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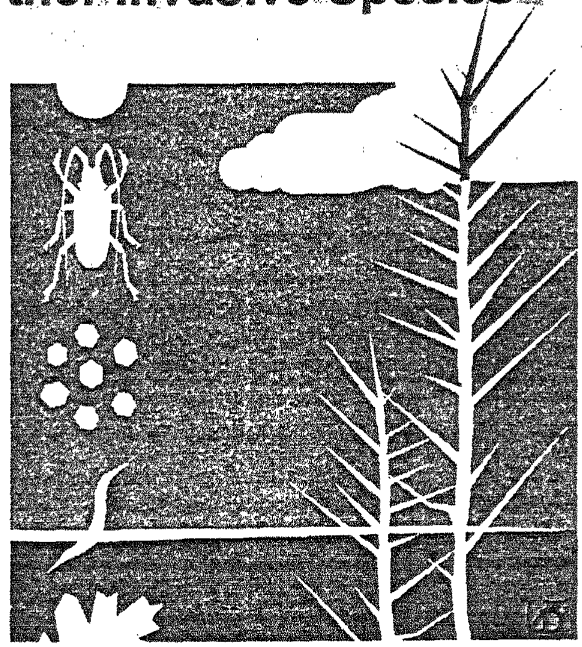
U.S. Department of Agriculture Interagency Research Forum on

11th

Gypsy Moth and Other Invasive Species



January 18-21, 2000

ACKNOWLEDGMENTS

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Proceedings
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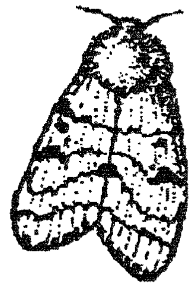
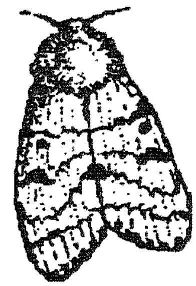
2000



January 18-21, 2000
Loews Annapolis Hotel
Annapolis, Maryland



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USDA

FOREWORD

This meeting was the eleventh in a series of annual USDA Interagency Gypsy Moth Research Forums that are sponsored by the USDA Gypsy Moth Research and Development Coordinating Group. The title of this year's forum reflects the inclusion of other invasive species in addition to gypsy moth. The Committee's original goal of fostering communication and an overview of ongoing research has been continued and accomplished in this meeting.

The proceedings document the efforts of many individuals: those who made the meeting possible, those who made presentations, and those who compiled and edited the proceedings. But more than that, the proceedings illustrate the depth and breadth of studies being supported by the agencies and it is satisfying, indeed, that all of this can be accomplished in a cooperative spirit.

USDA Gypsy Moth Research and Development Coordinating Group

Ernest S. Delfosse, Agricultural Research Service (ARS)
Vic Mastro, Animal and Plant Health Inspection Service (APHIS)
Steve Yaninek, Cooperative State Research, Education and Extension Service (CSREES)
Robert Bridges, Forest Service-Research (FS-R), Chairperson

The program committee would like to thank Abbott Laboratories and USDA, Animal and Plant Health Inspection Service, National Biological Control Institute (NBCI), for their support of this meeting.

USDA Interagency Research Forum on Gypsy Moth and Other Invasive Species
January 18-21, 2000
Loews Annapolis Hotel, Annapolis, Maryland

AGENDA

Tuesday Afternoon, January 18

REGISTRATION
POSTER DISPLAY SESSION I

Wednesday Morning, January 19

PLENARY SESSION .... Moderator: J. Robert Bridges, USDA-FS
Welcome
Michael McManus, USDA-FS

Problems and Successes with the Biological Control of Weeds
Ernest Delfosse, USDA-ARS

A Cooperative Research Approach to Managing Exotic Invasive Pests
Peter Rush, USDA-FS

GENERAL SESSION .... Moderator: M. McManus, USDA-FS
Invited Presentations
Presenters: T. Center, USDA-ARS; L. Humble, Pacific Forestry Centre, British Columbia; R. Frampton, Ministry of Agriculture, New Zealand

Wednesday Afternoon, January 19

GENERAL SESSION .... Moderator: J. Podgwaite, USDA-FS
Gypsy Moth Nucleopolyhedrosis Virus: Reflections and New Directions
Presenters: J. Elkinton, University of Massachusetts; V. D'Amico, USDA-FS; J. Slavicek, USDA-FS; M. Shapiro, USDA-ARS; R. Webb, USDA-ARS

POSTER DISPLAY SESSION II

Thursday Morning, January 20

GENERAL SESSION .... Moderator: V. Mastro, USDA-APHIS
Asian Longhorned Beetle
Presenters: M. Keena, USDA-FS; S. Lingafelter, USDA-SEL; D. Lance, USDA-APHIS; J. Aldrich, USDA-ARS; A. Sawyer, USDA-APHIS; M. Smith, USDA-ARS; Z. Yang, Chinese Academy of Forestry, China; B. Wang, USDA-APHIS; A. Hajek, Cornell University; L. Youqing, Beijing Forestry University, China

Thursday Afternoon, January 20

GENERAL SESSION .... Moderator: A. Liebhold, USDA-FS
Quantitative Approaches to Studying Biological Invasions
Presenters: A. Liebhold, USDA-FS; A. Hastings, University of California, Davis; A. Sharov, Virginia Polytechnic Institute & State University; J. Logan, USDA-FS; K. Hopper, USDA-ARS

GENERAL SESSION .... Moderator: K. Thorpe, USDA-ARS
Research Reports
Presenters: J. Novotný, Forest Research Institute, Slovakia; R. Fuester, USDA-ARS; R. Fusco, Abbott-Valent

POSTER DISPLAY SESSION III

Friday Morning, January 21

GENERAL SESSION .... Moderator: J. Logan, USDA-FS
Impacts of the Interaction of Physical and Biological Disturbance Agents on Forest Ecology
Presenters: K. Ryan, USDA-FS; K. Smith, USDA-FS

GENERAL SESSION .... Moderator: K. Shields, USDA-FS
Research Reports
Presenters: H. Thistle, USDA-FS; R. Haack, USDA-FS; H. Evans, Forestry Commission, United Kingdom

Closing Remarks

CONTENTS

PLENARY PRESENTATIONS

A COOPERATIVE APPROACH TO MANAGING EXOTIC INVASIVE PESTS

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The Northeastern Area, State and Private Forestry, has been involved in developing a Strategic Plan, in cooperation with the North Central and Northeastern Research Stations, to address our cooperative efforts in eradicating/managing exotic invasive species. For several years these organizations have, collectively, spent a significant portion of their available resources on the management of exotic invasive pests. Recognizing that, and the fact that exotic invasive introductions continually increase due to the increase in global trade, we felt it was appropriate to examine the way we cooperatively responded to these introductions in order to maximize our efficiency.

After a brief introduction, the strategic plan provides our purpose, our vision, and our goals. The **Purpose**, as stated in part, in the Plan is "To develop an effective strategy for NA, NC, and NE to address the problems resulting from exotic invasive insects, diseases, and plants impacting our forests." Our **Vision**, similarly stated, is "The United States is a country where the establishment of new exotic invasive forest pests is rare. Where an infestation does occur, Forest Service units work together effectively with Federal and state plant regulatory agencies to deal with the infestation. Through vigorous research and the development of effective technologies, exotic invasive pests already established are effectively managed to reduce their spread and to minimize the damage to our urban and rural forests." The Plan then lists the eight **Goals** that will guide our efforts, both in State and Private Forestry and in Research, in the future. I will discuss these goals, along with the objectives that were developed to help us achieve them.

Goal 1: Respond quickly by assisting in the detection, evaluation, eradication, and monitoring of new exotic forest pest introductions while managing established exotic pests efficiently, effectively, and in environmentally acceptable ways.

- *Objective*: Increase inter- and intra-agency effectiveness in prevention, detection, suppression, monitoring, and restoration.
- *Objective*: Continually review our process on how we react to new infestations or problems.
- *Objective*: Where appropriate, expand the cooperative effort in exotic invasive species to other FS units and other agencies.

Goal 2: Increase research and development on the biology of exotic forest pests and develop and improve control methods for these pests in cooperation with universities and other cooperators.

- *Objective*: Increase our scientific understanding of exotic forest pests.

Goal 3: Create increased awareness of invasive pests through information and education and technology transfer.

- *Objective*: Increase the awareness of exotic invasive species with our federal and state cooperators and their partners.
- *Objective*: Increase public awareness of exotic invasive species through targeted and focused outreach activities.

Goal 4: Clarify Forest Service roles and responsibilities, in partnership with other agencies and cooperators, in the management of exotic pests.

- *Objective*: Improve coordination between NA, NC, NE, and APHIS.
- *Objective*: Establish roles for specific individuals for the daily operation related to invasive species.
- *Objective*: Clarify the Forest Service support role in the northeast and mid-west.
- *Objective*: Support international activities and recognize their importance in combating exotic invasive pests through agency-level and other programs.

Goal 5: Integrate consideration of exotic invasive pests into all FS programs, but in particular the Urban Forestry and Stewardship programs.

- *Objective*: Develop program criteria to integrate exotic species management into Urban and Community Forestry and Stewardship programs.

Goal 6: Establish a policy to address restoration of the damages associated with the eradication activities of exotic invasive pests.

- *Objective*: Formulate an approach for dealing with the destructive impacts associated with eradication of some exotic pests and provide funding to support such activities.

Goal 7: Determine our role, responsibilities, and capacity to respond in the detection, monitoring, and management of invasive weed species that adversely effect forest ecosystems.

- *Objective*: Evaluate our current organizational capacity with respect to staffing, technological expertise, and budgetary constraints.
- *Objective*: Assess the significance of invasive forest weeds on the eastern forest ecosystems.
- *Objective*: Determine our approach to participating in the management of invasive forest weeds of the eastern forest ecosystems.

Goal 8: Support activities that contribute to preventing new introductions.

- *Objective*: Continue to participate in the conduct of pest risk assessments in cooperation with APHIS.
- *Objective*: Continue to provide international technical assistance where appropriate.
- *Objective*: Continue to participate in development and evaluation of the Exotic Forest Pest Information System for North America (EFPISNA).

The Goals and Objectives section is followed by a brief overview of current programs and activities for the Northeastern and North Central Research Stations, the Northeastern Area, and the Forest Health Technology Enterprise Team, Morgantown, WV. The strategic plan concludes with a detailed listing of tasks associated with each of the objectives listed earlier in the document.

Though the document is printed in final form, we do not consider it a completed strategic plan. Rather we view the Strategic Plan as a "living document" that will be updated in the future as more information becomes available. Your views would be appreciated.

STATUS OF RESEARCH ON THE CHEMICAL ECOLOGY OF THE ASIAN LONGHORNDED BEETLE, *ANOPLOPHORA GLABRIPENNIS* (COLEOPTERA: CERAMBYCIDAE)

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Agricultural Research Center-West, Beltsville, MD USA 20705

ABSTRACT

Logs infested with Asian longhorned beetles (ALB) from sites in Chicago, Illinois, were transported to the APHIS quarantine facility in Otis, Massachusetts. Aeration extracts were prepared by confining groups of 5-10 male or female adults that emerged from these logs in the spring of 1999 in 1 L glass chambers (sometimes with twigs of Norway maple, *Acer platanoides*), and drawing air over the beetles by vacuum (~1 L/min) through an adsorbent polymer (Super Q, Alltech Associates, Inc.; 200 mg). The volatile natural products were eluted with methylene chloride, and the extracts were analyzed by the gas chromatography - electroantennographic detector technique (GC-EAD) and GC-mass spectrometry (GC-MS) in the electron impact and chemical ionization modes. Males produced two compounds not detected from females, and antennae from ALB males and females were especially sensitive to these male-specific compounds. The electrophysiologically active male-specific compounds were identified by their MS, followed by synthesis of standards verifying the structures as dialkyl ethers of a type heretofore unknown from insects: 4-(*n*-heptyloxy)butanal and 4-(*n*-heptyloxy)-1-butanol. In preliminary tests in the quarantine laboratory these compounds appeared to stimulate flight and walking in both sexes. However, July 1999 field tests in China failed to demonstrate attraction to these compounds, with or without a mixture of six host volatiles. Laboratory and field observations indicate that ALB males are territorial and that males recognize females upon antennal contact. Further testing is needed to determine the behavioral role of the male-specific volatiles and the chemical identity of the female contact recognition pheromone.

POTENTIATION BETWEEN ZWITTERMICIN A AND *BACILLUS THURINGIENSIS* SUBSP. *KURSTAKI* AGAINST GYPSY MOTH AND ITS EFFECT ON THE MIDGUT MICROBIAL COMMUNITY

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ABSTRACT

We have shown that the antibiotic zwittermicin A potentiates *Bacillus thuringiensis* subsp. *kurstaki* (Btk) against gypsy moth larvae. We have also shown that zwittermicin A alters the composition of the larval midgut microbial community. This research may (1) increase pest control measures by improving Btk efficacy and delaying insect resistance development, (2) elucidate new mechanisms for Bt potentiation, and (3) increase understanding of insect midgut physiology in association with microflora.

BIOLOGICAL CONTROL OF *MELALEUCA QUINQUENERVIA*

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ABSTRACT

Melaleuca quinquenervia (Cav.) S. T. Blake (Myrtaceae) is a tree native to the coastal wetlands of eastern Australia. Introduced into Florida as an ornamental early in the century, it is highly invasive in a variety of wetlands in south Florida, where it is estimated to infest at least 182,000 ha (including environmentally sensitive areas such as Everglades National Park). The tree is allergenic, highly flammable, and alters hydrologic regimes through soil accretion around its base. Its tendency to form virtual monocultures is a severe threat to biodiversity in the region. Currently, mechanical and herbicidal killing of mature trees often produces a flush of saplings from the released seeds of dying trees, thus not solving and often exacerbating the problem. Biological control is expected to play a major role in the long-term management of *M. quinquenervia* invasions.

The Australian melaleuca snout beetle *Oxyops vitiosa* Pascoe, a biological control agent of *M. quinquenervia*, was first released in south Florida during Spring 1997. Habitats with short hydroperiods, intermediate stages of melaleuca invasion, and dry winter conditions engendered field-colony development, whereas populations failed at fully aquatic sites. Transect sampling estimated the population at more than 2000 adults and 22,000 larvae, one year after release of 3300 larvae at a site near Estero, Florida. By June 1999, the numbers swelled to over 72,000 adults and nearly 14,000 larvae. Adults and larvae were subsequently collected from this site and

relocated to other areas. Populations of *O. vitiosa* are now widely established in southern Florida. Tip dieback is becoming evident and trees are appearing defoliated as old senescent leaves are unable to be replaced.

Evaluation of a melaleuca sawfly (*Lophyrotoma zonalis*) determined that it was host-specific to melaleuca. However, two toxic peptides have been identified in the larvae. These peptides have been implicated in livestock poisonings by another sawfly species so plans to release this agent are on hold until this can be investigated further.

Within the Fergusoninidae, the sole genus *Fergusonina* contains flies that form galls in association with nematodes on several plant genera in the Myrtaceae. This involves a mutualistic association on myrtaceous plant buds (flower buds, inflorescence buds, shoot buds) and young leaves. Numerous myrtaceous species (*Eucalyptus, Melaleuca, Corymbia,* etc.) were sampled for the gall complex along the coast of Australia during April and September, 1999. Galls were collected from 29 different host species for PCR amplification and sequencing and gall tissue for histological comparisons. The timed development of shoot bud galls and the oviposition behavior of *Fergusonina* from *Melaleuca quinquenervia* were observed. Preliminary comparisons of sequences from flies and nematodes show that most species attack only a single host plant species. Histological sections demonstrate that gall cell morphology and formation is similar within the different gall types from the myrtaceous hosts examined and is similar to described work on Anguinid nematodes. Juvenile nematodes and fly eggs were deposited into the apical regions of developing shoot or inflorescence buds where nematodes appeared to induce hypertrophied, uninucleate cells prior to the hatch of fly eggs. After 44 days, fly eggs hatched and external gall morphology became more pronounced.

Fourteen species of *Melaleuca* from 5 Australian states were sampled. Galls were found on 8 of these. *Fergusonina* flies and *Fergusobia* nematodes were recovered from 5 species of the *Melaleuca leucadendra* complex. Controlled oviposition studies showed that flies make leaf tissue wounds with diagnostic scars. These scars can be used for no choice oviposition tests for species specificity screening in Australia. Injection of nematodes ($N = 30$) into leaf bud tissue resulted in one gall with a developed nematode suggesting that nematodes initiate gall formation. Phylogenetic relationships among *Fergusonina* spp. were investigated using mitochondrial cytochrome oxidase sequence data in order to assess patterns of host-specificity and host-switching in this group. Multiple larval and adult specimens were dissected and reared from galls on 19 plant species within the genera *Eucalyptus, Corymbia,* and *Melaleuca*. Molecular analysis resulted in clear resolution of species and the relationships among them. Results show that the degree of host specificity of fergusoninids is high, with most species feeding on only a single host plant species. Patterns of host-switching appear to be conservative; most host-shifts have been onto closely related (congeneric) hosts and have been associated with fly speciation. Information from these studies will be used together with host specificity screening to help justify importation to Florida of the fly/nematode complex on *M. quinquenervia*. Several other arthropod natural enemies are also under investigation as potential biocontrol agents for this wetlands invader.

NONLINEAR TRANSMISSION OF THE GYPSY MOTH NPV

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ABSTRACT

Previously we reported that transmission rates of the gypsy moth nuclear polyhedrosis virus (LdMNPV) are nonlinear, and violate the mass-action assumption that is a key element of many models of disease transmission. The mass action assumption is a feature of the "Anderson-May" models that have been used to describe many host-pathogen systems; we believe that an understanding of the idiosyncrasies of this system could improve use of LdMNPV as a biopesticide.

We discussed several mechanisms that might be responsible for the nonlinearity observed in our experiments; the effects of induced foliage responses such as tannins on LdMNPV, the effects of heterogeneity in host susceptibility to infection, and the effects of spatial distribution of pathogen (considered in detail at this forum). We tested the hypothesis that spatial clumping is a major cause of the nonlinearity of transmission rates that we have previously demonstrated. Spatial clumping is a pronounced feature of the transmission of nucleopolyhedrosis viruses in insects such as gypsy moth, because larvae become infected by feeding on foliage contaminated with polyhedral occlusion bodies (POBs) of the virus that are deposited when other larvae die from the virus. These POBs spread across the foliage to some extent, particularly under the influence of rain, but generally remain highly concentrated within the cadavers of virus-killed larvae that decompose on the foliage. We found that clumping significantly reduced mortality of gypsy moth from LdMNPV, and presented preliminary findings suggesting that clumping may be the cause of nonlinear transmission.

EPIZOOTIOLOGY OF GYPSY MOTH NUCLEOPOLYHEDROSIS VIRUS

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ABSTRACT

Research in my laboratory over the last decade has elucidated much about the dynamics of nucleopolyhedrosis virus *LdMNPV* in gypsy moth populations. Steve Woods collected data on the prevalence of *LdMNPV* in a series of high and low-density populations. He showed that there was a distinct bimodal wave of mortality during the larval sage. Larvae infected as neonates died about two weeks later. These larvae provided inoculum that triggered a second wave of mortality that began in the fourth instar. There are three or four cycles of infection and death during the larval stage, but only the first cycle is evident as a distinct peak of mortality. Kathy Murray focused on transmission of *LdMNPV* between generations. She showed that surface contamination of eggs is by far the most important mechanism.

Greg Dwyer brought mathematical skills to my lab. He developed a model of the gypsy moth LdMNPV system similar to that of Anderson & May and he tested the model against to Steve Wood's field data. The model fit well at high density but underestimated mortality at low density. He also developed a way to estimate transmission coefficients from experiments that involved rearing infected and uninfected larvae inside mesh bags on foliage. Follow-up experiments by Vince D'Amico showed that the transmission rates calculated in this way were nonlinear functions of pathogen density, a violation of the so-called mass action assumption that is common to most host/pathogen models. Subsequent experiments explored the cause of this nonlinearity. D'Amico showed that the cause was not due to damage-induced changes in foliage quality. Dwyer showed that variation in host susceptibility (a feature common to all host/pathogen systems) accounted for much of this nonlinearity. D'Amico showed that clumping of pathogens is another cause. Dwyer constructed a revised model, incorporating the variation in susceptibility, and demonstrated a much closer fit to Wood's field data than with his earlier model. He has used this model to explore the long-term dynamics of the gypsy moth/pathogen system. These simple models have given us a much improved way to predict mortality from *LdMNPV* than earlier regression models developed by Steve Woods.

ASIAN LONGHORNED BEETLE AND OTHER EXOTICS:

THE CAMPAIGN TO KEEP THEM OUT OF BRITAIN

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ABSTRACT

Threats from international movement of forest pests are increasing in relation to both the quantity and speed of global trade. Although such threats have been recognized for many years and phytosanitary legislation has been put in place by virtually all importing countries, the numbers of exotic pests establishing in new locations continues to increase. The problem is, therefore, global in scale and it is not always easy to predict which pests are likely to pose threats and be moved internationally, especially since many organisms are not associated with the traded product itself but with associated wooden packaging material.

Britain is clearly not unique in having concerns about the threats posed by international pests, but is fortunate in being an island surrounded where the sea acts as a natural barrier to reduce the likelihood of natural immigration of pests. Both the flora and fauna of Britain are impoverished in relation to the rest of Europe and so there are concerns about pests from near neighbors in continental Europe and from countries farther afield. Membership of the European Union requires a consolidated approach to plant health measures and the mechanisms in place are designed to both recognize threats and be prepared for surprises. The EU Plant Health Directive, although applying across all Member States, is actually enacted through national legislation, which, in the case of Britain, is the Plant Health (Forestry) (Great Britain) Order 1993, and later amendments. The process of recognizing threats and developing appropriate actions is Pest Risk Analysis (PRA). Britain uses the EPPO PRA scheme, based on a questionnaire providing both qualitative and quantitative responses, all of which are supported by verifiable data. If the pest is regarded as posing a quarantine threat, measures to reduce or prevent importation can be put in place and contingency plans drawn up for dealing with the threat.

The recent infestations of *Anoplophora glabripennis* in the USA and the high level of interceptions of the beetle in international trade have thrown into sharp focus this new threat to hardwood forests in many countries of the world. In Britain, a campaign of increased publicity and directed surveys of warehouse and storage facilities has shown that the beetle is intercepted frequently but, so far, does not appear to have attacked living trees, even in close proximity to sites where live adult beetles have been found. Ongoing threats posed by bark beetles, especially the eight toothed spruce bark beetle, *Ips typographus*, have also featured significantly in

campaigns to prevent introduction. Live adult *I. typographus* have been found in both pheromone traps at ports and during inspections of timber imports. Extensive surveys of spruce forests have not revealed any established populations of the beetle. Changes to the availability of potential resources for this and other bark beetles indicates that risks are rising and it is important to maintain a high level of vigilance in the future.

THE NEW PEST ADVISORY GROUP:

ASSESSING THE THREATS FROM INVASIVE SPECIES

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ABSTRACT

The New Pest Advisory Group (NPAG) is a part of USDA, Animal and Plant Health Inspection Service, Plant Protection and Quarantine. The NPAG assesses exotic plant pest introductions into the USA to determine the recommended course of action. The pests may include arthropods, plant pathogens, weeds, and mollusks. The NPAG leaders develop an ad hoc panel of members from federal, state and university sources with regulatory and scientific expertise for the particular exotic pest. Through literature searches, data sheet preparation, and discussion with the panel, the NPAG makes consensus recommendations to Plant Protection and Quarantine management in response to the pest introduction.

MANAGEMENT OF LYMANTRIID INCURSIONS USING RECENT NEW ZEALAND EXAMPLES

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ABSTRACT

Like other trading countries New Zealand has been continually subject to incursions of exotic arthropods and diseases. While it is not always possible to predict the impacts of such incursions, there is no doubt that the number of these is increasing and a variety of approaches are required to their management. Recent New Zealand examples of incursions of particular relevance to the forestry sector include the two lymantriid species, *Orgyia thyellina* Butler (white spotted tussock moth) and *Teia anartoides* Walker (painted apple moth, formerly *Orgyia anartoides*).

In 1996, white spotted tussock moth was found to be present in a 7 km^2 area in the eastern suburbs of Auckland. This species was "declared" eradicated in 1998 as the result of a successful program, based on aerial applications of *Bacillus thuringiensis* var. *kurstaki*, initiated by the then Ministry of Forestry. Details were presented at the 1998 United States Department of Agriculture Interagency Gypsy Moth Research Forum (Bain 1998).

Painted apple moth was first found in May 1999 in the Auckland suburb of Glendene in what appeared to be a very confined area. In contrast to the white spotted tussock moth program, the Ministry of Agriculture and Forestry's response has comprised:

- (i) a delimiting survey (ultimately covering an area 1 km in radius around the initial find) involving inspection of potential hosts;
- (ii) weekly checks of known infested sites/properties and their immediate neighbors (22 of 1351 sites in an extended 1 km radius zone) primarily to monitor the effectiveness of control measures (iv-vi below);
- (iii) follow-up surveys of the 1 km radius zone at 6-7 week intervals;
- (iv) 3-4 ground applications of chlorpyrifos or deltamethrin to known infested sites (hosts, potential hosts and some inanimate objects) and their immediate neighbors at 7-10 days intervals;
- (v) strategic host tree removal; and
- (vi) vegetation movement and disposal controls.

Subsequently, in late September 1999 painted apple moth was reported from another Auckland suburb, some 15 km from the original area of infestation. A similar approach to eradication was adopted in this suburb in which 11 of 1200 sites in a 1 km radius zone have been found to be infested.

HOST RANGE OF *APHANTORHAPHOPSIS SAMARENSIS* (DIPTERA: TACHINIDAE), A LARVAL PARASITE OF THE GYPSY MOTH

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ABSTRACT

Aphantorhaphopsis (=*Ceranthia*) *samarensis* (Villeneuve), a European tachinid, has been released in North America for biological control of gypsy moth, *Lymantria dispar* (L.). The literature suggests *A. samarensis* has a limited host range, all reports being from *L. dispar* or *Orgyia recens* (Hübner), both lymantriids. To obtain more information on the host range of this fly, 3 methods were used: (1) field collection and rearing of potential alternate or alternative hosts at sites in Europe where the fly was abundant, (2) choice tests in which females of *A. samarensis* were offered both gypsy moth and native North American species of Lepidoptera, and (3) host suitability tests in which European nontarget species were artificially inoculated with mature eggs of *A. samarensis* dissected from gravid females to see if development could occur. A total of 851 caterpillars, in at least 54 species in 11 families, were field-collected over 5 years, but none yielded *A. samarensis*, with two possible exceptions, both lymantriids: larvae of *Lymantria monacha* (L.) and *Orgyia antiqua* (L.), yielded puparia similar to those of *A. samarensis*. In lab tests, females of *A. samarensis* were offered 11 species of North American Lepidoptera in 5 families, but only one lymantriid, *Orgyia leucostigma* (J. E. Smith), was parasitized. In host suitability studies, 10 species of Lepidoptera in 8 families were inoculated with mature eggs of *A. samarensis*, but parasitism was not successful except in *L. dispar*. All of our observations strongly suggest that *A. samarensis* is an oligophagous parasitoid of Lymantriidae, possibly restricted to the genera *Lymantria* and *Orgyia*.

PINE SHOOT BEETLE RESEARCH UPDATE

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ABSTRACT

Established populations of the pine shoot beetle, *Tomicus piniperda* (L.) (Coleoptera: Scolytidae), were first detected in the US in 1992. As of January 2000, *T. piniperda* was known to be established in 271 counties in 11 US states (IL, IN, MD, MI, NH, NY, OH, PA, VT, WI, WV) and 25 counties in Ontario and 8 counties in Quebec, Canada.

In a 1998 study, we found that marked and released *T. piniperda* were captured in traps up to 400 m outside of operational sawmills and simulated millyards despite the abundance of brood material present in the millyards; 400 m was the furthest distance to which traps were placed in 1998. In 1999, we investigated *T. piniperda*'s potential for longer range dispersal in the absence of suitable breeding material. In this study, traps were placed out to 2 km in an open agricultural field. Marked and released beetles were captured up to 800 m from a central release point. In a companion study conducted in Geneva, New York by Al Barak (USDA APHIS, OTIS) marked and released *T. piniperda* adults were recaptured up to 2 km from the release point. Such studies indicate that *T. piniperda* is capable of long distance flight and that adults could be carried even further by strong winds.

Four pheromone candidates (nonanal, myrtenol, α-pinene-oxide and *trans*-verbenol) and three host compounds (ethanol, terpinolene, and (+)-3-carene) were tested in 1999 for synergism of attraction to the standard α-pinene bait. Various combinations of these semiochemicals resulted in moderate increases in attraction to α-pinene. Further research in 2000 will focus on the most promising attractant blends.

In 1998, more than 1000 ha of scattered pine stands in southwestern Ontario were suffering high levels of mortality. *Tomicus piniperda* was implicated as the principal mortality agent involved. One question that was asked was whether the Ontario *T. piniperda* populations were different genetically from the US populations. To investigate this question, we collected adults from six US sites (IN, MI, NY, OH) and Ed Czerwinski (Ontario Ministry of Natural Resources) collected from six Ontario sites. M. Carol Carter (Portland State University) conducted the genetic relatedness studies using DNA fingerprinting by random amplified polymorphic (RAPD) DNA. Preliminary results indicate that the Ontario populations are not genetically distinct from the US populations. We hope to do a similar study in 2000 in which the Quebec populations will be compared with populations from Ontario and New York.

In Ontario in 1999, no new *T. piniperda* populations were detected from an extensive survey conducted by Ed Czerwinski along northern Lake Huron to Sault Ste. Marie east to Sudbury and North Bay, then south along Georgian Bay to the current *T. piniperda* distribution in southwestern Ontario. In the 1000-ha *T. piniperda* infestation in southwestern Ontario, severe shoot feeding has been observed on Scotch, red, white, and jack pine, and *T. piniperda* reproduction has been observed on standing live Scotch, red, and jack pine. Peter deGroot (Canadian Forest Service) initiated growth impact studies in Ontario in 1999.

PATHOGENS FOR CONTROL OF *ANOPLOPHORA GLABRIPENNIS*

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ABSTRACT

Studies of pathogens of *Anoplophora glabripennis* (ALB) are being conducted at several laboratories in the U.S.: L. Bauer (USDA, FS, E. Lansing, MI), surveying naturally occurring pathogens from the Chicago infestation, has found microsporidia and fungi and, potentially, a virus; V. D'Amico (USDA, FS, Hamden, CT) and associates have been using voltage clamp techniques to compare strains of *Bacillus thuringiensis* for activity against ALB and are planning field studies in China next year; L. Solter (IL Natl. Hist. Surv.) and associates have tested 4 species of entomopathogenic nematodes for activity against ALB larvae. Our laboratory is working on entomopathogenic fungi naturally associated with ALB larvae and adults and potential use of fungi for control of ALB.

To investigate use of fungi against ALB, we have been rearing ALB on artificial diet in the USDA quarantine on Cornell campus. To optimize growth of these long-lived insects, we have been experimenting with different diet recipes and rearing conditions. One study comparing the Harley & Willson diet (developed for *Plagiohammus spinnipennis*) with a diet developed in Ningxia by Jun and Ogura for ALB also investigated additions of phloem-cambium from maple, cellulose, or sawdust to each diet recipe. Larvae grew faster on the Jun and Ogura diet and adults were larger and lived longer. The different additives made no overall difference in growth so we recommend using cellulose because this is more efficient to use and more standardized.

We have isolated 17 species and/or strains of hyphomycete fungi from *Anoplophora* adults and larvae collected in China, Japan, and the U.S. In addition, L. Bauer found one ALB adult killed by an entomophthoralean fungus from the Chicago infestation. We conducted bioassays in China during August 1999 to compare 5 strains of *Beauveria* at 2 different doses against both adult (Yinchuan, Ningxia) and larval (Hefei, Anhui) ALB. The fungal strains we used had mostly been isolated from adult Coleoptera and two were obtained from companies producing and selling these fungi as products for pest control: Nitto Denko producing *B. brongniartii* to control *A. malasiaca* in Japan and Mycotech producing *B. bassiana* to control numerous pests in the United States. Results from bioassays against larvae using these strains were not promising. However, results from adults demonstrated LT50s of 7.8-8.7 days for 4 of the strains at the higher dose. We plan to continue laboratory bioassays comparing strains and will conduct field studies during the next season, especially investigating application technology developed by Nitto Denko based on attaching fungus-impregnated bands around trees so that adults inoculate themselves while walking on tree trunks.

IMPACT OF A CHINESE LADY BEETLE ON HEMLOCK WOOLLY ADELGID:

INITIAL FIELD CAGE STUDY

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ABSTRACT

The lady beetle *Scymnus* (*Neopullus*) *sinuanodulus* Yu et Yao was imported from China to the USDA Forest Service quarantine facility in Ansonia, CT for evaluation as a potential biological control agent against *Adelges tsugae,* the hemlock woolly adelgid (HWA). *Scymnus sinuanodulus* feeds specifically on adelgids and is one of the most abundant predators of HWA in China. To evaluate its reproduction and impact on adelgid populations in the field, we conducted an experiment in which beetles where caged on infested hemlock branches.

The experiment consisted of 3 treatments: (1) unbagged branch, (2) bagged (white nylon mesh) branch with no lady beetles, and (3) bagged branches with a single, previously mated female beetle. In mid-April when most first-generation HWA eggs had been laid, adelgid ovisacs were counted and the number of eggs per sac was estimated. The treatments were then placed randomly on the branches. Half of the branches were collected and brought to the laboratory for examination in late May when first-generation adelgid nymphs were partially grown. The second half were collected and examined in early July when the second adelgid generation was present as first-instar aestivating nymphs. Branches were examined under a microscope and the number of HWA and *S. sinuanodulus* progeny were counted. At the first evaluation, branches with beetles that produced progeny had 66% fewer adelgid nymphs than branches with empty bags. Also, branches with no bags had 44% fewer adelgids than branches with empty bags suggesting a strong bag effect. At the second collection date, there were no significant differences in the number of HWA per branch among treatments, although there were 20% fewer adelgids in bags with beetles than in empty bags. The high initial HWA population may have already caused a decline in tree health, reducing suitability to host the next generation. Our results show that *S. sinuanodulus* can have a significant impact on the first generation of HWA under field conditions. This study was initiated later in the season than we believe beetle egg laying would begin. The experiment will be repeated with beetles placed in the field earlier in the spring. We believe this will increase the impact of the beetle because the voracious larvae will complete their development before first-generation adelgid eggs hatch. Beetles will also be caged in larger bags on branches with lower adelgid densities. This should reduce the impact of tree health and bag effects on the HWA populations. Based on the biology of this beetle and its association with adelgids in China, we believe that it can effectively maintain HWA populations at low levels.

GYPSY MOTH PARASITISM IN THE NATIVE RANGE DURING OUTBREAK TERMINATION AND THE SUBSEQUENT LATENCY PHASE

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ABSTRACT

In Alsace, northeastern France, parasitism of gypsy moth was studied during outbreak termination (1995) and the first 4 years of the subsequent latency phase (1996 through 1999). Dramatic changes in the guild of parasitoids and abundance of the major species were observed. The tachinid *Parasetigena silvestris* (Robineau-Desvoidy) was a key parasitoid during outbreak termination and the first year of the latency phase. During year 2 through 4 of the latency phase, the most constant and omnipresent parasitoid was the tachinid *Ceranthia samarensis* (Villeneuve). The tachinids *Blepharipa schineri* (Mesnil) and *Compsilura concinnata* (Meigen) showed a peak of abundance during year 2 and during year 4 of the latency phase, respectively.

Field studies of the egg laying behavior of *B. schineri* showed that parasitoid females were highly responsive to very small and scarce amounts of host kairomones in the forest environment. This behavioral trait as well as the high specificity for gypsy moth and the relative ease to rear the parasitoid make this species a potentially very promising biological control agent of gypsy moth in low host density situations.

The negative results obtained during surveys of non target hosts of *C. samarensis* suggest that the parasitoid has a narrow host range, probably confined to the Lymantriidae. The great specificity of *C. samarensis* for gypsy moth and its abundance at low host density make it another very promising biological control agent of gypsy moth. As *C. samarensis* occurs in a wide range of cool and humid climates in Europe, from northeastern France to northeastern Poland, very likely biotypes of *C. samarensis* exist that would survive in the varied niches of the northeastern U.S.A. where gypsy moth causes problems.

ANOPLOPHORA GLABRIPENNIS (COLEOPTERA: CERAMBYCIDAE) FECUNDITY AND EGG VIABILITY ON *ACER SACCHARUM* IN THE LABORATORY

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ABSTRACT

Anoplophora glabripennis (Motschulsky) is one of the more recently introduced nonnative invasive species that has caused environmental and economic damage in the United States. Its primary host trees include species of maple (*Acer*), poplar (*Populus*), and willow (*Salix*). There is a critical need for information on the basic biology of *A. glabripennis*; information on fecundity is especially important to understand the population dynamics and predict population growth of *A. glabripennis*.

Adults used in these studies emerged from infested logs obtained from Chicago, IL in February 1999. Sixty mating pairs were used to assess weekly fecundity, viability, and female longevity. Twenty additional mating pairs were used to assess daily fecundity over the first 5 weeks of oviposition. Freshly cut *Acer saccharum* logs (3-7 cm diam, 20 cm long) with waxed ends were provided weekly for oviposition.

Anoplophora glabripennis lays more eggs and survives longer in the laboratory on *Acer saccharum* than is generally reported. Females laid an average of 68 eggs over the 73 days that they lived; 89% hatched. The female with the highest fecundity (161 eggs) lived 106 days; 158 of her eggs hatched. This implies that under favorable conditions (optimal hosts and few mortality factors), the beetle population could increase fairly rapidly. Females lay few if any eggs in the first week, indicating that a period of maturation feeding is required. The longer females lived the more eggs they were able to mature. Both the highest daily fecundity (2 eggs/day) and the highest weekly fecundity (12 eggs/week) occurred during the third week. Over the first 5 weeks, females laid an average of 1 egg per day. Most females laid no eggs during the last 2 weeks of their life. Over a lifetime, females chewed many pits (270) in the bark, but laid eggs only in 26% of the pits. Females generally laid more eggs in a week on larger diameter logs than on smaller diameter logs. Females laid more eggs on the first day the log was placed in the jar than on the other days of each week. The average prefeeding weight of the females was 0.8 g (range: 0.4 to 1.6 g). Female weight did not significantly affect longevity or fecundity, probably because eggs mature in the female a few at a time over her entire lifetime. Fecundity was positively correlated with longevity. The implication of these findings for control programs is that the sooner adults can be killed or removed, the fewer eggs will have been laid.

ANOPLOPHORA GLABRIPENNIS FROM EGG TO ADULT

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ABSTRACT

There is a critical need for information on the basic biology of *Anoplophora glabripennis* (Motschulsky), a recently introduced nonnative invasive species. With this information one can predict the timing of biological events that are fundamental to the development and improvement of exclusion and eradication methodologies. The results of a life-table study and analysis of infested logs are presented here.

Eggs used in the life table study were obtained from 30 mating pairs each from the Ravenswood, Chicago, IL (RC) and Bayside, New York, NY (BN) strains. *Acer saccharum* logs (3-7 cm diam, 20 cm long) were provided for oviposition; twigs were provided for food. Time in each stage and instar was determined for 200 individuals from each strain at 25°C and 60% RH. Larvae were reared on red oak borer diet, observed daily for molting and weighed every other week. When 84 days old, half of the larvae were chilled (5°C) for 91 days; the other half were not chilled.

Eggs of *A. glabripennis* hatched in 15 days; the newly hatched RC larvae weighed 4.3 mg and BN larvae 3.9 mg. After 84 days, the RC larvae weighed 1.8 g and the BN larvae weighed 1.5 g. The average instar of both the RC and BN larvae was 7 after 84 days. From the fourth week on, RC larvae were significantly heavier than BN larvae. Larvae of both strains spent progressively longer time in each instar up to the seventh instar. As many as 12 instars were observed for unchilled, normal-size larvae and one smaller larva went through 14 instars. The heaviest unchilled larva was an RC that weighed 3.3 g. The earliest pupation occurred after 97 days when the larva was in the sixth instar. Females spent an average of 18 days as a pupa verses 17 for males. Mortality is < 20% and 40-50% of the mortality occurred in the first instar.

In February 1999, 181 *Acer platanoides*, 132 *A. saccharinum*, and 11 *Fraxinus* sp. logs infested with *A. glabripennis* cut in Ravenswood, Chicago, IL were brought into quarantine. The logs, which averaged 66 cm in length and 10 cm in diam, were held at 23°C and 40% RH. Adult emergence began on May 11 and peaked June 7-14. The sexes emerged nearly synchronously. Adult females were significantly heavier (0.7 g) than males (0.5 g). In general, adult weight decreased with number of weeks to emergence, probably due to log desiccation. Larger adults tended to eclose from larger diameter logs. *Acer platanoides* logs had more oviposition pits and significantly more exit holes than *A. saccharinum* logs. The number of oviposition pits and exit holes increased with log diameter (to 15 cm) and then declined. On *A. platanoides* logs, 31% of

the oviposition pits resulted in an exit hole compared to only 14% on *A. saccharinum* logs and 19% on *Fraxinus* logs. There were new exit holes on 40% of the *A. saccharinum* and 46% on of the *Fraxinus* logs compared to 77% of the *A. platanoides*. Forty-six percent of all the logs had old exit holes and 13% of these showed signs of wound repair. This result indicates that the logs had been used by successive generations of the beetle.

SIBERIAN MOTH: SEX ATTRACTANT FOR A POTENTIAL NEW PEST FROM ASIA

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ABSTRACT

Lindlar semihydrogenation of the tetrahydropyranyl ether of (E)-7-dodecen-5-yne-1-ol generated a mixture of Z,E-5,7-dodecadienol, over reduction products, (E)-7-dodecenol, Z-5-dodecenol, and a rearrangement product, E-6-dodecenol. Aliquots of the mixture of alcohols were converted to acetate and aldehyde mixtures. Field trapping experiments were conducted against the Siberian moth in Siberia, Russia using traps baited with a virgin female moth or 100 μg synthetic mixtures of the aldehydes, alcohols, and acetates alone or in combinations. The tests showed that an 1:1 aldehydes:alcohols blend was as attractive to males as virgin female moths. Additional field tests with combinations of individually pure compounds showed that a binary mixture of *Z,E*-5,7-dodecadienol and *Z,E*-5-7-dodecadienal (78:22) alone was a potent male sex attractant for the Siberian moth. The mixture will be useful as monitoring tool for this destructive defoliator of conifer forests in Asia or as surveillance tool at ports in the USA where the pest might invade.

IN VITRO FORMATION OF RESTING SPORES BY THE GYPSY MOTH FUNGAL PATHOGEN *ENTOMOPHAGA MAIMAIGA*

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ABSTRACT

Resting spores (azygospores) of the fungal pathogen of *Lymantria dispar* (gypsy moth), *Entomophaga maimaiga*, have been used to release this biological control agent in areas where this pathogen is not established. *E. maimaiga* resting spores naturally produced in larvae have always been field-collected for this purpose. We have found that *E. maimaiga* can produce resting spores in Grace's insect tissue culture medium (95%) plus fetal bovine serum (5%). The majority of mature spores are produced between 7-21 days after cultures are initiated. Spore production varies by fungal isolate; among 38 isolates tested, 10 produced no resting spores while 7 produced > 1000 resting spores/ml. Resting spore production was not affected when different isolates were mixed. Glycerol (used for fungal storage), trehalose, and selected amino acids each inhibited resting spore formation. Fetal bovine serum was required for spore production but presence of > 5% yielded lower resting spore densities. A large surface area:volume ratio (12.5 cm^2:1 ml versus 4.2 cm^2:1 ml) was required for abundant formation of resting spores. At present, resting spores have only been produced in low volumes with a maximum of 3×10^4 resting spores/ml. We are continuing to investigate methods for optimizing *in vitro* production of resting spores and are concurrently investigating dormancy requirements of *in vitro*-produced spores.

ADULT BEHAVIOR OF THE ASIAN LONGHORNED BEETLE

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ABSTRACT

Field observations were used to characterize daily activity patterns of Asian longhorned beetles (ALHB), *Anoplophora glabripennis* (Motschulsky) (includes syn. *A. nobilis* (Ganglbauer)). The studies were conducted in a small shelterbelt of *Populus* x. Opera adjacent to the Qingtongxia Field Station in Ningxia Hui Autonomous Region, China. Pairs of unmated, marked beetles were released on each of approximately 20 trees. Setal patches on the elytra were marked (felt-tip pen) with distinct combinations of patterns and colors, allowing beetles to be tracked individually. Two releases were made 7 d apart during late July and early August 1999. After each release, trees were checked four times daily (ca. 0700, 1100, 1600, and 1900 hours) for seven days, and numbers and activities any beetles (both marked and unmarked) was recorded.

Depending on sex and release period, beetles were observed resting on 79 to 90% of occasions, with the remainder of the observations divided among walking, feeding, mating, mate-guarding, and (for females) oviposition-related behavior. Over 40% of beetles were found on larger (>1 cm diameter) woody portions of trees except in the early morning when all but 10 to 20% of beetles were on small twigs (upon which they feed) or leaves. Beetles were found at all heights in trees at all times of day, although they tended to be higher in the early morning than at other check periods. Microhabitat and activity appeared to be influenced both by the need to feed, mate, and oviposit and by such physical factors as temperature and/or evaporation deficit. Percentages of marked beetles that were observed in the shelterbelt declined steadily from >70% of all released beetles on the first day after release to <5% by sixth day. Of those marked beetles that were observed during the checks, the percentage that were observed on the tree upon which they were released declined from >90% on day one to <50% by day five. Overall, then, ALHB adults were not highly active but slowly "diffused" away from individual host trees. In these and in additional, less structured, observations, flight was observed only rarely. Despite this, individual beetles, when pressed, were capable of sustaining flight until out of sight. Also, we saw no behaviors that strongly suggested any long- or medium-range orientation to potential mates. Instead, our observations tend to support earlier indications that mate recognition is mediated primarily by contact, and quite possibly by a contact pheromone.

MODELING CLIMATE CHANGE INDUCED BARK BEETLE INVASIONS

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ABSTRACT

Some western US pine forests have evolved with bark beetle disturbance as an integral part of an adapted system. Lodgepole pine, for example, has co-evolved a relationship with fire and mountain pine beetle (*Dendroctonus ponderosae* Hopkins) disturbances that serve to maintain it as a seral component of spruce/fir climax forests. Without the interaction of these two disturbance agents, lodgepole pine would be lost from much of its distribution. In contrast, other pine ecosystems have not evolved in consort with bark beetle disturbance. The high-elevation, 5-needle pines, e.g. whitebark pine, are typically found in environments lacking sufficient thermal input for maintaining synchronized, adaptive voltinism for mountain pine beetle populations. Global warming of the magnitude projected by current global circulation models has the potential to significantly impact the geographic distribution of many species. In this paper I explore the potential consequence of global warming on the distribution and outbreak status of mountain pine beetle with respect to high-elevation habitats. I begin this investigation by exploring the dynamical properties of an existing model of mountain pine beetle seasonality (see Logan and Bentz, these Proceedings). The dynamical properties of the thermal habitat are characterized by regions of adaptive, synchronous seasonality separated by regions of maladaptive, asynchronous seasonality. Global warming, by even conservative estimates of a CO_2 doubling scenario is great enough to move high elevation habitats from a maladaptive thermal regime to an adaptive regime, with potentially deviating consequences for whitebark pine. Finally, the implications of this analysis are discussed for exotic as well as for native invasive species. In particular, the modeling approaches I discuss can be applied for assessing the potential distribution of an exotic introduction. Additionally, theoretical analysis of the model has provided insights into experimental protocols for characterizing the potential geographical limits and seasonality of a new or hypothetical introduction.

MODEL ANALYSIS OF MOUNTAIN PINE BEETLE SEASONALITY

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ABSTRACT

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is a natural disturbance agent of considerable consequence in western pine forests. This economically and ecologically important insect has a strong requisite for maintaining a strict seasonality. Given this ecological requirement, it is somewhat surprising that no evidence for diapause or other physiological timing mechanism has been found. Seasonality and phenological timing for this species are apparently under direct temperature control. We investigate the consequences of direct temperature control by first constructing a computationally efficient phenology model based on previously published temperature dependent developmental data. We then explore the dynamical properties of this model when subjected to observed micro-habitat temperatures representing a range of thermal habitats from one region of the mountain pine beetle distribution. We also investigate the consequences of global climate change on phenology and seasonality. Our results indicate that an adaptive seasonality is a natural consequence of the interaction between developmental parameters and seasonal temperatures. Although this adaptive phenology appears to be resilient to temperature fluctuations, changes in climate within the magnitude of predicted climate change under a CO_2 doubling scenario are capable of shifting a thermally hostile environment to a thermally benign environment. Similarly, increasing temperature by the same amount resulted in phenological disruption of a previously favorable thermal habitat. We discuss the implications of these results for restricting the current distribution of mountain pine beetle, and the potential for shifting distribution due to global climate change.

UTAH GYPSY MOTH ERADICATION PROGRAM: 1988-1999 PROGRAM SUMMARY

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ABSTRACT

In 1988 gypsy moth, *Lymantria dispar* (L.), adult male moths were captured in Delta pheromone traps on the University of Utah campus in Salt Lake City, UT. An aerial application program which began in 1989 treated 482 ha in Olympus Cove east of Salt Lake City. Subsequent delimitation and ground surveys in 1989 discovered larva and egg masses in three canyons east of Salt Lake City in addition to isolated infestations in Provo and Bountiful, UT.

To eradicate these infestations biological insecticide treatments were applied annually from 1990-1993. Various formulations of *Bacillus thuringiensis* var. *kurstaki* (*Btk*) were applied three times at 5-7 day intervals using rotary winged aircraft. All applications of *Btk* were applied at 24 BIU's per acre using electronic rotary atomizer type nozzles. The largest application program occurred in 1991 when 12,115 ha were treated. Treatment difficulties were abundant as spraying occurred in hazardous terrain with numerous updrafts and downdrafts in the steep canyon areas. Differences in host phenology due to elevation gradients necessitated dividing spray blocks into smaller sections which significantly lengthened the application period. Other eradication strategies included mass trapping and a quarantine program. In 1998 and 1999, approximately 350 ha were aerially treated using *Btk* on new introductions within Knutsons Corner of Salt Lake City.

A detection and delimitation trapping program has continued since 1988. Although a detection trapping grid of 610m grid was attempted in the mountains east of Salt Lake City, the steep terrain made this type of trap array impossible to complete. Traps are placed at selected intervals based on terrain and vegetative characteristics in mountainous terrain. In urban areas, a 610m grid system is employed. Along the Wasatch Front corridor in Utah, detection traps are placed at 800 to 3200m intervals depending on the presence of host type. Delimitation programs again depend on terrain, but whenever possible a delimitation grid of 150m is employed. Several special projects have been conducted during the eradication program. A few of the more important projects included: (1) Environmental fate of *Btk* applied in mountainous terrain; (2) Canyon drift and dispersion of *Btk* and its effects on select nontarget Lepidopterans in Utah; (3) Cellular fatty-acid analysis of *Btk* in commercial preparations, and (4) Effectiveness of grid systems for pheromone trapping sparse gypsy moth populations in mountainous terrain in the Intermountain west. In 1999, seven single catches of adult male gypsy moths occurred, only one was found in a previously treated area. No ground or aerial application program will occur in 2000. Instead, a 4 ha mass trapping grid will be installed around each positive catch using 22 pheromone traps/ha.

THE IMPORTANCE OF MICROSPORIDIA IN GYPSY MOTH POPULATIONS IN SLOVAKIA

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ABSTRACT

Entomopathogens are an important factor in the natural regulation of gypsy moth populations in Slovakia. Studies conducted on permanent plots in Southwestern Slovakia indicated that the relative importance of entomopathogens varies during the differing phases of gypsy moth abundance. Viruses (mainly NPV) are most important during the culmination and latency phases whereas bacteria are important during the progression and regression phases. Microsporidia - infected larvae can be found during all population phases and are also a significant factor in mixed infections associated with viruses especially in later instars. Two genera, *Vairimorpha* and *Nosema* are found commonly though they tend to be site specific in the permanent plots.

Studies were initiated in 1996 to evaluate the feasibility of applying suspensions of microsporidia spores to enhance the efficacy of these entomopathogens in managing gypsy moth populations at low densities; we refer to this strategy as "control in advance." In 1997 we applied *Vairimorpha lymantriae* in 10 x 10 meter plots in a 10-year-old oak plantation (*Quercus robur*), using ULV ground application and at a dose of $1x10^{12}$ spores/ha. Mortality of larvae infected with microsporidia was 23%. In 1999, we conducted on additional study to evaluate three species of microsporidia – *V. lymantriae*, *Nosema portugal* and *Nosema* sp. from Poland using the same procedures as in the initial study. Recovery of infected larvae (17 days post-treatment) varied from 6.8 to 66.7% and among the treatments, *N. portugal* was the most effective. Examination of non-target Lepidoptera collected from within the sprayed plots indicate that none were infected by microsporidia; this supports our laboratory studies that concluded that these microsporidia are host specific to the gypsy moth.

We conclude that microsporidia can be used as a component in a strategy to better manage gypsy moth populations in Slovakia at low levels and that they should be considered for introduction as a classical biological control agent against the gypsy moth in North America.

PEST RISK ASSESSMENT TO SUPPORT PROPOSED RULE CHANGE FOR SOLID WOOD PACKING MATERIALS

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ABSTRACT

Many exotic forest pests can be readily transported into the United States on untreated wooden pallets, crating, bracing, and other solid wood packing materials. Recent introductions of forest pests associated with importation of solid wood packing materials indicate that current United States regulations likely are inadequate to exclude such pests. Most (97%) of quarantine-significant tree pests found by port inspectors are associated with solid wood packing materials. About 9% of maritime shipments contain bark, providing protection for numerous pests, despite bark-free import requirements. A pest risk assessment was drafted for the solid wood packing material pathway to provide scientific support for development of more effective regulations applicable to all import countries. The document includes a description of pathway characteristics, an assessment of potential for pest introduction and establishment, and analyses of potential economic and environmental effects. Twenty potential pests of concern, including insects, fungi, and nematodes, representing an array of geographical origins, host types, and pest habits were selected for detailed analysis of pest risk potential. Pest risk potentials were described in relation to current regulations and practices and without regard to potential mitigation measures or proposed regulations (i.e., baseline assessment). For each potential pest, seven risk elements were evaluated by experts to obtain an overall qualitative ranking (high, moderate, or low risk). Probability of pest establishment was described by elements for: pest with host at origin potential, entry potential, colonization potential, and spread potential. Elements describing consequences of establishment included: economic damage potential, environmental damage potential, and social and political considerations. To improve rating consistency, objectivity, and transparency, criteria were developed to define each element. In addition to the qualitative rankings, quantitative projections of economic impact were developed for several potential pest species based upon hypothetical scenarios of introduction and spread. Additional steps planned in the development of new import requirements include a public comment period for the pest risk assessment, development of proposed mitigation alternatives, a risk reduction analysis, an environmental impact statement, and an economic analysis.

BACTERIA ASSOCIATED WITH ASIAN LONGHORNED BEETLE ADULTS

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ABSTRACT

The Asian longhorned beetle (ALB), *Anoplophora glabripennis*, a pest native to China and Korea, is established in at least two states, New York and Illinois, and has been found in dunnage arriving in several ports of entry. The beetle has few reported natural enemies, is difficult to control, and has the potential for becoming a very serious pest in the United States. At present the only reliable control technology available is the cutting and incineration of infested trees. The availability of less socially disruptive and destructive control tactics is desirable, including environmentally soft biopesticides that could be applied as either sprays or baits. The beetle's diseases have not been intensely studied, certainly not in the United States, and there are relatively few reports on the microorganisms associated with the pest, and what role they may play in the beetle's life cycle.

Bacteria representing several genera were isolated from the alimentary tracts of adult Asian longhorned beetles collected from sites in Chicago, IL and Bayside, Queens, NY. *Staphylococcus sciuri* was the most common isolate, i.e., from thirteen of nineteen beetles examined. Several opportunistic human pathogens including *S. xylosus*, *S. intermedius*, *S. hominis*, *Pantoea agglomerans*, *Serratia proteamaculans* and *Klebsiella oxytoca* also were isolated, but with lower frequency. The most interesting bacterium found was putatively identified as *Tsukamurella inchonensis* also an opportunistic pathogen, possibly of Korean origin, and perhaps a beetle symbiont. Further studies are underway to verify the putative *T. inchonensis* classification and determine its symbiotic role, if any, in the beetle. There is no evidence, at this time, that any of the microorganisms isolated are ALB pathogens.

PHYSIOLOGICAL MECHANISMS FOR PROCESSING CONIFER TERPENES IN SIX SPECIES OF LYMANTRIIDAE

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ABSTRACT

The family Lymantriidae exhibits a wide range of feeding specificity, from strictly monophagous to broadly polyphagous. Many Lymantriids specialize on conifers which contain terpenes as their major defensive compounds. However, many Lymantriids can feed on both conifers and angiosperms. We propose to determine how various species of Lymantriidae exhibiting different host ranges process conifer terpenes.

Our system includes 6 species of Lymantriidae, 3 whose host range includes both conifers and angiosperms (white-marked tussock moth (*Orgyia leucostigma* J.E. Smith), gypsy moth (*Lymantria dispar* L.), and rusty tussock moth (*O. antiqua* L.)), and 3 that specialize on conifers (pine tussock moth (*Dasychira pinicola* Walker), Douglas fir tussock moth (*O. pseudotsugata* McDunnough), and nun moth (*L. monacha* L.)). Test monoterpenes include bornyl acetate, limonene, and myrcene. All test monoterpenes occur in *Larix* species, which are common host trees of these 6 species. The overall approach to this research is to feed larvae known amounts of monoterpenes, and determine the fate of these terpenes using gas chromatography of frass (excretion), gas chromatography of larvae and exuviae (sequestration), identification of metabolites (metabolism), and bioassays with enzyme inhibitors (metabolism).

Metabolism appeared to be the most important mechanism used to process monoterpenes in gypsy moth, white-marked tussock moth, and nun moth. The presence of borneol, a metabolite of bornyl acetate, shows that bornyl acetate is metabolized, and the absence of limonene and myrcene suggests that they are completely metabolized. Excretion appears to be somewhat important in processing bornyl acetate, however there is substantial variation among species. Importance of mechanisms for processing monoterpenes depends on both the stadium of gypsy moth and the concentration of bornyl acetate.

In the future, we will complete experiments using synthetic monoterpenes and diterpene acids in artificial diet. Results will be compared between the generalist and specialist species.

FIRE, INSECTS, AND EXOTICS:

MULTIPLE DISTURBANCE INTERACTIONS

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Climate/weather, fire, fauna, and flora are dynamically interconnected. Changes in one factor are likely to result in changes in the other factors. Fire regimes are changing due to changes in land use, and possibly climate. As a result of these changes the frequency and severity of fires are changing. This has major implications for the likelihood of future insect, disease, weather, and fire disturbances both at the stand and landscape levels. Four examples of disturbance interactions: whitebark pine-fire-blister rust, rangeland-fire-exotic weed invasion, coniferous forest-blowdown, and coniferous forest-fire-bark beetles are used to illustrate the dynamic interactions. Restoration and maintenance of ecosystems requires that we have a greater understanding of disturbance regimes and their interactions. This will require a greater level of interdisciplinary research.

INTRODUCTION

Weather, fire, fauna, and flora have always interacted to shape landscapes. Today disturbance factors are on new trajectories due to changes in land use, the introduction of exotic species, and possibly climate change. The purpose of this paper is to discuss how fire interacts with other physical and biological disturbance factors to shape landscapes.

Landscapes are aggregates of stands of varying history. Forest stands have been affected by multiple fires, insect attacks, catastrophic storms, pathogens, and varying land use practices. Understanding multiple disturbance processes is critical to the restoration of landscapes (Fig. 1). Historic fire regimes varied in their frequency and severity from frequent low severity fires typical of many of the long-needled pine forests, to infrequent and severe stand replacing fires in many of the cooler, wetter types. While we characterize vegetation types by their dominant fire regime it is important to recognize that the various vegetation types had a range of severities owing to localized, and often random variations in fuels, terrain, and weather. As the severity of the fire varied so did survival of vegetation, organic matter consumption, nutrient cycling, and soil heating thereby affecting a host of cascading processes including secondary succession and erosion. As the severity of fire varied stands were placed on a new succession-trajectory with long-lasting consequences for species composition and stand structure.

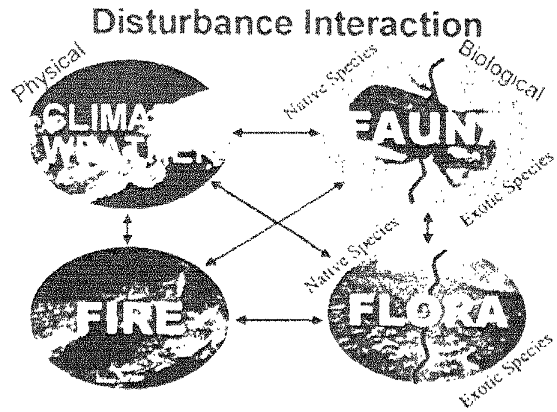

Figure 1. Multiple disturbance interactions combine to shape landscapes by affecting both the disturbed stand and the likelihood of future disturbances to both the disturbed and adjacent stands.

Another feature of fires is their patchiness, or mosaic (Fig. 2). The implications of varying fire disturbance patterns, or mosaics, to flora and fauna are significant. The implications are both direct, that is, affecting the disturbed patch, and indirect, that is, affecting adjacent patches. For example, the opening created by a fire increases the likelihood that adjacent areas will experience wind-throw, or that insect build up in burned trees will spread to adjacent unburned ones.

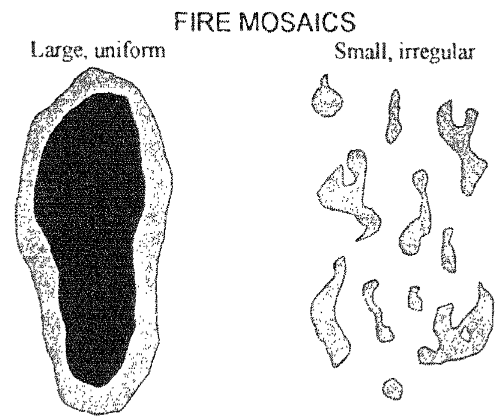

Figure 2. Fire mosaics vary across the landscape depending on fuels, weather, terrain, and land use patterns. Light gray represents low and moderate fire severity where many individual plants survive whereas dark gray represents high severity stand replacement fire where few individual plants on the site survive.

We now recognize that landscape fragmentation, agriculture, and fire suppression have resulted in major changes in fire regimes in many forest and rangeland types. The result is a major shift in the selective pressure exerted by fire. As fires become more severe, or too frequent (i.e., beyond the historic range of variability) fewer individuals and species in the native community survive. This creates conditions favorable for the spread of exotic and invasive species. Likewise changes in fire regime can be expected to affect other disturbance processes.

Whitebark Pine-Fire-Blister Rust

Whitebark pine (*Pinus albicaulis*) (WBP) has evolved with periodic fire and mountain pine beetle (*Dendroctonus ponderosae*) (MPB) outbreaks (Keane and others 1990). Now it has the additional factor of white pine blister rust (*Cronartum ribicola*) (BR), an exotic species introduced from the Old World. Whitebark pine is widely distributed in high mountain ranges of the Northwest. WBP is a key species in the West where runoff from high mountain catchments is critical for water supplies. Most WBP grows in unroaded wilderness areas and national parks. Therefore our ability to use intensive management for restoration and maintenance is limited. WBP is a long lived, shade and drought tolerant species. Its seeds are an extremely important food source for many species, including the grizzly bear (*Ursis arctos*). Its seed is wingless and relies on the Clark's Nutcracker (*Nucifraga columbiana*) to open the cones. The Nutcracker is the dispersal vector for WBP. There has never been a documented seedling from a rodent cache. Regeneration comes from unclaimed seeds. MPB and fire are naturally occurring disturbances. Blister rust is an exotic species that kills cone-bearing branches first. Natural BR resistance is low.

Whitebark pine is declining throughout most of its range due to MPB, BR, and fire exclusion (Keane and Arno 1993). Most of the time fires are relatively easy to suppress at higher elevations in whitebark pine. Fire suppression has been very successful in reducing disturbance. Most areas are rapidly succeeding to subalpine fir (*Abies lasiocarpa*). Nutcrackers prefer to cache seeds in openings, particularly in recent burns (Keane and others 1990). And WPB seedlings do well in reduced competition. Without fire there is no regeneration. Without regeneration there is no selection for BR resistance. And we can expect to loose the species from the landscape. Therefore we need to increase the amount of disturbance either through natural fire, prescribed fire, or mechanical means in order to sustain and restore whitebark pine.

Fire and Exotic/Invasive Species

The next example of altered disturbance processes I would like to briefly discuss is the change in fire regime in the sagebrush-grasslands and pinyon-juniper woodlands of the semi-arid West. The introduction of a number of species from the steppes of Eurasia, principally cheatgrass (*Bromus tectorum*) has increased the frequency of fire to the point where sagebrush is no longer able to complete its life cycle (Young and others 1987, Billings 1990). Fires are becoming larger, more frequent, and more uniform. Likewise, in many Pinyon-juniper woodlands the native understory of mostly perennials has been lost to cheatgrass and other exotic annuals.

Cheatgrass-dominated ranges are highly susceptible to wildfires. As a result of the annual growth habit, cheatgrass sets seed before most of the perennials. Cheatgrass produces an abundance of fine fuel biomass that is more uniformly distributed across the landscape than the native bunch grasses. Given the greater fuel continuity of the cheatgrass, fires spread at lower wind speeds than in native sagebrush-bunchgrass communities. As a result cheatgrass-dominated rangelands burn more readily than native grasses. Cheatgrass-fueled fires exhibit the highest rates of spread of any surface fuel. Fires often burn very hot, killing native species. And they spread rapidly resulting in large uniform burns. Fires often result in the complete loss of tree and shrub cover and the destruction of watershed, wildlife, and range values. Fires lead to an increased dominance of cheatgrass which results in a shortening of the average fire return interval from the 50- to 100-year range to 5 years or less.

The increased frequency, severity, and uniformity of fires has drastically altered the western landscape. Many of the native plant species that evolved in these semi-arid ecosystems are not resistant to the increased level of fire-caused disturbance and are rapidly being replaced by exotic flora. And a number of native fauna species are losing critical habitat and are being lost from the landscape because of increased fire disturbance. Without some type of treatment the native grasses, forbs, shrubs and trees cannot reestablish.

In an attempt to break the short return fire cycle a number of scientists and mangers are using greenstripping, a combination of plowing strips and the planting of low flammability species (Monsen 1994, Pellant 1994). The idea behind greenstripping is to plant slow burning plants at strategic places in the landscape so as to limit the spread of wildfires, thereby break the short fire return cycle, and give native species the chance to compete. However, a number of the low flammability plants are themselves exotics (e.g., forage kochia (*Kochia prostrata*)). Considerable research is needed to determine which species will provide the greatest reduction of fire potential, which species have the least potential to disrupt the development of native communities, and how to define the most strategically sound areas on the landscape to place greenstrips.

The first two examples, whitebark pine and semi-arid rangelands and woodlands involved exotics and our attempts to modify disturbance patterns to reduce the negative impact of the exotic. In the case of whitebark pine we want to increase the amount of fire disturbance. In the semi-arid rangelands we want to reduce the amount of disturbance. The last two disturbance interactions involve natural disturbances.

Catastrophic Storms and Fire

On 4th of July, 1999 a line of thunderstorms crossed northern Minnesota blowing down 10 to 100 % of the trees on nearly 200,000 hectares of conifer and hardwood forest. Most of the blowdown was within the Boundary Waters Canoe Area Wilderness (BWCAW) and adjacent areas to the east. Because most of the area is an unroaded wilderness the potential for harvesting damaged trees is minimal. However, adjacent to the BWCAW there are numerous private residences and businesses so there is considerable public concern for the potential threat of catastrophic wildfire and insects epidemics. There is some possibility that a number of native bark beetle and wood boring species will increase in downed or damaged trees leading to additional damage to forests outside the wilderness boundaries. The greater concern is, however, for the fire potential.

Analysis by fire behavior and control specialists indicates that fire crews would find it tough going trying to construct fire line by hand through the wind fall. Finney (2000) used the FARSITE Fire Area Simulator model to predict the spread and intensity of fires under a variety of weather conditions in the blowdown area. His analysis indicates there is a major threat of uncontrollable wildfire in the blowdown area. Fire growth rates in the blowdown area are expected to be 10 to 12 times greater than in non-damaged areas (Finney 2000). Spread rates under even mild burning conditions are expected to exceed the line construction rates of fire crews. And if a wildfire occurs under average conditions or worse the fire will essentially be uncontrollable. It will burn until there is a major change in the weather. Based on preliminary fuel inventories and historic weather he concluded that there is a major threat of wildfire coming out of the wilderness area and potentially impacting private property. Finney (2000) further tested the feasibility of conducting prescribed burns to treat fuels at strategic locations that would take advantage of the natural barriers provided by lakes in the area. He found that fuel treatments that effectively reduced fuels could be effective in reducing the area burned by 50 percent.

Catastrophic wind storms are common although they don't often occur on such a broad scale. Large fires are also common throughout the boreal forest. Large fires have also occurred in blowdown forests (Stocks 1975). There clearly is an increased potential for wildfire disturbance following the storm disturbance. The interaction of the two disturbances is likely to yield a mosaic of new patterns of species composition and stand structure that will dominate the landscape on centuries time scales. Any attempt to modify fuels to reduce wildfire potential will also have major effects on the future of disturbance in the BWCAW.

Fire and Insects

In much of the West there is a dynamic interaction between bark beetles and fire. As forests age the incidence of bark beetle attack increases, opening the forest and adding more fuel for subsequent fires. For example, in the late 1970's and early 1980's MPB killed trees on thousands of hectares in the Greater Yellowstone Area. In 1988 wildfires burned approximately 550,000 hectares in the GYA. About two-thirds of this area was burned by crown fires. Trees in these areas were too badly burned to provide suitable habitat for the more aggressive, primary bark beetles such as MPB. In the remaining burned area trees received varying degrees of injury. Many of these provided suitable habitat for a number of primary and secondary bark beetles as well as woodborers in the Buprestidae and Cerambycidae. For example, many of the Douglas-fir (*Pseudotsuga menziesii*) on the Park's Northern Range only showed superficial signs of scorching in a narrow band at the ground-line. Heat from smoldering duff was adequate to kill the cambium of these trees and they eventually became infested with Douglas-fir beetle (*Dendroctonus pseudotsugae*) (DFB). Likewise along the edge of more severely burned areas lodgepole pine (*P. contorta*) had dead cambium on the lower few decimeters of the bole. Above the dead cambium boles became infested with the pine engraver (*Ips* spp.). In 1991, three years after the fire, there was still some delayed mortality (Ryan and Amman 1996). Of those trees attacked by insects, in general they found that primary bark beetles, principally DFB, preferred lightly injured trees with adequate green crown and functional phloem transport. Based on their review of the literature these trees would have been expected to survive had it not been for insect attack. Secondary bark beetles like *Ips* spp. did better on more severely girdled trees. Still, in the absence of significant crown scorch, many of these trees would have been expected to have survived had they not been attacked. Generally if wood borers were the first insects attacking the trees, the trees were too severely injured to have survived. In general they found insects built up first in more severely injured trees and then attacked less injured trees, or unburned trees nearby. Based on these observations it appears that the species initially attacking a fire-scorched tree depends on the amount of crown injury and percentage of the stem circumference killed (Ryan and Amman 1996). Any changes in future fire regimes that affected fire injury can be expected to affect the potential for future insect populations.

CONCLUSION

Landscapes have been shaped by a history of complex interactions between climate and multiple disturbance factors. The above four examples illustrate the dynamic coupling between the multiple disturbance factors of weather, fire, insects, disease, and exotic species. The restoration and maintenance of ecosystems rests on our ability to strike a balance between the needs of society in the near term and the disturbance processes that shape ecosystems over the millennia. If we are going to restore and sustain ecosystems it is going to require a much higher lever of interdisciplinary integration than previously.

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GENETIC VARIABILITY IN GYPSY MOTH FEMALES DIFFERING IN FLIGHT POTENTIAL

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ABSTRACT

The introduction of nonnative invasive species generates concerns about the possible establishment of exotic taxa and the potential of conspecific exotics to hybridize with extant nonnative pests. Identifying such pest strains remains a major concern of regulatory agencies both nationally and abroad. Due to the increasing globalization of markets, geographic strains of the gypsy moth, *Lymantria dispar* L., have been introduced to new habitats. Within Palearctic populations of the gypsy moth, the frequency of female flight ranges from no flying in Western Europe to fully flying in the Far East, including the Japanese Islands. In this study, large-scale genetic variability in Palearctic strains of the gypsy moth was estimated from structural protein loci and compared with a strain-specific index of female flight potential.

Allozymes were analyzed in females of *L. dispar* strains from Japan - Hokkaido, Russia - Mineralni, Russia - Black Lake, Lithuania - Juodkrante, Poland - Wroclaw, Germany - Lampertheim, and United States - Connecticut. Genetic variability in each strain was estimated by genetic diversity, fraction of polymorphism, and average number of alleles per locus. For each geographic strain, frequencies of females exhibiting "unsustained flight" (from free-flying studies, W. Wallner, USFS, Hamden, CT) and of "no flip" females (the female moth cannot right herself, M. Keena, USFS, Hamden, CT) were used to calculate a phenotypic index of "female flight potential." Calculated as the difference from unity of the average frequency for both unsustained flight and no flip, the index also was graphically compared to gene diversity.

As measured by gene polymorphism over 11 loci, genetic variability was highest in females from the Russian and Japanese populations. Average heterozygosity was highest in the Polish (H=0.213) strain and similar to that of the Russian (0.182) and Japanese (0.198) strains. The Polish strain had the greatest number of alleles at a locus, though the Russian (1.64 alleles per locus) strains had the largest number over all loci. A plot of gene diversity by flight potential over all geographic strains suggested a trend between increasing variability at gene loci with higher female flight potentials.

Allozymes provide estimates of gene diversity and are helpful in identifying regions of origin, but their usefulness for identifying gypsy moth strains with female flight is limited by the lack of

unique markers. In this study, estimates of genetic diversity derived for females (as opposed to earlier studies in which both sexes were used) gave a higher heterozygosity for a central European strain. However, the number of alleles over all loci was highest in the Far Eastern strains and is consistent with hypotheses of gypsy moth's Paleartic distribution. The lack of a direct association between the genetic variability and the frequency of female flight could be because female flight potential is a product of multiple loci. If this is the case, estimates from a limited number of loci might not gauge the genetic impact on such a polygenic character. Future research could expand the number of genetic characters to test links with incidence of female flight in geographic strains to increase our understanding of expression mechanisms among polymorphic loci, and provide baselines that are crucial for constructing a linkage map for this pest.

SPATIAL ANALYSIS OF THE CHICAGO ASIAN LONGHORNED BEETLE INFESTATION

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ABSTRACT

The Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky) (ALB), was first reported from Chicago, IL on July 9, 1998. Several adult beetles were discovered in a truck that had hauled firewood from the Ravenswood neighborhood of Chicago. Infested trees, including some that had apparently been dead for several years, were found near a warehouse of a company that had imported plumbing supplies, packed in wooden crates, from China. A visual survey revealed additional infested trees, and a quarantine was imposed on a 12-block area on July 17. By September, 130 infested trees had been removed and the quarantine had been expanded to 12.3 mi^2. In the spring of 1999, the ground-based survey was supplemented using bucket trucks and tree climbers, revealing many more infested trees. By the end of 1999, the quarantined area was 14 mi^2, and 1165 trees, predominately maples and elms, had been removed.

Infested trees have been found at 5 additional locales around Chicago: Addison, 20 mi. W of Ravenswood (54 trees); Summit, 15 mi. SW of Ravenswood (24 trees); the Kilbourn Park area of Chicago (3 trees); Loyal University in Chicago (1 tree); and a forest preserve near O'Hare airport, 10 mi. W of Ravenswood (4 trees).

The initial discovery and all outlying infestations were found, not as a result of survey activities, but by citizens who had noticed adult beetles. Because of limited resources, survey activities have generally been restricted to areas within one block (1/8 mi.) of known infestations. This limited detection program does not appear to have contained the infestation, which appears to have spread at least 2.5 mi. from the point of origin by natural dispersal of the insect. It is not known how long this has taken, but in some cases recently infested trees have been found nearly a mile from the nearest known earlier infestations. In addition, known human-assisted displacement has carried the beetle up to 10 mi. away. It is suspected that the Addison infestation, if not the one in Summit, had an origin independent of the one in Chicago.

Based in part on the Chicago data, several types of survey have been developed for the ALB. An *intensive core-area survey* would examine every host tree, by bucket truck or tree climber, within 0.5 mi. of any tree known to be infested. A *delimiting survey* from the ground would visually inspect all public trees and 4 private properties per city block, once every other year, in the area

extending 1.0 mi. beyond the boundary of the intensive core-area survey. A *targeted survey* would identify sources of, and then "trace-forward," host material that had been removed from quarantined areas. An *area-wide survey* would sample 2 host trees at each of 9 well-separated sites per mi^2 in an area extending 25 mi. from the center-of-origin of an existing infestation.

ASSESSING LOSS POTENTIAL IN FORESTS FROM EXOTIC SPECIES INTRODUCED IN SOLID WOOD PACKING

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ABSTRACT

Exotic species have many deleterious effects, one of them is that they often competitively displace or directly destroy native species. Indeed, exotic species are second only to habitat destruction in causing the disappearance of native species. Some 360 exotic insect species are established in forests in the United States. The effect of newly introduced pest species is a function of the characteristics of the pest organism, the characteristics of the host(s), the nature of the pest-host interaction, and the interactions of the pest-host complex with the biological and physical environment. The potential loss from exotic forest pests introduced in solid wood packing was assessed during our study using formal risk assessment procedures. We used an epidemiological approach for this risk assessment. We used specific case histories to exemplify the kind of impact expected from exotic invasive forest pests (note that they are not meant to represent the totality of damage expected from all exotic species, nor do they represent the only examples). In our approach, each pest was described in terms of its damage potential, time to build up a damaging population within a discrete area, rate of spread, hosts attacked and host susceptibility conditions, expected geographic range, and other details relevant to damage forecast. The distribution and density of hosts susceptible to each of the nine pest cases was obtained for each county in the continental United States plus Hawaii. Host growth minus natural mortality and harvest was assumed constant. Likely points of introduction and initial establishment were determined and used as the initial infestation foci. From these initial foci, each pest was analyzed separately in terms of its yearly spread. Hosts increasingly came under attack as the pest expanded its range. The buildup period required to reach damaging levels was simulated with a logistic function (a parameterized Weibull). The loss for the pest being considered was estimated yearly for a thirty year forecast. Losses were expressed in terms of timber volume and value. Data for our studies and model parameters were obtained from the literature and from heuristics from an expert panel. The pests chosen and the analysis conducted are not meant to be additive nor inclusive of all damage types under all possible circumstances. The cases are meant to illustrate some of the expected effects of the introduction of new insect pests into American forests through the solid wood packing pathway. In summary, data to establish the impact of a pest species and which make up the supporting information for damage estimates included: a) United States distribution of the resource at risk; b) density of the resource at risk; c) expanding "fronts" of the infestation over time (single vs. multiple entries, slow vs. fast moving bugs); d) pest-induced mortality and damage; and e) average expected forest growth. Damage estimates were obtained yearly by multiplying 'green' timber values by estimated yearly damage.

STUDIES ON MODE OF ACTION OF STILBENE OPTICAL BRIGHTENERS OR

"I GET A KICK OUT OF YOU"

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ABSTRACT

Although the gypsy moth nuclear polyhedrosis virus (LdMNPV) has been used successfully to reduce gypsy moth populations, the virus acts slowly and larvae may continue to feed for some time after exposure. Greater larval mortality and faster kill might be achieved by the addition of chemicals to the virus preparation or by the use of more active virus isolates. Several years ago we discovered that optical brighteners (= fluorescent brighteners) could not only serve as radiation protectants but could act as virus enhancers. Initial tests demonstrated that LC_{50}s could be reduced by as much as 2000-fold in laboratory tests, and that LT_{50}s by the addition of selected stilbene brighteners. Subsequent research indicated that selected brighteners also could act as enhancers in other insect-virus systems. Recent research has centered on the mode of action of these chemicals. Stilbenes, such as DIDS and SITS have long been used in mammalian systems because of their biological activities. It has been demonstrated that they can act as anion transport inhibitors, cation transport inhibitors, and carbonic anhydrase inhibitors. Because of these biological activities, studies were initiated to determine whether other inhibitors of anion and cation transport, as well as carbonic anhydrase inhibition could act as enhancers for LdMNPV. Whereas organic calcium channel blockers reduced virus activity, several inorganic calcium channel blockers (cobalt, manganese, ruthenium, zinc) acted as enhancers. All potassium channel blockers reduced virus activity, whereas carbonic anhydrase inhibitors acted as enhancers. At present, different combinations of enhancing chemicals are being tested to determine if additive or synergistic effects could be obtained. These tests are necessary and instructive but they are not direct measures of brightener activity.

BIOECONOMICS OF MANAGING THE EXPANSION OF EXOTIC PEST SPECIES WITH BARRIER ZONES

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INTRODUCTION

In this paper I address two questions: what are economic benefits from slowing the spread of a pest species, and when to give up with eradication project and replace it by slowing the spread.

Three strategies can be used to manage exotic pest species: (1) *total-area management* is applied uniformly through the whole area of the species (e.g., eradication or biological control); (2) *scattered management* is applied to local areas where pest density is high (e.g., IPM); and (3) *barrier zone management* is applied mostly along population boundaries. Barrier zones can be used not just for stopping the spread of a pest species, but also for slowing the spread, or eradication.

Barrier zones were used against several insect species. In 1923 a barrier zone was established along the Hudson River to prevent the spread of the gypsy moth to the west (McFadden and McManus 1991). This zone was managed until 1941 when it finally became infested. It did not stop the advance of population front, but the rates of spread were reduced (Liebhold et al. 1992). Currently the USDA Forest Service is conducting the Slow-the-Spread (STS) project, which goal is to slow the spread of the gypsy moth to the west and south by early detection and eradication of small isolated colonies ahead of the moving population front (Leonard and Sharov 1995). In the Appalachian Mountains, where sufficient historical data was available, the rate of spread has been reduced from 21 km/yr to 9 km/yr (Sharov and Liebhold 1998b).

After the screwworm was successfully eradicated from the US in 1966, a barrier zone was set along the border of Mexico to prevent the reinvasion of this cattle parasite (Knipling 1978). Screwworm populations were managed using sterile insect release. Later, the eradication program was expanded to Mexico and Central American countries with a goal to move the barrier zone towards Panama.

Before africanized honey bees entered the US, there was an attempt to stop their spread in Mexico (Flakus 1993). In 1985 a Bee Regulated Zone was established by the USDA in the Tehuantepec region. However, this zone was soon invaded and the goals of the project were transformed into slowing the spread. It is believed that the project has postponed the invasion of africanized honey bees by 2 years.

The boll weevil was successfully eradicated in Virginia, both Carolinas, Georgia, Florida, Alabama, California, and Arizona (Smith 1998). However, further progression of eradication was more difficult than expected because of increase in insect resistance, decrease in the abundance of natural enemies, and other environmental and economic problems. Whether complete eradication of the boll weevil in the US is possible or not, it is important to keep the pest from spreading back into areas where it has been eradicated. Thus, barrier zones are maintained along the borders of the area where eradication was successful.

MODEL OF ECONOMIC BENEFITS FROM USING BARRIER ZONES

Let us consider economic benefits from managing the spread of invading species. The most simple case is a pest species spreading along the infinite habitat strip of uniform width. Without a barrier zone, the species spreads at its maximum rate of v_{max}. In a space-time diagram, damage occurs in the area below the line $x = tv_{max}$ (Fig. 1). If the rate of spread is reduced from v_{max} to v, then damage occurs in the area below the line $x = vt$. Thus, benefits from slowing the spread occur in the shaded area between lines $x = tv_{max}$ and $x = vt$ (Fig. 1). Benefits are discounted with time (i.e., immediate benefits are more valuable than postponed benefits). The present value of benefits from slowing the spread is equal to

$$B = \int_0^\infty tD(v - v_{max})e^{-\alpha t}dt = \frac{D(v - v_{max})}{\alpha^2} \qquad (1)$$

where D is damage per unit area per year, and α is the inflation rate per year.

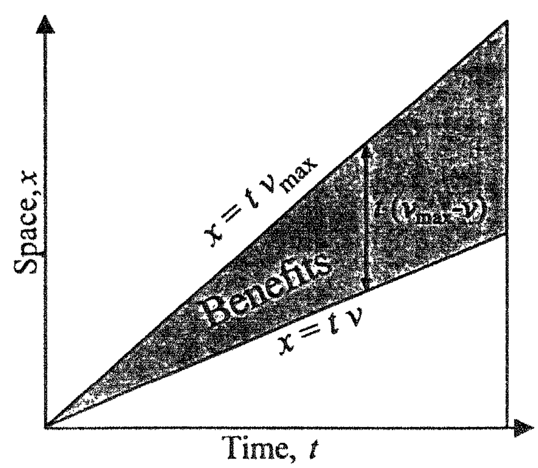

Figure 1. Space-time diagram of benefits from slowing the spread of a pest species.

The cost, $C(v)$, of slowing the spread per unit length of the barrier zone is a function of target rate of population spread, v (Fig. 2A). $C(v_{max}) = 0$, because no management is needed if the population spreads with its natural rate, v_{max}. The smaller is the target rate of spread, v, the higher is the cost of the program; $C(0)$ is the cost of stopping the spread.

The present value of net benefits, NB, is equal to benefits B minus inflation-corrected costs.

$$NB = B - \int_0^{\infty} C(v)\, e^{-\alpha t} dt = \frac{D(v - v_{max})}{\alpha^2} - \frac{C(v)}{\alpha} \qquad (2)$$

The program is optimal if it generates maximal net benefits, NB. The optimal target rate of population spread can be found by solving the equation $dNB/dv = 0$. The solution is

$$\frac{dC}{dv} = -\frac{D}{\alpha} \qquad (3)$$

The slope of the cost function should be equal to damages, D, divided by inflation rate, α. In Figure 2B, the line with a slope of $-D/\alpha$ touches the cost function at the point that corresponds to the optimal target rate of spread, v_1.

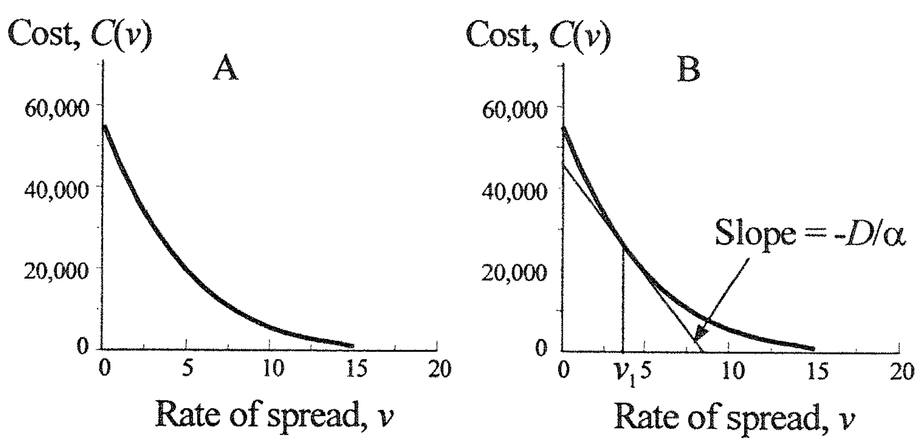

Figure 2. Cost, $C(v)$, of slowing the spread per unit length of the barrier zone as a function of target rate of population spread, v (A); determining the optimal target rate of spread, v_1 (B).

If damage, D, is high, then the slope, D/α, is steep; hence, the target rate of spread is low. If damage is low, then the slope, D/α, is gentle; hence, the target rate of spread is large, and little management is needed. In two cases equation (3) has no solution for positive rates of spread: if the damage is too low (Fig. 3A), or if the damage is too high (Fig. 3B). In the former case, the optimal strategy is to do nothing. In the latter case, a solution may exist for some negative rate of spread. A negative rate of spread means that the population front retreats due to barrier-zone management. Eventually it leads to eradication of the species. If damage is so high that there is no solution of equation (3) even for negative rates of spread, then eradication should be done in one step rather than with a barrier zone.

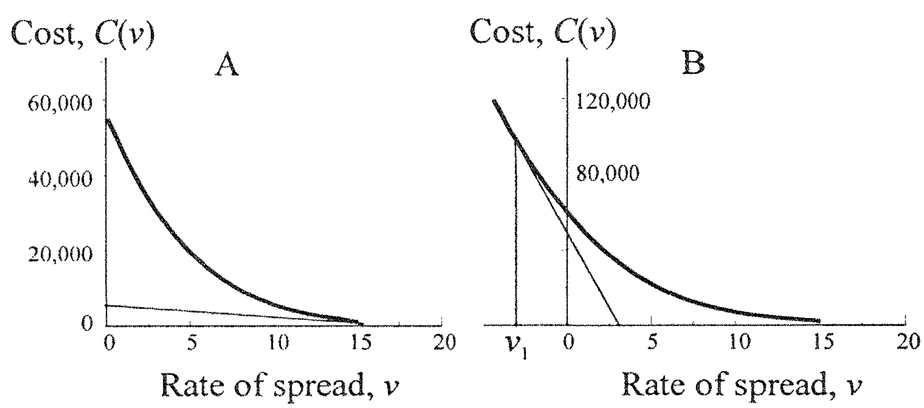

Figure 3. Two cases where equation (3) has no solution for positive rate of spread: (A) damage is too low and doing nothing is the best strategy; (B) damage is too high and eradication (negative rate of spread, v_1) is the best strategy.

The model described above is oversimplified because it assumes that a population spreads along an infinite habitat strip. Sharov and Liebhold (1998a) developed 2 more realistic models: (1) population spread in a rectangular area from one side to the opposite side, and (2) population spread in all directions from the center. In both cases, the optimal target rate of population spread is a function of time rather than a constant. Thus, a more sophisticated optimization method is needed. Sharov and Liebhold (1998a) used the Euler's equation of variational calculus for solving the problem. In short, net benefits (2) are maximized by changing the control function $v(t)$, which is the rate of spread at time t.

A typical solution of Euler's equation is shown in Figure 4. The horizontal axis is the location of the population front relative to the introduction point; the total length of the potential area is 1000 km. The vertical axis is the target rate of spread. The upper branch of the graph corresponds to slowing the spread because the rates of spread are positive, and the lower branch corresponds to eradication because rates of spread are negative. As the population front approaches the end of the potential area, slowing the spread is no longer needed. The optimal target rate of spread becomes equal 20 km/yr, which is the rate of unmanaged spread in this example.

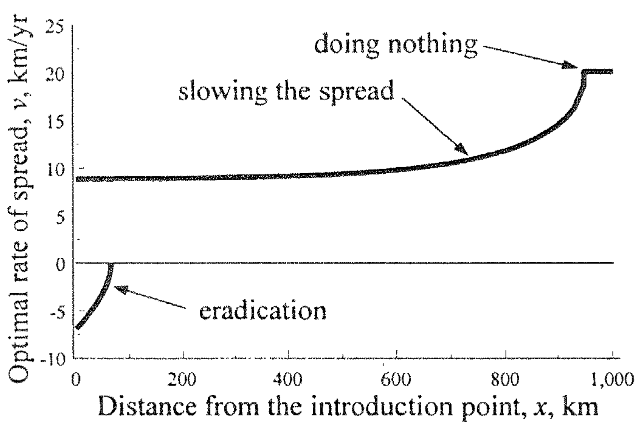

Figure 4. Optimal management of a barrier zone for a population that spreads in a rectangular area of 1000 km width from one side to the opposite side. Management strategy depends on the location, x, of the population front from the introduction point.

If the population has occupied most of its potential area, then the only solution is slowing the spread or doing nothing (upper branch in Fig. 4). But if the pest has just arrived and has not spread far enough, then both slowing the spread and eradication are possible solutions. These two strategies correspond to 2 local maxima of net benefits. Euler's equation does not tell us which of these solutions is the best. Thus we need to compare net benefits for each strategy.

Figure 5 shows net benefits from slowing the spread and eradication as a function of distance from the introduction point, x. Net benefits from eradication decrease rapidly with increasing distance; this means that eradication is most profitable when the population front has not spread far enough from the introduction point. Net benefits from slowing the spread change very little with increasing distance from the introduction point. The intersection of two lines in Figure 5 indicates the maximum size of an infestation that can be eradicated. If the population is larger, then slowing its further progression generates greater net benefits than eradication. Stopping the spread is never an optimal strategy (unless there are natural barriers) because it generates lower net benefits than either eradication or slowing the spread.

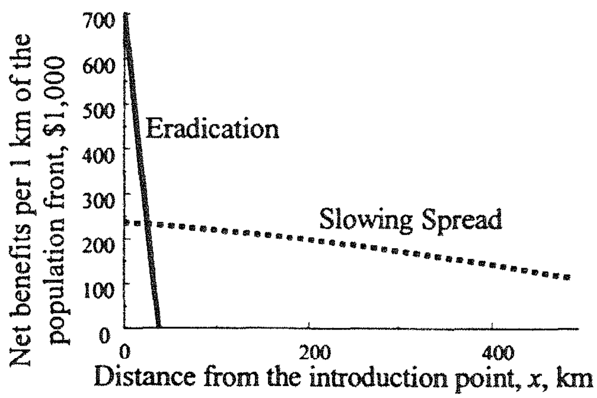

Figure 5. Net benefits from slowing the spread and eradication as a function of distance from the introduction point, x.

Sharov and Liebhold (1998a) applied this model to the spread of the gypsy moth in North America. The minimum distance from the end of potential range, at which it is beneficial to slow the spread, is 49-53 km. The optimum target rate of spread is 3-4 km/yr (except if the population front comes close to the end of potential area). The maximum radius of a population that can be eradicated is 195 km for the annual inflation rate of 4%, and 45 km for the inflation rate of 10%.

DISCUSSION

Any bioeconomic analysis is based on the assessment of costs and benefits. But when a new exotic species arrives, there is a lack of understanding of potential damage and possible management costs. If the pest species is potentially dangerous, eradication is the first logical option even if economic assessment is not available. As information about the species accumulates, a reasonable evaluation of costs and benefits of the project is needed.

Eradication costs are not limited to manufacturing and application of pesticides. They also include pest monitoring, public relations, potential lawsuits, risk to human health, and other indirect costs (Dahlsten and Garcia 1989). Cost/benefit estimations are never absolutely certain. We take best knowledge and evaluate potential strategies. As we learn more about the species, the model and the strategy are updated.

If eradication project has smaller net benefits than slowing the spread, then it should be transformed into a containment project. Termination of eradication projects is often politically charged; thus, the benefits of some projects may have been overestimated and costs underestimated in order to keep these projects going. But it is wrong to view the termination of an eradication project as a total failure. Even if eradication was not achieved, the project might have postponed the spread of the pest species by several years. Postponing or slowing the spread of a pest species generates economic benefits, as shown by the model. Transition from an eradication objective to containment is an adjustment in the pest control strategy that makes it more effective in a given situation.

ACKNOWLEDGMENTS

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EVALUATING THE SUCCESS OF SUPPRESSION OF ISOLATED GYPSY MOTH COLONIES USING PHEROMONE TRAPS

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ABSTRACT

The goal of the Slow-the-Spread (STS) project, initiated by the USDA Forest Service in 1993, is to slow the progression of gypsy moth populations in the U.S. by early detection and suppression of isolated colonies beyond the population front. Suppression of isolated colonies often results in eradication because mating success is limited in low-density populations. Our objective was to evaluate the effect of treatments in low-density isolated colonies. The traditional method of treatment evaluation based on egg mass sampling can not be used in low-density populations because egg masses are too scarce. Thus, we had to use moth counts in pheromone traps to evaluate treatment success. The success of an individual treatment was evaluated by a reduction in moth counts in the area treated adjusted to the natural change in moth counts in the control area around it. Moth counts were interpolated in each 500-m cell using kriging. Then these estimates were averaged in all cells within the area treated and in the neighboring 24 x 24 km area (control). The buffer area around treatment blocks (2 km wide) was not considered in the analysis. We propose to use the coefficient of treatment success

$$T = \frac{N_t \, n_{t-1}}{N_{t-1} \, n_t}$$

where N_t is the average moth counts in area treated in year t, n_t is the average moth counts in the control area in year t, and t is the year of treatment. Mating disruption treatments (Disrupt II, 30 g AI per ac) are evaluated in the following year after treatment. Thus, for evaluating mating disruption, N_t and n_t in this equation should be substituted with N_{t+1} and n_{t+1}, respectively. A treatment is considered successful if $T < 1/3$, partially successful if $1/3 < T < 2/3$, and unsuccessful if $T > 2/3$. Results of treatment evaluation are available at URL: www.ento.vt.edu/~sharov/stsdec. Out of 110 blocks in Virginia, West Virginia, and North Carolina treated in 1993-1998 with Bt or mating disruption, 89 were successful, 15 were partially successful, and 6 were not successful. The difference between the proportion of successful Bt treatments (77%, N=66) and successful mating disruption treatments (86%, N=44) is not statistically significant. This analysis shows that mating disruption is at least as effective as Bt treatments against low-density isolated colonies of the gypsy moth.

A PRELIMINARY DESCRIPTION OF ANTENNAL SENSORY RECEPTORS OF *ANOPLOPHORA GLABRIPENNIS*

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ABSTRACT

Anoplophora glabripennis, an exotic Asian longhorned beetle (ALB), was first detected in the United States infesting living trees in Brooklyn, NY, in 1996. Since that time, other infestations have been discovered in New York City and Long Island, and Chicago, IL. This wood-boring beetle, previously unknown in North America, could become a significant forest pest throughout the United States. There is little information on attractants for longhorned beetles or on the location of sensory receptors and how they might function. Here, we report our preliminary findings on potential sensory receptors on the antennae of ALB.

Freshly cut ALB-infested logs were transported from Chicago, IL and Queens, NY to the USDA Forest Service Quarantine Laboratory, Ansonia, CT, where adults emerged. Living male and female beetles were fixed in a 1:3 mixture of dimethoxypropane and absolute ethanol. Antennae were processed for scanning electron microscopy (SEM). The antenna of both sexes consists of a basal scape, pedicel, and flagellum. The latter is divided into 9 similar annuli joined to each other by membranes so that the flagellum as a whole is flexible. Preliminary observations with SEM revealed a variety of bristles and hairs on the scape, pedicel, and flagellum. On the basis of their location and surface structure, the long hairs near the junction of annuli likely function as trichoid sensilla, responding to annular movement. That the setae covering most of the surface of the flagellum might function as sensory receptors seems unlikely because they closely resemble the setae on the elytra and other parts of the body. Smaller spines are dispersed among the longer setae on all of the annuli. Whether these function as sensilla will be determined by histological and ultrastructural analysis of the underlying cells. However, most of these spines are covered by the larger, longer setae, so it is unlikely that they have an olfactory function. A number of cuticular structures that bear the surface characteristics of chemosensory sensilla (basiconic, styloconic and coeloconic pegs, and sensory pores or pits) are located at the apex of the most distal annulus of the antennae of both male and female ALB. Many of these structures closely resemble insect chemoreceptors that are known to have an olfactory function. However, few of these structures have been located and they are in an area of the antenna that apparently is used for surface contact. This leads us to speculate that these cuticular structures might function as contact or short-range chemoreceptors. Ultrastructural work is underway to determine whether antennal structures function as sensilla.

DEVELOPMENT OF IMPROVED STRAINS OF THE *LYMANTRIA DISPAR* NUCLEAR POLYHEDROSIS VIRUS

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ABSTRACT

To facilitate commercial production of the *Lymantria dispar* nuclear polyhedrosis virus (LdNPV) we have developed improved viral strains through genetic and genetic engineering approaches. As described below, LdNPV strains that produce wild type (WT) numbers of polyhedra with WT potency in cell culture, and with increased potency and killing speed have been developed.

During replication in cell culture the LdNPV exhibits a high rate of mutation in the 25K few polyhedra (FP) gene (Bischoff and Slavicek, 1996, *J. Gen. Virol.*, 77: 1913; Bischoff and Slavicek, 1997, *J. Virol.*, 71: 1097). Once 25K FP mutants form they become the predominate virus type after just a few serial passages (Slavicek *et.al.*, 1995, *Biol. Con.*, 5: 251). FP mutants have the traits of production of very few polyhedra, synthesis of polyhedra that contain few or no viral nucleocapsids, and production of approximately 10 fold more budded virus particles compared to WT virus (Slavicek *et.al.*, 1992, *J. Inverte. Path.*, 59: 142). In order to enable polyhedra production in cell culture bioreactors LdNPV strains needed to be developed that either have a lower frequency of FP mutant formation and/or that could outcompete FP mutants. To solve the FP mutant problem we have developed two improved viral strains through genetic selection techniques. Isolate A21-MPV exhibits a lower frequency of FP mutant formation compared to WT virus (Slavicek *et. al.*, 1996, *J. Inverte. Path.*, 67: 153), and isolate 122b is able to outcompete FP mutants during production in cell culture bioreactors. Both of these viral strains have been successfully produced in cell culture bioreactors. Patents have been obtained on LdNPV isolates A21-MPV and 122b from the U.S. Patent and Trademark Office.

Polyhedra produced in the Ld652Y cell line are approximately 20-40 fold less potent compared to polyhedra generated by the same viral line in gypsy moth larvae. Examination of viral occlusion revealed that polyhedra produced in the Ld652Y cell line contained approximately half the number of viral occlusions compared to polyhedra produced in larvae. However, a few polyhedra generated in the 652Y cell line contained a large number of viral nucleocapsids. This finding suggested that a viral variant existed within the viral population that was able to occlude WT levels of viral nucleocapsids. We developed a selection protocol to isolate viral variants (selected strains) that occlude WT levels of viral nucleocapsids. Through the selection method we have isolated selected strains that occlude high numbers of viral nucleocapsids in polyhedra

produced in the Ld652Y cell line. Polyhedra produced in the Ld652Y cell line by these viral strains exhibited the same potency as Gypchek polyhedra produced in gypsy moth larvae. In addition, polyhedra produced in gypsy moth larvae by the selected viral strains exhibited potencies approximately 3 fold higher than polyhedra produced by Gypchek in larvae. A patent has been obtained on the selection procedure developed to isolate selected strains from the U.S. Patent and Trademark Office.

The LdNPV requires approximately 10-14 days to kill its host. The insertion of foreign genes and deletion of viral genes from the viral genome have been successful in increasing the killing speed of the *Autographa californica* NPV. The deletion of the ecdysteroid UDP-glucosyl transferase gene from the AcNPV genome generated a virus that killed its host in approximately 25% less time compared to WT virus. The function of the viral EGT is to inactivate ecdysteroids through sugar conjugation. The inactivation of ecdysteroids results in an extension of the larval instar period, which results in the production of increased viral progeny. After identifying an EGT gene in the LdNPV we generated a virus lacking this gene in an effort to increase viral killing speed (Riegel et al., 1994, *J. Gen. Virol.*, 75: 829). The EGT minus LdNPV strain killed infected 5th instar larvae in about 35% less time compared to WT virus (Slavicek et al., 1999, *Biol. Cont.* 16: 91). In addition, larvae infected with EGT minus virus gained less weight compared to larvae infected with WT virus.

During analysis of the 25K FP gene we identified a gene in the LdNPV with homology to the enhancin genes present in granuloviruses. The enhancin proteins are able to degrade mucin and may have the function of degrading the peritrophic membrane within the larval midgut to facilitate viral passage through the membrane. We characterized the LdNPV enhancin gene homolog (E1) and found that it is required for full viral potency (Bischoff and Slavicek, 1997, *J. Virol.*, 71: 8133). Deletion of the E1 gene generated a virus with about half the potency of WT virus. We discovered a second enhancin gene in LdNPV after sequencing the viral genome (Kuzio et al., 1999, *Virol.* 253: 17), and found that it also is needed for full viral potency. Deletion of both enhancin genes from the LdNPV genome generated a virus that was over 1000 fold less potency than WT virus. This result indicates that the enhancin genes are necessary for viral potency. We are currently continuing the characterization of enhancin function and will try to manipulate the enhancin genes to increase viral potency.

MOLECULAR CHARACTERIZATION OF A SECOND ENHANCIN GENE HOMOLOG

IN THE *LYMANTRIA DISPAR* NUCLEAR POLYHEDROSIS VIRUS

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ABSTRACT

Enhancins are a group of metalloproteases first found in the granuloviruses (GVs) that have the ability to enhance the potency of nuclear polyhedrosis viruses (NPVs). We have previously identified an enhancin gene (E1) in the *Lymantria dispar* NPV (Bischoff and Slavicek, 1997, *J. Virol.*, 71:8133). Recently a second enhancin gene homolog (E2) was identified during the sequencing of the LdNPV genome (Kuzio et al., 1999, Virol., 253:17). E2, located between 155.8 and 158.2 kbp on the viral genome, exhibits a 30% amino acid identity to the LdNPV enhancin 1 protein, and contains the characteristic metalloprotease HEXXH zinc binding domain. Northern analysis of viral RNAs indicate that the E2 gene is expressed at late times postinfection. When the E2 gene was expressed in a rabbit reticulocyte coupled transcription/translation system, a protein of the predicted 89 kDa was visualized. A recombinant virus containing a 2.0 kbp deletion in the E2 gene was constructed and confirmed by southern analysis. When tested in bioassay to determine the effect of the E2 protein on viral potency, a very slight drop in potency was consistently noted in infections of 2nd instar *L. dispar* larvae in comparison with wild type viruses.

PATTERNS OF TREE INJURY AND RESPONSE TO ICE STORM 1998

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ABSTRACT

Weather-related stem and branch breakage commonly occurs to trees during winter storms. An unusually severe and widespread storm in January 7-8, 1998 affected 17 million acres of forestland in northern New England and New York. Adjacent portions of eastern Canada were also greatly affected. Forest managers and the wood processing industry are concerned about damage to the northern hardwood resource resulting from tree mortality, decreased growth, and loss of wood quality due to ice storm injury.

To determine the relationship of storm injury to damage, a five-year study is underway to determine the relationships among crown loss, tree growth, and tree wound response. During the 1998 growing season, 484 injured trees were selected from the storm footprint in Maine, New Hampshire, and Vermont. Selected trees were tagged and categorized by species (sugar maple, red maple, yellow birch, paper birch, and white ash), size (large poles, 20-30 cm dbh and standards, 30-60 cm dbh) and crown loss (class A with less than one-half crown loss, class B with one-half to three-quarters crown loss, and class C with greater than three-quarters crown loss).

The survival or death of each tagged tree will be determined at the end of each growing season for 1999-2002. The number of years for closure of a drill wound (1-cm-diameter x 5 cm deep) inflicted in October 1998 will be used to assess relative growth rates and the closure wound response. Annual growing season (1999-2002) cambial electrical resistance measurements will be used to assess growth potential. The growth response index of individual trees (the periodic growth rate for years following the ice storm divided by the periodic growth rate prior to the ice storm) will be used to assess actual changes in radial growth. A subsample of the trees will be felled and dissected throughout the study period to assess the progress of wound-initiated discoloration and decay. Additional trees that were injured during previous storms during the last 10-20 years will also be felled and dissected for comparisons of internal patterns of discoloration decay. The tree dissections will be incorporated into field demonstrations for forest and wood resource professionals. Photographic records of standing and dissected trees will form the basis of a database to be used to develop teaching tools for tree injury and damage.

Preliminary conclusions after two years of this five-year study include:

- Branch architecture contributes to tree sensitivity to storm injury.
- The survival of intact primary branches near the point of crown breaks results in slower progress of wound-initiated discoloration.
- The greatest amount of wound-initiated discoloration due to the storm occurred in trees with basal scars from previous wounds.

MOVEMENT OF *ANOPLOPHORA GLABRIPENNIS* AND *ANOPLOPHORA NOBILIS*: STUDIES OF FLIGHT, ORIENTATION AND DISPERSAL POTENTIAL

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ABSTRACT

The Asian longhorned beetle (ALB), *Anoplophora glabripennis* Motsch., is native to China and Korea. *A. glabripennis* was first discovered in North America in New York in 1996, followed by its discovery in Chicago, Illinois in 1998. ALB is believed to have colonized North America as a stowaway in solid wooden packing materials (i.e. crating, palettes, dunnage) originating from China. Larvae of this species feed in the cambium and xylem of a large variety of hardwood tree species, including maple, first killing branches and eventually the entire tree.

USDA-APHIS-PPQ has mounted a campaign to eradicate this pest from North America by establishing domestic quarantines that prohibit local transportation of potentially infested wood, aggressively scouting for infested trees and eliminating them, and imposing a new and more stringent shipping rule that requires wooden packing materials from China be treated to kill wood borers (18 September 1998 Federal Register 63 FR 50100-50111, Docket No. 98-087-1). However, in spite of these efforts, which have resulted in the removal of over 3,900 trees in New York and over 1,200 trees in Chicago, ALB-infested trees were discovered during 1999 in three areas outside quarantine zones in New York (including ca. 1,000 trees) and Chicago (including ca. 315 trees) (USDA-Forest Service 1999).

Research directed at ALB includes efforts focused on the eradication of ALB, as well as on the management of ALB should eradication fail. In regard to eradication, where the aim is to eliminate all reproductively viable individuals from the infested areas, establishment of quarantine boundaries inside of which intensive search and destroy operations are conducted, is essential. Delineation of such boundaries are based in large part upon the dispersal potential of ALB. Furthermore, central to the development and implementation of management strategies for ALB, is an in-depth understanding of its population dispersal potential, as well as other key biological and behavioral characteristics. Such an understanding of the process of invasion is a cornerstone to the development of a proactive program for the prevention and early detection of

new introductions. Therefore, investigations of ALB (*A. glabripennis* and *A. nobilis*) movement were initiated in Gansu Province in north-central China during 1999. These investigations included studies of both the individual ALB flight and orientation behavior, as well as its population dispersal potential.

Individual Flight Behavior. The first year of a two-year study of the flight distance, direction, orientation and host selection behaviors of individual adult beetles of *A. glabripennis* and *A. nobilis* was conducted under natural field conditions in Gansu, China. In addition, evaluation of how this behavior is affected by key environmental parameters (i.e. wind direction and speed, temperature, cloud cover, angle and aspect of sun, time of day) and biotic factors were also determined. During these studies a total of 450 adult ALB were evaluated. To date, analysis of these data has shown that an individual ALB can fly an average distance of ca. 25- 46 m in a single flight, which ranged from 3 - 420 m. These data also indicated that flight propensity and flight distance are strongly influenced by the time of day. Most importantly however, this data suggest that the size (linear distance) of host-free space is a key factor governing dispersal distance. Furthermore, the data also indicate a strong directionality to flight, as well as a strong landing orientation to standing trees.

Population Dispersal. The first year of a multi-year study of the season-long population dispersal potential of *Anoplophora glabripennis* was conducted under natural field conditions in Gansu, China. The Mass-Mark Recapture (MMR) method was employed, in which over 16,000 adult ALB were marked and released. These included both newly emerged (0-24 hr old) ALB (obtained from caged infested logs), which were released daily, as well as free living field collected ALB (of unknown age), which were released weekly. ALB were recaptured weekly for a total of 14 weeks by sampling groups of trees at 50, 100, 150, 200, 250, 300, 400, 500, and 600 m from the release points in each of the primary compass directions (N, NE, E, SE, S, SW, W, NW). In addition, ALB were also randomly sampled around the outer periphery of the study area. During this 3.5 month study, dispersal distance, direction, and rate, as well as body size and egg load of recaptured ALB were determined. In addition, daily environmental data (temperature, wind direction and speed, rain fall), weekly ALB population density (n=769 trees; calculated based upon meters of linear tree canopy), and landscape heterogeneity (spatial aspects) were also determined. Field experimentation was completed in early October 1999. To date, analysis of the data has shown that the mean dispersal distance for male and female *A. glabripennis* and *A. nobilis* ranged from approximately 220 - 300 m. More notably, this study showed that ALB can disperse over 1,400 meters in a single season, carrying eggs, well over the previously reported distance of 100-200 meters. In addition, these studies showed a noticeable directional effect as well. Analysis of recapture data relative to ALB population density (temporal and spatial) and landscape heterogeneity are in progress. Molecular techniques are also being employed in an effort to predict the potential dispersal distance of ALB. To this end, ALB larvae (20 larvae) were collected from 5 trees beyond the outer recapture distances (740 - 1,350 m) from the center release site in each of the 8 primary compass directions. Molecular analysis are only now being initiated.

The second year of the individual flight behavior and population dispersal studies will be conducted in China during 2000. The implications and practical application of the new information developed in the individual flight and orientation behavioral studies will also be explored (i.e. trap development and host tree selection). In addition, data from these studies, together with investigations of ALB colonization behavior, will be utilized for the development of prediction models of ALB dispersal and establishment under different landscapes at risk to ALB invasion in the U.S.

APHIS GUIDELINES FOR THE LYMANTRIIDAE

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ABSTRACT

In 1992, APHIS began a new series of plant pest documents called Guidelines. These documents were designed to offer options for dealing with a particular class of pests, assuming that any one of the pests in that class became a matter of concern that could require some sort of regulatory action. The documents are worldwide in scope, that is, all the important and possible pests of that class of pests are dealt with. In several cases, guidelines have been prepared for a few significant pests of worldwide import. These options deal with general information about that class of pests, field identification/ specimen handling of that class of pests, survey options, regulatory options, and control procedures. Since that date, a number of Guidelines have been produced, including one on the family Lymantriidae. The Lymantriidae Guidelines contain information on 136 Lymantriids which have been identified as pests or potential pests. Among these are the familiar gypsy moth, the browntail moth, and the white-spotted tussock moth. Generally, information taken from the world literature is summarized for each species for which such information is known and which would be useful in any kind of control program, should one become necessary. Options taken from programs against known pests are summarized as well, and presented in a way which might be useful for programs against unknown or lesser known Lymantriids. Known life cycle history useful from a program standpoint are summarized. Steps for identification procedures are given. Survey options include a possible survey program, types of traps, lures (if known), and specialized surveys. Regulatory options include the kind of regulated articles that might need to be controlled, the types of establishments that may need to be regulated, the regulatory treatments needed to keep commerce flowing through the regulated area, and examples of regulatory activities which may need to be implemented. Control procedures are highly structured and offer a decision table to help decide what kind of action or program to undertake. Controls are balanced with a view to current concepts of the use of all bio-control options that are possible and away from the pure application of insecticides in the environment. These bio-control options against the Lymantriidae include biological insecticides, useful microorganisms, various natural insecticides, and plant extracts. Behavioral manipulations, classical biological controls, augmentation, conservation of natural enemies, enablement and autocidal control options are also covered. Other control options include habitat manipulation, host-plant resistance, and mechanical means of control. Sections dealing with a more in-depth discussion of regulatory, survey and control options are in Addenda and provide the tools needed to get a program underway within a minimal time frame. Finally, the known biology of a number of species is written, with an emphasis on those features useful when drawing up a program, especially features which can be safely extrapolated to a Lymantriid about which little or nothing is known.

STATUS OF SPRAY MODEL DEVELOPMENT

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ABSTRACT

Over the last 25 years, the USDA-Forest Service has developed modeling techniques to predict deposition of aerially sprayed material. This modeling effort was in response to the relatively inexact nature of aerial spraying at a time when environmental concerns were increasing and chemical application was increasingly expensive. These modeling efforts have markedly advanced the understanding of deposition from aerially released sprays and powders and have contributed to dramatic increases in the technical level of aerial spraying both through applicator practice and improved equipment. The original models were known as FSCBG and AGDISP.

Currently, there are two primary directions in which this modeling effort is moving. USDA-FS is a partner in a Cooperative Research and Development Agreement (CRADA) with USEPA. USEPA is successfully completing a model development effort which brings this type of modeling into the regulatory arena. This effort adopted AGDISP as the core deposition code (around which many modules have been added) and christened the new model AgDrift.

The other thrust of the effort is in the development of a GIS-based model so output will be displayed spatially overlain on maps. This model, dubbed SprayAdvisor, will serve as a platform for future development including development of a genetic algorithm for spray system optimization, a complex terrain deposition and drift model, real-time GIS-based drift estimation available to a pilot during application and other smaller efforts. Finally, pest mortality and dose response models will be tied to the deposition model to yield estimates of operational efficacy.

EFFICACY OF PESTICIDES ON THE

ASIAN LONGHORNED BEETLE *ANOPLOPHORA GLABRIPENNIS*

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ABSTRACT

One of our major cooperative projects since 1997 has been evaluating the efficacy of different insecticides in China against the Asian longhorned beetle, *Anoplophora glabripennis*. Following the field test conducted in 1998, more studies were done in 1999.

Five systemic insecticides including Disyston (AI: Disulfoton), Merit (AI: Imidacloprid), Metasystox-R (AI: Oxydemeton-methyl), Monitor (AI: Methamidophose), and Othene (AI: Acephate) were tested in field through soil injection, trunk injection and trunk implanting at two sites in Gansu province of China. Trees at the first site were primarily *Popular alba var pyramidalis* (height = 8.5 m, and DBH = 10.9 cm) that was once considered to be one of the least preferred species by the beetle. These were ornamental trees on roadside, and close to city residential area. Applications were made three times at this site: April, June and September for soil injection, and May, June, and July for trunk injection and implanting. Trees at the second site were mainly *P. nigra var thevestina* (height = 8.0 m, and DBH = 8.6 cm). These were windbreak trees planted in rows and surrounded by farmland. They are highly preferred and heavily attacked by the beetle. Applications were made two times at the second site: July and September for soil injection, trunk injection and trunk implanting. Efficacy of these insecticides were evaluated by checking the mortality of adult beetles during flight season, and by checking mortality of all stages of beetles through dissecting trees in late November.

The following 8 insecticides were tested in laboratory together with water as the control: Biflex 2 EC (bifenthrin), DeltaGard* 5C (deltamethrin), Astro 3.2 (permethrin), Orthene 75S (acephate), Dursban 4E (chlorpyrifos), Lindane 20%, FICAM (bendiocarb), and Regent (fipronil). Three dosages of each insecticide were tested. Newly collected willow (*Salix matsudana*) twigs were

dipped into insecticide solutions for 1 minute and then placed in cages together with a pair of beetles at 25-32°C. Fipronil and permethrin were also selected for testing their residual effects to the beetle. This was done by spraying insecticides onto tree twigs at different times of the year and then providing beetles with these treated twigs. Mortality of beetles was checked once every 24 hours for a week for both tests.

All data collected from the field tests are still in evaluation. However, based on our preliminary analyses, efficiency of different insecticides varied depending on the time of application and tree species as well as population level and stage of the beetle. Generally, imidacloprid seemed to cause higher mortality to the beetles than other insecticides tested, especially, when applied through trunk injection. Samples of different parts of treated trees have been collected for chemical analyses of the levels of insecticides in trees. Similar chemical analyses for treated trees in the US started in 1999, when imidacloprid and Bidrin (dicrotophos) were applied through soil injection, trunk injection and, implanting to sugar maple (*Acer saccharum*) and red maple (*Acer rubrum*) located in western Massachusetts. These data together with data that will be collected in 2000 by dissecting treated trees left from 1999 will provide us more information about the efficacy of these insecticides against the beetle.

Results of laboratory test showed that the 8 tested insecticides had very good immediate effects on adult beetle, i.e., an almost 100% mortality within 72 hours from each insecticide, though there were slight differences among different insecticides. However, fipronil and permethrin showed very poor residual effects against the beetle. Less than 25% mortality resulted when the two insecticides were applied to twigs 2 weeks before the treated twigs were provided to the beetle.

More field and laboratory tests of insecticides for controlling the beetle together with residual analyses of these insecticides will be conducted in China and the US in 2000.

FIELD TESTING GYPCHEK - *IS THERE MORE TO DO?*

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ABSTRACT

Gypchek (a gypsy moth nuclear polyhedrosis virus product) has been registered with the U. S. Environmental Protection Agency for use against the gypsy moth using either aerial or ground equipment. Environmental concerns over the effects of non-specific insecticides applied to forest ecosystems have stimulated interest in the use of Gypchek. When properly applied at the appropriate dosage against appropriate population structures under appropriate weather conditions, the product will usually provide adequate foliage protection; however, the product is expensive and is non-forgiving if applied under marginal conditions. Yes, there is more to do if Gypchek is to fulfill its potential. Specifically, overall efficacy should be improved, especially for the one-application treatment option. Secondly, cost reduction is needed for the virus, its formulation, and its application. While improvements in efficacy and cost must arise from laboratory research, such improvements must be field-validated. Thirdly, the "window of application" must be widened. Currently, Gypchek must be applied against first-second instar larvae to be effective, leaving program managers with little leeway in time to achieve a reasonable benefit.

Gypchek product improvement may arise from a number of sources including improved natural or engineered strains, improvements in formulations such as improved UV protection (= increased persistence of the viral agent) and improved stickers (= increased persistence of the deposit). Feeding stimulants may be added to formulations to overcome feeding repellency, which may be overlooked in laboratory studies. Additives such as enhancers can be added. However, our past research indicates that product improvements will lose an order of magnitude in increased efficacy when transferred from the laboratory to the field. Thus, product improvements that show promise in the lab require field validation.

The product must reach the target site to be effective. Increasing effective spray deposition by optimizing droplet size, number, and canopy penetration remains a target for additional field research. The effects of weather on program success should be addressed - current recommendations for spraying Gypchek are based more on experienced opinion than hard data.

Finally, the virus that is the active ingredient of Gypchek has the potential to spread in time and space. New strategies and tactics that take advantage of such potential spread should be conceived and field validated.

POTENTIATION BY A GRANULOSIS VIRUS OF GYPCHEK, THE GYPSY MOTH NUCLEAR POLYHEDROSIS PRODUCT: FIELD CONFIRMATION

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ABSTRACT

We used a bugs-in-bags approach to confirm a laboratory finding that the co-application of Helicoverpa armigera granulosis virus (HaGV) with Gypchek (LdMNPV) increased viral mortality at a given dose compared to that resulting from Gypchek applied alone. We applied Gypchek and the granulosis virus in various combinations against several gypsy moth instars under field conditions (with a Blankophor BBH + Gypchek treatment included as a comparison of virus enhancers), and determined the residual effects of the treatments over a 3-week period. The addition of HaGV at 1% to Gypchek resulted in a log increase in observed mortality, confirming the laboratory finding of such potentiation. The addition of Blankophor BBH at 1% resulted in a two-log increase in observed mortality. The addition of HaGV at a lower dose of 0.1% resulted in no consistent increase in recorded mortality, and 1% granulosis virus applied alone was inactive against gypsy moth. The residual activity of Gypchek was little enhanced by the addition of the granulosis virus at either dose.

OBSERVATIONS ON *ANOPLOPHORA GLABRIPENNIS* AND *ANOPLOPHORA MALASIACA* IN SOUTH KOREA

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ABSTRACT

We searched for populations of *Anoplophora glabripennis* (Motschulsky) for six weeks in South Korea during July and August 1999 and, after finding one, investigated the ecology of the beetle. We also found *Anoplophora malasiaca* (Thomson). Museum collection records in South Korea indicated the presence of endemic populations of *A. glabripennis* there. Because South Korea is different in climate, topography, and ecology from China, where work is currently underway by scientists from other USDA agencies, we felt that our investigations in Korea would complement and perhaps provide a contrast with those going on in China.

Anoplophora glabripennis was sought in urban and forest habitats within about 50 miles of Seoul and in forest habitats at Mt. Sorak National Park on the eastern coast of South Korea. The only population of *A. glabripennis* located was at Mt. Sorak National Park. Small numbers of *A. malasiaca* were found at several locations around Seoul and at Mt. Sorak.

The only tree species *A. glabripennis* was observed to attack in South Korea were silver maple, *Acer saccharinum,* and Chinese maple, *A. palmatum.* Silver maple is not native to Korea, and both *Acer* species attacked were planted as ornamentals. Although *Populus*, *Betula*, and *Salix* have been cited as hosts elsewhere in the world, extensive searches of those taxa in various habitats in South Korea did not turn up *A. glabripennis*. *Anoplophora malasiaca* apparently attacked sycamore, paper birch, and silver maple. None of those species is native to South Korea.

At the site at Mt. Sorak National Park containing *A. glabripennis,* all 44 ornamental silver maples were measured and assessed for beetle damage. Beetles generally attacked silver maples >10 cm DBH and on the main trunk as high as 2-4 m. Many larger trees sustained heavy damage, but were still alive. After it was determined that silver maple was a preferred host in Korea, areas in Seoul with major street tree plantings of that species were located and a brief survey was carried out. There were well over 1,000 silver maples planted along streets in northern sections of the city. However, no evidence of *A. glabripennis* was found in the survey.

After chewing an oviposition pit in the bark and placing an egg, the female covers the egg with a plug of frass. In the field, *A. glabripennis* was observed to oviposit on relatively flat surfaces on the trunk and main branches. However, females also oviposited in twigs as small as 1 cm in diameter in the laboratory when no larger material was available. In this case, the egg was simply inserted through a slit in the bark. First instars emerged from the eggs after about a week in the laboratory and began to feed.

Two ichneumonid wasp species were associated with silver maple trees damaged by *A. glabripennis*. The female of one parasitoid species was observed to antennate fresh egg niches of *A. glabripennis* and then probe them with the ovipositor. The species, which currently are being identified, are probably both in the genus *Lissonota*.

A major research objective was to investigate the dispersal of adult beetles. Harmonic radar was used to that end. The technique involved attaching a small radar-reflective antenna (Alberta Microelectronic Corporation, Edmonton, Alberta, Canada) to an individual beetle, releasing it, and then relocating it at time intervals using a portable radar device (RECCO AB, Lidingo, Sweden). Harmonic radar may prove to be a useful tool for tracking *A. glabripennis* in the field. However, a more durable radar-reflective tag than is currently available and a more dependable means of attaching the tag to the adult beetle are needed.

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INSECT NATURAL ENEMIES AND THEIR POTENTIAL FOR BIOCONTROL OF ASIAN LONGHORNED BEETLE

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ABSTRACT

Asian longhorned beetle (ALB) (*Anoplophora glabripennis*) is a serious pest in China. It can attack over 20 host tree species, specifically broadleaf species. For biocontrol purposes, we initiated investigations of its insect natural enemies.

Compared with other longhorned beetles, few natural enemies of ALB have thus far been identified. This may be one reason for the outbreaks of ALB over large areas. To date, we have not found any egg parasitoids. There are, however, larval parasitoids: *Dastarcus longulus* Sharp (Coleoptera: Colydiidae), *Scleroderma guani* Xiao et Wu (Hymenoptera: Bethylidae), *Bullaea* sp. (Diptera: Tachinidae), and *Megarhyssa* sp. (Hymenoptera: Ichneumonidae); and pupal parasitoids: *D. longulus, S. guani*, and *Aprostocetus* sp. (Hymenoptera: Eulophidae). *D. longulus* and *S. guani* are the most important among these natural enemies of ALB, as they parasitize both larvae and pupae.

D. longulus, in many areas, has been reported to have parasitization rates of 50-70%. Female *D. longulus* lay eggs in frass and sawdust in host gallery or on the host gallery wall. First instar larvae possess thoracic legs and crawl about in search of a host. Upon finding an acceptable host, the larvae lose their thoracic legs and attach to the body of its host for feeding. It is an ectoparasite, feeding singly or gregariously on its host (1-27 individuals per host), but in all cases the host is killed. *D. longulus* is considered to have the highest potential for use in biological control of ALB.

S. guani usually parasitizes longhorned beetle species whose larvae are small, ca. 15 mm in length. It is an idiobiont ectoparasitoid. Female wasps first paralyze their host by stinging, which immobilizes the host, and then lay eggs on the host body. Larvae are gregarious while developing on their host. After hosts are consumed, mature wasp larvae spin cocoons and pupate. Parental wasps remain with their young until they have completed their development and emerged as adult wasps. Should their eggs or larvae become separated from the host,

parental wasps have been observed to return them to the host. Most female wasps are apterous. The degree days of *S. guani* is 448.89 for development from egg to adult. It can be mass reared for biocontrol. Therefore, *S. guani* has great potential for use in the biological control of ALB larvae, specifically 1^{st} to 3^{rd} instars.

IMPACTS OF *ANOPLOPHORA* SP. IN CHINA

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ABSTRACT

Main species and their distribution, causes and control methods of *Anoplophora* in China are briefly discussed. In China, main species of *Anoplophora* included *Anoplophora glabripennis*, *A. nobilis* and *A. chinesis*, which had brought about enormous damage to forest.

ALB and *A. nobilis* was emphasized in this paper because of their serious damage in China. Because most of "Three North" areas with abominable natural geological and climatic environment are not the native habitat of ALB, and plantation area of poplar is increasing continually, these are few local rapid growing tree species suitable to these areas. To the contrary, poplar inevitably becomes the preferred tree species in construction of protection forest for its adaptability, fast growing ability and acceptability by people. Since 1980s, most of the first-stage artificial forest mainly made up of poplar of the world-famous "Three North" shelter forest system has been almost devastated by A. *glabripennis* and *A. nobilis*. Now, there are reports that *A. glabripennis* and *A. nobilis* have been introduced into Western Huanghe Corridor, Qinghai, Jilin, and even Hami of Xingjiang and Heilongjiang.

To analyze the damage causes of *Anoplophora*, we can find answers from the inherent bio-characteristic of *Anoplophora* and the irrational cultivation, utilization and management of poplar trees. According to the studies of *Anoplophora* in China, the control measures can be summed up to 3 levels, which were respectively aimed at pest, individual tree, pest population and forest and even ecosystem. However, effective and simple methods are still in searching. Because of the limitation of the first 2 level methods, many efforts are still taken to search effective and simple control methods. Only the 3rd level measures were toward whole forest and their effects were sustainable. Thus they are the basic methods to control *Anoplophora*.

Great progresses had been attained after 20 years' research on management of *Anoplophora*. Biology, ecology, control measures and other behavior were systemic studied. According to the habit of adults, new type insecticides with high technology had been made up, such as imidacloprid, contacting-breaking microcapsule. Some volatile compounds from ash-leaf maple had been isolated and identified. After field test, some of them were proved to be attractive in certain degree to adult of *A. glabripennis*.

The concept of 1st generation, 2nd generation and strengthened 2nd generation shelter forest was put forward firstly according to the construction of tree species composition. Rational

arrangement of multiple tree species and its basic theories that included stability of ecosystem, relative resistance principle and risk dispersing mechanism were presented firstly. Its main aim was to change the situation that forest systems were composed of single tree species or variety that was susceptible to the beetle and to strengthen the resistance of tree species to *Anoplophora*. It was also pointed out that tree species in the forest included resistant trees, immune trees and luring trees that were aimed at *Anoplophora*.

It was pointed out that ecological reasons cause serious damage of poplar longhorned beetle in China, which included irrational selection of tree species and cultivation way. Therefore, a proposal are put forward that the relationships among host tree, longhorned beetle, natural enemy and living habitat should be considered thoroughly when we try to control *Anoplophora*. Then, we should strengthen the studies on *Anoplophora* as follow in order to find effective methods to control the beetles. It can be seen from Figure 1. Lastly, suggestions for further Sino-US cooperation on ALB was put forward, which included development of attractant, biological control, and chemical control so on.

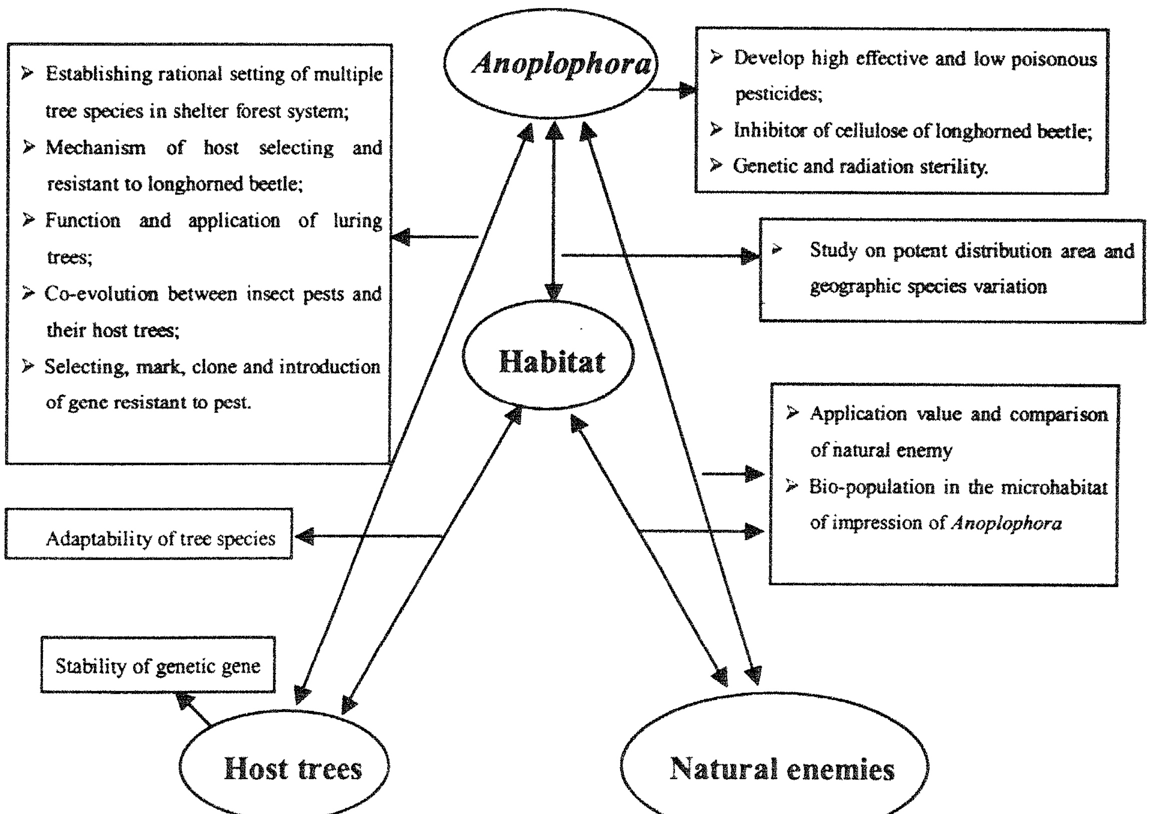

Figure 1. Frame of studies to control *Anoplophora*.

USDA Interagency Research Forum on Gypsy Moth and Other Invasive Species
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