy thinning by increasing water uptake and photosynthesis.

Variation in Response by Pine Engraver Beetles (*Ips pini*) to Ipsdienol and Lanierone in Western Montana and Northern Arizona

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Pheromone specificity in pine engraver beetles (*Ips pini* Say) differs across North America. This variation makes suppression trapping and monitoring difficult without area-specific information. Our objective was to further increase understanding of area-specific pheromone attraction in northern Arizona and western Montana. We evaluated variation in response by pine engraver to the attractant pheromone ipsdienol and synergist lanierone. Five isomeric blends of ipsdienol (+03/-97, +25/-75, +50/-50, +75/-25, +97/-03) were tested with and without the synergist lanierone. Insect catches from the Lindgren-funnel traps were collected weekly for four weeks, and traps were re-randomized after each collection. Regression analysis indicates that the level of (-)-ipsdienol and the presence of lanierone increased catch numbers of *Ips pini* in both populations. Overall, the treatment combination of +03/-97 ipsdienol with lanierone resulted in higher catch numbers than other treatments. Increased attraction to traps with lanierone present, and lack of attraction by lanierone alone, support lanierone's role as a synergist. The similarity in pheromone specificity between *Ips pini* populations in western Montana and northern Arizona, and differences from other populations in southeastern United States, raises questions as to the origin of the northern Arizona population.

Evaluation of Bait Logs for Containment of the Brown Spruce Longhorn Beetle (*Tetropium fuscum* Fabr.)

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L. Humble and **E. Allan,** *Canadian Forest Service, Victoria, British Columbia*

The brown spruce longhorn beetle, *Tetropium fuscum* Fabr., infests fresh stumps and cut logs as well as living spruce trees. In June 2000, we placed logs of recently felled red spruce in various configurations and baited some with host volatiles to compare their attraction to the brown spruce longhorn beetle, *Tetropium fuscum* Fabr., in Point Pleasant Park, Halifax, Nova Scotia. The number of *Tetropium* pupal cells per log was significantly greater in 6-log decks than in logs arranged vertically or in horizontal spokes, or in girdled red spruce trees. Baiting log decks with 5 different combinations of host volatiles (e.g., a-pinene, ethanol) did not increase *Tetropium* infestation. Within decks, logs on the bottom were more infested than those on top. In a subsample of more than 1 000 larvae extracted from pupal cells, about 65% were *T. fuscum* and 35% were *T. cinnamopterum*, a native cerambycid. Log decks have potential use in containing the spread of *T. fuscum.*

Ecological Processes

T.R. Torgersen, *US Forest Service, La Grande, Oregon*

Forest disturbances such as the activity of insects and wood-rotting fungi have complex relationships to other living and dead components in the healthy forest. My two decades of research have identified and quantified ecological connections between western spruce budworm (*Choristoneura occidentalis*) predation by foliage-foraging, log-dwelling Camponotus and Formica ants, and by insectivorous birds. The cycle includes ecological connections to snags, dead wood-dependent and secondary cavity-nesting birds, snag-nesting pileated woodpecker (*Dryocopus pileatus*), coarse woody debris, and predation on ants by pileated woodpeckers and black bears (*Ursus americanus*). The poster is in the public domain, and may be downloaded in a variety of formats from <www.fs.fed.us/pnw/lagrande/publications.htm>.

Recent Invasions of North America Lepidoptera Defoliators in Slovakia (Central Europe)

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Three North American Lepidoptera invaders in Slovakia have been recorded since 1987: *Coleotechnites picaella* Kearfott (Gelechiidae); *Parectopa robiniella* Clemens and *Phyllonorycter robiniellus* Clemens (both Gracillaridae). Three survey methods were used to determine the presence of each species on newly infested areas. Their occurrence was mapped during systematic field trips from 1992 to 2000. Data was also acquired from people involved in the faunistics of Lepidoptera (members of entomological societies) and from faunistic records in the local entomological journals. *Coleotechnites picaella* was identified by spruce damage and by determination of adults during the flight period. Each of the black locust miners was identified by the type of larval mine and by the presence of adults.

Coleotechnites piceaella was found for the first time in eastern Slovakia in 1990. At present it is mainly known from southern to southeastern Slovakia as a pest on ornamental (*Picea pungens* and *P. omorica*) and forest trees (*P. abies*). *Parectopa robiniella* and *P. robiniellus* started to attack black locust (*Robinia pseudoacacia*) stands in the southwestern Slovakia in 1987 and 1992, respectively. Both these species are presently causing heavy defoliation of black locust stands in the southern part of Slovakia.

Biological Role of Ambrosia Fungi Associated with *Trypodendron* Spp.

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Ambrosia beetles bore into sapwood and their larvae feed exclusively upon ambrosia fungi. The beetles are thought to infest only dying, diseased or fallen trees or stored logs. A dark fungus was found to stains the walls of the galleries while a white fluffy fungus was located in the larval niches. Sampling fungi from the adult beetles, pupae and larvae; from infested wood; and by dissecting the mycangia of female adults, revealed two or three fungal species for each of the three *Trypodendron* species sampled in British Columbia. We hypothesize that some of these fungi help two hardwood-infesting species to overcome host defenses or even kill the trees.

The fungi from *T. retusum* were inoculated into fresh trembling aspen logs and into standing trees to test their ability to colonize host tissue and pathogenicity. The results may alter our view of the potential damage caused by ambrosia beetles and their associated fungi, not only on lumber but also in standing trees.

Oviposition Patterns of a Cambium Miner, *Phytobia Betulae*, within and among Birch Genotypes

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S. Hinkkanen and **H. Roininen,** *University of Joensuu, Joensuu, Finland*
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More than 15 species of the genus *Phytobia* (Diptera: Agromyzidae) have been described in North America but their biology is poorly known. We studied *Phytobia betulae* Kang in Fennoscandia, which is similar to North American *Phytobia* in that it mines the stems of woody plants. We measured oviposition patterns in shoots of birch (*Betula pendula*) to test whether birch genotypes differ in their susceptibility and to determine those tree characteristics that correlate with successful host use. Successful ovipositions of *Phytobia* were measured in 8 young birch genotypes in a field experiment (southeastern Finland). Oviposition occurred within 5% of the available long shoots, but was more concentrated within fast-growing genotypes and within fast-growing long shoots within genotypes. Oviposition frequency did not vary among experimental blocks or among compass quadrants within birch crowns. Oviposition preference was sufficiently strong to result in significant aggregations of P*hytobia* within shoots: 11% of shoots selected for oviposition contained more than one *Phytobia* and 22% of *Phytobia* shared their shoot with at least one other larva. Although birch shoots were about 20-fold more abundant than *Phytobia*, there nonetheless appears to be intraspecific competition for host resources among *Phytobia* larvae.

FOUNDERS' WESTERN FOREST INSECT WORK CONFERENCE AWARD SPEECH

RAMBLINGS

John H. Borden, *Department of Biological Sciences, Simon Fraser University*

Ladies and gentlemen, fellow forest entomologists. I am particularly pleased to receive the Founders' Award of the Western Forest Insect Work Conference, because above all else, I consider myself to be a forest entomologist. It might be customary on an occasion such as this to make a lengthy speech on the lives and times of long-dead founders of our profession. I am certainly deeply in their debt, and profoundly honoured to receive this award in their memory.

However, I have been a forest entomologist for 38 years, and am certainly venerable enough to be considered at least a bit of a founder in my own right. Therefore, I'm going to give a long speech about myself. You will doubtless find mention of my own mentors, who by age alone, lie even closer than me to the true beginnings of our profession.

I have entitled this presentation *Ramblings* for good reason. Firstly, our vocation involves a great deal of travel. Secondly, at my age, this title increasingly describes my way of thinking. So I'm going to ramble through my life to give you some idea of the experiences and thoughts that have shaped one of your colleagues. This is my story.

My travels began early. I was born in 1938 in Berkeley, California, nine months after my father got his Ph.D. One year later, the family moved to Vancouver, where my father had taken a position as an Assistant Professor in the German Department at the University of British Columbia (UBC). I don't remember the trip, but I understand that I cried a lot and was generally unpleasant.

It was not until 1946, when I was eight that I genuinely fell in love with travelling. That summer, our family of four set out for Berkeley in our 1940 Chevrolet sedan. I remember the old cement road surface of Highway 99, with strips of tar between the plates, the forested hills of Oregon, and the broadening plains of northern California. One night I laid in bed in the auto court (later known as a motel), and listened to the diesel freight trucks passing by. I felt an almost overwhelming sense of adventure, of expectation, of wonder and of freedom. To this day, the smell of diesel exhaust makes me long to travel again.

The summer that followed was idyllic, full of warm earth and the scent of eucalyptus in the California sun, real blue jeans with long pant legs, and learning to roller skate on an empty street. While most of my time was my own, each afternoon my mother would sit on the front porch of our rented house, and read out loud a chapter from an Oz book. At first she read only to my friend Ricky and me. But word spread, and before long, by early afternoon there would be a sizable crowd of expectant listeners sitting patiently on the dry lawn, probably about a three-block catchment area.

What do Oz books have to do with forest entomology? Well, they are fantasy, at least to me. Fantasy leads to imagination. I know that imagination expressed in play by children leads, in turn, to originality in adults. Today I firmly believe in unstructured play for children. Although my play today is somewhat more structured (I have to publish the results), as a forest entomologist I still get to play in the woods. Perhaps some of my originality stems from that carefree California summer.

Some of you may know me as determined and highly competitive in nature. I may have honed these traits at summer camp in August of my 12th year, when I still went by my middle name Harvey. Morecroft Camp was nestled in a beautiful second-growth forest around two little coves on the east shore of Vancouver Island near Nanoose Bay. There was lots of time for imaginative play, but by the age of 11 my inclination for that passtime had ended, and I spent most of my unstructured time with other boys, throwing rocks into the water. The camp had both girls and boys, and we were divided into two mixed-sex tribes, the Nanaimo (to which I belonged) and the Nanoose. We had a month-long competition in many activities dreamed up by our imaginative counsellors. One day they announced that the boys would have a cross-country run (the girls at that time being considered too delicate for such a feat). I was timid and lacked confidence. I quailed at the prospect. I loved to run, but I was awfully slow.

Off we went in a closely bunched pack, a few loudmouths proclaiming their certain victory. But the course was long, and the day was hot. Gradually, the pack strung out. To my surprise, about a third of the way through the race, I found myself in a group of three boys, in front! A strapping 14-year-old named Ross quickly fixed that, and bolted away, never to be seen again. I was left with Bradley, a taciturn 13-year-old who gradually pulled away from me. I lost sight of him at the turning point, and ran alone the entire return leg down the dusty road back to camp. I ran partly out of new-found determination, and partly out of fear of what might be catching me from behind, a fear that I have never quite lost.

As I rounded the corner into the grassy field that marked the finish line, I was astonished to see the crowd of girls and counsellors waiting for their fellow tribespersons. They were equally astonished to see me. I heard someone say "It's Harvey!" And they cheered. It was the first time that I had ever heard applause for something that I did on my own. And I won three points for the Nanaimo tribe. From that day on I loved competition.

Because of my father, I also came to love British Columbia. My father grew up in Germany. At the age of 17, he discovered, to his surprise, a great family secret. He had been born an American. When he was four, his widowed mother had returned with him and his sister to Germany after the death of his father. He promptly left home, made his way to Hamburg, and got a one-way passage to New York (the place of his birth) working as a cabin boy on a freighter. He arrived at Ellis Island with nothing but his birth certificate and a pair of brass knuckles that he had found on the ship. After some time, the authorities located his snobbish New England relatives. They spurned him, but did find him a job in a coal mine in upstate New York. There he re-learned English by correspondence courses, and after that worked his way west across America. At the age of 24, he quit a highly skilled job as a photoengraver, and entered UCLA where he majored in German literature and botany. Years later, when anyone asked him where he learned to speak such good German, he always said UCLA.

As a German professor, he wasn't very good. But he was a passionate amateur archaeologist, and he became very good at that. When he was 40, UBC allowed him to switch to archaeology, as long as he kept his full teaching load in German. But money was short, and so he took me with him in the field as a docile source of cheap labor. I learned the craft well, in surveys and digs all over the province, and it satisfied my need for both adventure and travel. I learned to think, not only like my father, but like a native who relied on nature, and thus to really appreciate nature. The life was tough. We camped outside, we got very hot, very wet, and very dirty.

I remember particularly one enchanted day when I was 13. We were surveying the upper Kootenay River south of Cranbrook, before the land was flooded by the Libby Dam in Montana. We came across a sandy knoll near a shallow stretch of river, a perfect place to wait for game to cross. Sure enough, the knoll was littered with obsidian and basalt flakes, and broken arrowheads where the native hunters had sat making and breaking tools while they waited for game. And while my father busied himself elsewhere, I sat on top the knoll, imagining myself to be a fearsome hunter, waiting for my elk to cross the river.

Now almost 50 years later, in my profession as a forest entomologist, I retrace my father's footsteps across the land, from Squamish to Kitwancool, from the Chilcotin Plateau to Invermere, from Yahk to the Liard River Valley.

And everywhere I go, I feel my father's spirit watching over me.

Speaking of my father, his ghost rose unexpectedly last year on a forest health field trip out of Vanderhoof in north-central B.C. At one stop in the usual tour, the gathering of forest entomologists and pathologists assembled around a somewhat overly enthusiastic Forest Service Recreation Officer, who was to tell us about culturally modified trees. While his audience patiently fed the local mosquitoes, he explained at length that the lodgepole pines with basal scars that we thought were because of fire were actually native food trees. As the Indians traveled along the network of trails in early spring when food was scarce, they would strip the basal bark from one side of the vigorous young trees, and scrape off the thin layers of freshly laid cells near the cambium. The nutritious pulp sustained them until other food sources became more plentiful.

After enlightening us about native food trees, our teacher went on to talk about cultural deposits in the area, including a large prehistoric village site on which a potato farm now sat. Unable to contain myself, I blurted out that I had visited that farm with my father in 1952. "Who was your father? he asked. "Carl Borden" I murmured, suddenly embarrassed. "Not Charles E. Borden, the famous archaeologist?" he asked excitedly. "That's him" I replied. "And what do you do?" he said. "I'm a forest entomologist" I told him proudly, expecting approval. "Oh" he said, looking at me as if I had some sort of genetic defect, and moved on to another topic.

Because my parents, who were both successful academics, expected me to succeed scholastically, I chose to be mediocre. I was not supposed to do blue collar work, from which they both escaped, so I got various blue collar jobs, such a farm laborer, waiter on the railroad, and steel worker. Things came to a head in 1957 with a grade of 10% in Physical Chemistry at UBC, washing me nicely out of pre-med. So much for "my son, the doctor."

Not prepared to face the consequences of my failure, I ran away to California to visit my relatives, who I just knew would be glad to see me. It is thus not surprising that I overstayed my welcome, and failed to realize this until a crisis loomed. What to do? I didn't want to give up, grow up and go home. So I chose the military. I thought the Coast Guard would be nice. But it would be a month before they took me. So I walked around the corner in downtown Oakland and joined the Marines. Two days later I was in boot camp.

Now this was a rude shock. For the first time in my life I had to really face up to the consequences of my decisions. In the first place, I found the Marine Corps to be an organization totally devoid of and unreceptive to either humour or intelligent ideas, both of which I tried valiantly to offer. Secondly, Gunnery Sargeant McCants and his three assistant drill instructors seemed to be universally convinced that I had few skills of any use to the Corps, and they were especially intent on letting me know that I had no future at all in marching. Lastly, they were training us to kill people. But no-one wanted to be a cook, so I volunteered to go to cook's school to get out of the infantry. I hated it, and I was bad at it, the worst cook in the Corps, a trained killer of another sort if you will. It was a long 4 years.

I had enlisted between wars, and thus didn't endanger anyone, and I had time to grow up. Gradually I began to think that maybe, if I actually worked hard, I might succeed as a scholar. For my last tour, I was stationed at Marine Corps Air Station, Kaneohe Bay, Hawaii. Finally my time came to return to San Francisco for discharge. We were four miserable days at sea on an ancient troop carrier. On the morning of the fifth day, we were rousted out of our racks at zero dark thirty, and herded up on deck in a pitch-black, dank and foggy world. We sat there for two hours. Slowly the fog turned grey as dawn approached. Suddenly, the fog parted ahead of the ship, and there to my amazement, in brilliant sunlight in an otherwise grey world, not touching land but suspended from cloud to cloud, was the Golden Gate bridge. Surely this was a divine signal, my personal sign of a bridge that I could cross to a better life.

It was. Because I didn't want to return to UBC, the scene of my past failures, I had gained admission to Washington State University as a wildlife biology major. Ever eager, I arrived several days before classes began, and went to visit Dr. Irvin O. Buss, the senior wildlife biologist at the university. He asked if I wanted to go on a game check with some graduate students. I jumped at the chance. So off I went in a pick-up truck up to the town of Okanogan, where we stationed ourselves with a state Fish and Game Officer near the exit of a forestry road. We intercepted each and every grouse hunter heading home with a proud brace of birds. How could they resist three students who wanted to take samples from their birds, especially if they were guarded by a gun-carrying cop? The first student (with permission, of course) snipped off the wing tip and tail feathers for later analysis. The second aged the bird by shoving a blunt probe up its nether parts, searching for a diverticulum in the cloaca. And I (with permission, of course) removed the food-laden crop and gouged the eyes out with scissors, dropping each into separate vials of ethanol. I'll never forget the forlorn look on the faces of the hunters as I handed their once proud birds back to them. "This is wildlife biology?" I thought. "There has to be something better than this."

There was. In my second semester, I had to take an entomology course. I knew, halfway through, that I was going to be an entomologist. "Don't do it" said my botany professor. "DDT has solved all the really important entomological problems." Then it dawned on me that there were insects in the forest. Could I truly have my cake and eat it too? Could I work with insects in the forest, and return to those wonderful days of summer camp and roaming archaeological surveys? "Don't do it" said my entomology professors, intoning that forest insects are of little consequence compared to the really important pests of agriculture and medicine. So I decided to become a forest entomologist. Today I feel somewhat vindicated as the mountain pine beetle continues to kill about a billion dollars worth of timber every year in British Columbia.

My first day as a forest entomologist in 1963, however, did not go at all well. Earlier that year, I had narrowed my choices down to Oregon State University and the University of California at Berkeley, and had visited both campuses. Oregon State was acceptable, with interesting students like Gary Pitman, Bob Gara and Mike Atkins, but they seemed to complain a lot. At Berekely, there were more faculty and a whole bunch of students happily crammed into the basement of Agriculture Hall. I opted for Berkeley. Happy to leave Pullman, Washington, I said goodbye to Edna, my already long-suffering wife of one year, who returned to Vancouver to live with her parents, while awaiting the birth of our first child. And I, oblivious to any familial duties, headed off south in our Volkswagen beetle (I even took the car). Once again, California beckoned, this time where Ron Stark had offered me a summer job as a research technician at the princely sum of $475 per month.

Two days later, I arrived at the Department of Entomology in Berkeley very early in the morning. I signed in and asked where I could begin work. They told me Blodgett Forest, showed me a where it was on a map, and suggested I begin the following day. "Not likely" I said, jumped in the beetle and headed up through Sacramento, Auburn, Cool and Georgetown, arriving at Blodgett Forest headquarters in a cloud of red Sierra dust at about 1:45 p.m., ready to go to work. It was hot and silent. There was nothing moving, no sign of human life. Where was I to work? Whom would I work with? I wandered around aimlessly, raising little puffs of red dust.

Suddenly, out of the corner of my eye, I spotted something moving. Yes, it looked like a hard hat behind a ridge of fresh dirt, obviously an excavation for a new building behind it. I bested the ridge and called out "Hi" to the diminutive person facing away from me under the orange hat. Suddenly he wheeled to face me, a revolver raised in line with my chest. "Don't shoot, I said. I'm just a new graduate student" (at that moment I thought, one without much chance of a very long tenure). "Oh", he said, "nice to meet you", lowering the gun. This was Dick Tinus, a gun aficionado and fellow graduate student, who had been practicing quick draws in the basement excavation of what was to be Ron Stark's A-frame. Dick went on to become a very accomplished tree physiologist with the US Forest Service in Flagstaff, Arizona.

Only a little shaken (I was, after all, an ex-Marine cook), I explained my quest for Ron Stark, my new boss. "All the entomologists are up in the staff house", he said, pointing up a slight rise to a very new frame building, with a high front porch, not yet with any stairs, and as I was soon to learn, studs, but no walls in the interior. I looked at my watch—2:00 p.m. What would they be doing in there? I made my way around to the back, finding a low stoop and the back door slightly ajar. I pushed it open. On the far wall, in a small bed, I instantly recognized the prostrate form of Dave Wood, clearly sound asleep. To the left, Ron Stark, also asleep. To the right, similarly dead to the world, Imre Otvos and Jule Caylor, both forest entomology graduate students. I looked again at my watch, 2:05 p.m. What to do? I backed out quietly, closed the door behind me, sat on the stoop, and thought about Oregon State.

But I was irrepressible. I had to get to work—I was already on the payroll. So I boldly marched inside, up to the slumbering Ron Stark, and gently shook him by the shoulder. He turned his head, opened one eye, got me in focus, and asked "Who are you?" (or something like that). "I'm John Borden, your new graduate student," I eagerly replied. After a protracted silence, while he evidently mulled over this disquieting news, he uttered two more words, which I recall were not exactly comforting. So I went and sat on the stoop again, this time thinking really seriously about Oregon State.

Gradually, however, the people inside began to stir and stumble around. I soon learned that there had been a little celebration the previous night (such events seemed to occur quite frequently in 1963), and there had been a need to catch up on some lost sleep. The crew had not shirked work, however. They had gone straight from the Buckeye Bar and Grill out to the forest to take the pre-dawn reading of Dave Wood's boiler gauges, plugged into trees to assess their oleoresin exudation pressure as a measure of their potential resistance to bark beetles. In a series of tasks, with which I was to become all too familiar that summer, they had removed the sticky and resinous gauges, packed them into surplus ammunition bags, brought them back to headquarters, cleaned them with pressurized xylene while they had breakfast, and returned to the woods to plug a new set of trees. They had left the most healthy of the revellers, Alex Pannesenko, the mad Russian, out in the woods to take readings throughout the day, and only then had they taken a brief little nap.

It turned out to be a great summer. I loved working for Ron Stark, who showered me with ideas for research. In addition to carpentry on his new A-frame house and laboratory, I began to work out the life history of a cone-boring tortricid, and I supervised three summer students who completely debarked five fallen white firs, yielding much valuable life table data on the fir engraver. Both studies resulted in publications in refereed journals, not a bad start for a first summer of work.

I admired Ron greatly for his uncanny ability to recognize and nurture potential talent that others had missed in his students. He supervised each individual differently, with great patience, and only as much as necessary. Toward that end, he took me aside one day and told me to cool it because I was beginning to annoy people. Looking back, I wonder what took him so long. In August, he gave me the week off that I requested, so I could make a mad drive to Vancouver, where I arrived 1.5 days before the birth of our first son. But most importantly from a professional standpoint, when I came to him the following January to explain my new-found passion for insect antennae, and my desire to work with Dave Wood on olfaction in bark beetles, he unreservedly gave me his blessing.

And so the irrepressible John Borden came under the guidance of the irrespressible Dave Wood. With Dave's enthusiastic stimulation in a suddenly hot field, I raced through my masters and Ph.D. degrees in three years flat. But Dave also taught me the benefits of sharing ideas, the value of maintaining the highest possible standards in research, the sheer joy of rigorous editing, and particularly about scientific ethics. I had come to value his highly ethical nature the previous summer, because the boiler gauge project (which unfortunately never yielded publishable data) was done because of his disappointment with a study by another group, that had obtained contradictory data over a two-year period, but only published the "good" data from the first year. I again saw and admired his enduring sense of ethics over the next three years as he and Milt Silverstein steered their way cleanly through the highly competitive (and sometimes cutthroat) early days of bark beetle chemical ecology.

In 1966, I was hired by Simon Fraser University, a new university in British Columbia, which had sent a recruiting team to scour western US universities for likely faculty candidates. It was a good choice. My research career has allowed me to work with many forest insects in numerous situations, to emphasize basic as well as applied research, and to supervise 101 bright and able graduate students. Most unfortunately, Jim Richerson, my first Ph.D. student and a brilliant behaviorist, died of a massive heart attack two years ago in Alpine Texas, where he was head of the Biology Department at Sul Ross State University.

My success has been facilitated by a series of postgraduate mentors. These include: the late John Chapman, a scientist at the Pacific Forestry Centre, who taught me about ambrosia beetle biology and the importance of odour meterology; Hec Richmond, British Columbia's first consulting forest entomologist, who enthralled me with tales of ambrosia beetle swarms following logging trucks out of the woods, and who made it possible to do our first industrial experiment; and Bryan Beirne, the first Director of the Pestology Centre at SFU, who taught me how to avoid becoming an administrator. I have also had many gifted collaborators such as chemists Milt Silverstein, Cam Oehlschlager and Keith Slessor, and more recently Gerhard and Regine Gries. Since 1974, I have been dependent on two long term employees, Research Associate Harold Pierce, and my Technician Leslie Chong, whose efforts I deeply appreciate. In soap-opera fashion, my real wife calls Leslie "John's other wife".

There have been successful discoveries, the chance to influence government policy, and opportunities for international travel. I would like to tell you, through specific examples, a little about each of these.

Probably the most profound of the discoveries made through collaborative research were the early ones on the chemical ecology of ambrosia beetles. There were no high-tech short cuts to identifying pheromones when we began our work in 1967. Our first two targets were the striped ambrosia beetle, *Trypodendron lineatum* and its companion *Gnathotrichus sulcatus*. My then-technician, Eveline Stokkink, and I spent several years collecting litter and duff containing overwintering *Trypodendron* in the wet snow and cold spring rains around coastal dryland sorts. *Gnathotrichus*, which overwinters in its host, was collected in hundreds of infested stumps and logs, which were placed in Old Blue, a 10 ¥ 50 foot trailer, that had served many years in the construction industry before ending its days as a insect-rearing cage.

We were fortunate to be able to collaborate with Milt Silverstein, one of the truly great pioneers of the new field of chemical ecology, who had recently moved to the New York State College of Environmental Science and Forestry at Syracuse. We satisfied his ever increasing demands for more starting material by collecting the pheromone-laden frass from 21 000 male *Gnathotrichus* and 25 000 female *Trypodendron*. The frass was shipped in dry ice to Syracuse. *Gnathotrichus sulcatus* was the easy one. Its pheromone was identified as a simple 8-carbon compound, 6-methyl-5-hepten-2-ol, and given the trivial name sulcatol. What was more interesting was that it had two optical isomers, both of which were required to induce attraction, the first discovery in the world of such a phenomenon. Some time later, John McLean worked with Milt Silverstein to discover that males of the closely related species, *Gnathotrichus retusus*, produce and utilize pure (S)-(+)-sulcatol, now dubbed retusol by Phero Tech. The commercial demand for this compound stimulated Cam Oehlschlager to develop an innovative synthesis using porcine pancreatic lipase, the first industrial use of enzymes to produce a pure optical isomer of an insect pheromone.

The pheromone of *Trypodendron lineatum* was more difficult. We had identified a probable compound in 1970, but it was a 10-carbon, tricyclic molecule that defied synthesis for six more years, and thus could not be field tested. So in 1977 we naively published the tentative structure. By the spring of 1976, however, we did have a total of 23 m g of synthetic lineatin, produced by a long and difficult synthesis. Bear in mind that a milligram would be about the diameter of a period on a printed page, and this was about 2/100 of that, a virtually invisible amount. We made a benzene extract of synthetic lineatin and waited for good weather.

On April 28, 1976 John McLean and I climbed into the truck (we only had one at that time) and headed for Vancouver Island. It is perhaps ironic that the experimental site was on the shore of Lake Cowichan, where for many years lindane was aerially sprayed onto log booms in the lake at the astounding rate of 1 kg per ha. The spray program had been halted in 1970 when lindane was found in oysters at the mouth of the Cowichan River, leaving the forest industry with no effective direct control method for ambrosia beetles. At about 1:00 p.m. we set up a two-replicate experiment, two control sticky traps baited with benzene, and two experimental traps, each baited with half of the pheromone extract. It was a sunny afternoon, but cool, about 17ºC. Bill Nijholt had an experiment on the same site in which he was catching no *Trypodendron* in traps baited with a-pinene and ethanol. Because of this, we had debated whether to even set up our experiment, but finally irrepressible curiousity won out. We waited a long hour, and then checked the traps, prepared for the worst. But the first trap had six beetles on it (John remembers hundreds, but I'm sure there were six), and the next trap had about the same. What a feeling of exhaltation! We had a pheromone for a major forest pest that by today's prices causes about $200 million in damage every year in B.C.

One week later, when we terminated the experiment, we had caught 350 beetles. But we waited two more years to publish until we had verified this result with the product of two other synthetic schemes that respectively yielded 20 and 30 mg of lineatin. Soon after that, Keith Slessor devised a commercial synthesis, and after developmental research by John McLean, Staffan Lindgren and Terry Shore, in 1981 the world's longest running pheromone-based commercial integrated-pest-management program was started by Phero Tech. Today three different companies offer the program: Phero Tech, Eveline Stokkink's company, Woodstock, on Vancouver Island, and Bugbusters Pest Management in Prince George.

But there was one sour note. Remember I mentioned something about publishing naively? It came as a disappointing surprise that there was another synthesis for lineatin developed in Europe. By the time we published our careful results from three different syntheses, Pierre Vité and Alf Bakke had filed a patent for the use of lineatin in several countries, including Canada. Both I and Phero Tech, which had to pay royalties for many years, learned a great deal from this episode.

One opportunity to influence government policy arose through my association with Norm Alexander, the only graduate student I have had who was older than I, and the only one without a first degree. Back in 1975 Norm and I were riding in a pickup truck on the old stage coach road heading from Princeton toward Norm's field research site near Kelowna. Having a captive audience, Norm began to rant and rave about his pet grievance, the lack of forest pest management in the British Columbia Forest Service, there being at the time one lone Oxford-educated, Victoria-bound forester, Mike Finnis, who was responsible for pest management in some 30 million hectares of working forest. Now this was a long dirt road we were travelling, but Norm was relentless. Finally in desperation, I convinced him that if he was so adamant about this sorry state of affairs, we should write a brief for Dr. Peter Pearse's Royal Commission, which was then touring the province trying to figure out how to fix the province's tenure system.

So Norm and I met in my office after work, and met and met. Norm would rant and rave, and I, with great composure, would translate his rantings and ravings into erudite and compelling prose. At the end, we produced a brief. We appeared before the Commission. Norm, by my recollection, did most of the talking. Peter Pearse appeared to listen intently, but his report was a disappointment, reflecting the writings of Ma Murray, British Columbia's most famous frontier journalist, and long-time publisher of the Bridge River-Lillooet Weekly News. She said that having a Royal Commission was like using an outhouse. “It takes its seat, makes a report and lets the matter drop.” Dr. Pearse's report talked only vaguely about contractual obligations and the pest management responsibilities of the Forest Service and industrial licensees.

But someone in government did listen well. We had proposed a five-person organization for each of the province's six forest regions. Each region would have a supervisor of pest management under whom would serve a pest management researcher and an operations specialist, each with a technician. What was implemented was something not very different. In each region, a pest management coordinator would supervise a regional forest pathologist and an entomologist. In Victoria, a similar group would sit. While there has been some modification and downsizing in the six regions over the years, the basic format persists. What's more, most of the province's 42 forest districts now have a forest health officer.

Today, I am proud to say that all six of the province's Regional Forest Entomologists were my graduate students. One of them, Lorraine Maclauchlan, was very instrumental in writing British Columbia's new Forest Practices Code. In doing so, she managed to ensure that pest management is featured in 14 sections of the Act, in three regulations, in numerous standards, and in at least nine forest practices guidebooks. Of particular impact is the inclusion of forest health in the Operational Planning Regulations, which means that forest health issues must be considered before harvesting, and included in all resource management planning documents.

One of my most interesting travel experiences occurred in Nazareth, Ethiopia. I had been fortunate enough to hook up with the UNDP and FAO in 1988, and worked for them as a consultant until 1996 when the money dried up. In one assignment, I had conscripted my chemist collaborator, Keith Slessor, to accompany me to Kenya to review a project on desert locust pheromones at the International Centre for Insect Physiology and Ecology in Nairobi. It seemed only natural to drop in on our friend Tsedeke Abate on the way home. When he was a Ph.D. student at SFU, Tsedeke had told me that Ethiopians used leaves and berries of the pepper tree, *Schinus molle*, to repel flies. I sensed a potential chemical ecological coup that could have far-reaching implications.

So we checked into one of Addis Ababa's best hooker-infested hotels, and the next morning, we took off with Tsedeke and his driver, Safu, headed for the government research station in Nazareth. There we had to decide how to test Tsedeke's folklore experimentally. There was little available equipment. So we used dinner plates from the canteen, with a petri dish in the middle. In the dish we put the fly bait, some moist Ethiopian bread soaked in pea sauce and sour milk. Around the petri dish we put nothing (as a control), pepper tree leaves or berries, or macerated leaves or berries. Then we sat on stools outside the canteen (where we expected lots of flies), with the dishes on the ground in front of us, prepared to count all the flies that landed. We soon attracted a sizeable audience, who murmured and tittered on occasion, waiting expectantly for something momentous to happen. Nothing did. Only five flies landed in an hour.

So we sent Safu into town with instructions not to return until he found a place with flies. He came back quite soon, with good news. There were lots of flies around the slaughter house. So the next day, we set out for the slaughter house to repeat our experiment. We also added a second, more sophisticated experiment using ethanolic extracts of leaves and berries, carefully made by Keith Slessor with a mortar and pestle that he found in the lab.

The slaughter house was on the edge of town, in the middle of a grassy compound bounded by a high stone wall. The plain outside was strewn with bones of the unfortunate, spread by robbing hyenas. To one side of the tiny shack in the middle of the compound that served as the actual slaughter house was a cement pad, with a putrid, offal-filled shallow trench around its periphery. Beyond that was a convenient manure pile so we added a manure topping to the previous day's baits. We never did see the inside of the slaughter house, but from time to time we heard the plaintive last cries of an interesting assortment of animals as they faced their doom.

Safu was right. There were lots of flies. We placed the plates in the putrid ditch, and sat there in the increasingly hot Ethiopian sun counting the flies. We replicated over time, as the sun rose higher and hotter, and we began to feel increasingly unwell. And all the while, perhaps sensing our sickness, we were watched by vultures sitting on the stone wall patiently waiting for us to breath our last and fall off our stools.

The experiment worked, and back in Canada a graduate student isolated and identified two terpene alcohols that accounted for all of the bio-activity. They were not as potent as we would have hoped, and nothing practical ever came of this research. I did eventually realize, however, that in this project, and in many others in which I took part or observed in my travels, we were guilty of practicing scientific colonialism. In this practice, scientists from the developed world venture abroad to work in developing countries. We do field work in-country, often involving well-educated scientists from the local area (sometimes even avoiding being patronizing). But we do the tough stuff that requires a scientific and technological infrastructure, back in home laboratories. Then we turn over the discoveries to developing countries, leaving no equipment and no sophisticated technology, and can't understand why they're not grateful. I strongly feel that as long as we practice scientific colonialism (in any field, including forest entomology), developing countries will be most unlikely to acquire a scientific and technological infrastructure. I have long since ceased to work in Canada on problems of developing countries, and have encouraged both individuals and government to help in establishing the scientific and technological infrastructure that will allow developing countries to become part of the developed world.

Back home in Canada, I have the rare privilege of being able to do useful work every year in the forests that I love. About 2 years ago, I was returning from somewhere in the east, probably yet another futile rambling to Ottawa. It was a brilliant, cloudless day. As the aircraft began its descent to Vancouver, I looked out to the south from about 20 000 feet, and spread before me was the mountainous landscape spanning Hayes Creek and the Similkameen Valley east of the southern interior town of Princeton. As we advanced, I could see each valley: Shinnish Creek, Siwash Creek, Spukune, Red, Whistle and Willis Creek, Wolf Creek where I had surprised two young grizzlies taking a noon-time nap, and further off to the south, Whipsaw, Lamont, Copper, Friday, Saturday and Sunday Creeks. I could see the forestry roads leading up each valley, many with the names of the creeks they followed, but others with evocative names like Commander, Stemwinder and Rattler. Plainly in view were numerous recent cutblocks, every one logged because of the mountain pine beetle. I knew them all, and had done experiments in many. And at Sunday Summit, I could pick out the telltale red trees, marking the challenge of the continuing infestation. I knew this land. I knew its problems and its people. I had a small, but significant part to play in the protection of its forest resources. I was what I was always meant to become, a forest entomologist from British Columbia. And then I thought, there is nothing finer that one could be.

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