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Working Party 7.03.05: Integrated Control of Scolytid Bark Beetles
Working Party 7.03.07: Population Dynamics of Forest Insects

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ORAL PRESENTATION ABSTRACTS

RISK OF DISPERSAL IN WESTERN SPRUCE BUDWORM

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Western spruce budworms emerge as larvae in the spring before new-year buds are suitable resources. These foraging budworms disperse frequently during this period and many are lost from the population. These losses are interpreted as a risk of dispersal. We measured dispersal losses in field populations and found a relationship between these losses and previous defoliation, foliage density and weather factors. The increase in risk of dispersal associated with previous defoliation represents a lagged, density-dependent relationship between the budworm and its resource. This is the third species of spruce budworm for which the risk of dispersal has been demonstrated to be a significant population process.

RANGE-EXPANSION OF MOUNTAIN PINE BEETLE: BREACH OF THE HISTORIC GEOCLIMATIC BARRIER OF THE ROCKY MOUNTAINS IN CENTRAL BRITISH COLUMBIA, CANADA

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Localized tree-killing infestations of mountain pine beetle were first observed northeast of the Northern Rocky Mountains in British Columbia in 2002. To our knowledge, these were the first incidents of tree-killing population of this insect in the Peace River region that extends eastward to the jack pine forests of Alberta. The speed and rate of spread of mountain pine beetle into and within the region suggested that long range, aeolian transport in advective currents was the predominant dispersal mechanism. Using spatial point process models, we analyze establishment patterns relative to covariates reflecting various hypothesized modes of dispersal. Such modes included meso-scale atmospheric dispersal, anthropogenic transport of infested material, and the spread of insect populations into adjacent stands via corridors of suitable habitat. We found that landscape patterns of trees killed by mountain pine beetle predominantly suggested a wave front of insects deposited parallel to the Rocky

Mountains following meso-scale atmospheric dispersal above an “insect boundary layer.” Up to 2006, areas of highest intensity advanced up to 25km in a single year.

BARK BEETLE OUTBREAKS DRIVEN BY EXTREME METEOROLOGICAL EVENTS

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The eight-toothed spruce bark beetle (*Ips typographus*) is the most important insect pest in Central Europe's forests. About 85% of beetle infested stands are killed by this species. In Swiss forests, extreme meteorological events like storms, droughts and consecutive beetle infestations killed more than 30 million cubic meters of standing trees during the last two decades. This represents about six regular annual cuts of timber. Considering climate change, such extreme events are likely to become more frequent and an increase in bark beetle outbreaks and widespread infestations are to be expected. Nevertheless, during the last six years, no meteorological extremes occurred in Switzerland and *Ips typographus* infestations dropped to an endemic level, even under the influence of a continuously rise of the average temperature. This shows that storms and extended drought and heat periods are much more important key factors for *Ips typographus* outbreaks than the rise of the average temperature.

REMOTE SENSING AND BIOCLIMATIC MODELS AS TOOLS FOR A SURVEY OF INSECT OUTBREAKS IN BOREAL FORESTS

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Climatic drivers and forest disturbances have a close relationship. Spatial and temporal scale of insect outbreaks is expected to increase in the near future, due to dry summers and mild winters in high latitudes. Efficient and accurate methods are needed for monitoring and predicting changes of damages by pest insects. Remote sensing (e.g. optical and microwave satellite imaging and laser scanning) and geographical information system (GIS) could contribute to damage models, e.g. through mapping actual pest distribution or areas at risk of damage. Rapid development in techniques for acquiring, analysing and managing geoinformation and remote sensing has opened new ways in the field of forest protection. We outline an approach to map spatial distribution and defoliation intensity by *Diprion pini* and *Neodiprion sertifer* (Hymenoptera, Diprionidae) with an airborne (ALS) and terrestrial (TLS) laser scanning, aerial photographs and a satellite imagery (e.g. Landsat TM). The interpretation is based on georeferenced field plots by permanent plot sampling and adaptive cluster sampling, and changes in image features and leaf area caused by defoliation. The features of satellite images and 3D laser point data, as well as site variables are used to classify field points according to defoliation intensity. Predictive bioclimatic models for shifts in pest distribution and damage are based on remote sensing and GIS data, and operating at different levels of climatic change scenarios. The promising new technology will improve disturbance detection, predictive spatial modelling, and forest pest management.

REGIONAL CHARACTERIZATION OF EMERALD ASH BORER EFFECTS REVEALED BY FOREST INVENTORY DATA

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Since its discovery near Detroit, Michigan in 2002, the emerald ash borer, *Agrilus planipennis* Fairmaire, a phloem-feeding buprestid beetle native to Asia, has been rapidly expanding its range. In areas where this species has been established for many years, mortality of host ash, *Fraxinus spp.*, has been extensive but estimates of tree mortality across large regions have been lacking. Here we utilize data collected as part of the US Forest Service Forest Inventory and Analaysis (FIA) program to evaluate regional impacts of the emerald ash borer. These data are collected in permanent plots that are revisted every 1-4 years. Data collected up to 2007 provide ample evidence of ash mortality in the southern penninsula of Michigan. Results indicate that mortality increases toward 100% over a 5-10 year period following initial invasion.

INTEGRATED MODELING OF BEETLES, FIRES, FORESTS, AND CLIMATE CHANGE

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The interaction of forest structure, growth, and management has been widely simulated in the USA and several other countries using the Forest Vegetation Simulator (FVS). There are also several integrated FVS insect and disease extensions and the Fire and Fuel Extension (FFE), which have been widely used in North America. Originally developed to project forest growth and timber yield, the system has expanded to simulate and variety of forest ecosystem attributes. Development of the ArcFuels interface has allowed the efficient application of these tools for large, multi-stand landscape simulations. The recent addition to the system of the ecophysiological biogeochemical cycling extension (FVS-BGC), and the carbon reporting functions of the FFE, have created the potential to consider the simultaneous interaction of climate change and CO2 levels on forest disturbance processes and the effects of the disturbances on site-level carbon sequestration. In this presentation, we describe progress on the development and integration of stand growth, fuels and silvicultural management, bark beetles, fire, and climate change impacts using this suite of tools. We demonstrate linkages that permit the modeling of ecophysiology – beetle – fire – climate interactions in the context of stand- and landscape-scale carbon management.

INCORPORATING CLIMATE CHANGE INTO LARGE SCALE RISK ASSESSMENT OF MOUNTAIN PINE BEETLE

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The mountain pine beetle (*Dendroctonus ponderosae*) has become established east of the Rocky Mountains at several locations in western and central Alberta. Research on climate change in relation to the mountain pine beetle suggests that climatic limitations on the eastern spread of the mountain pine beetle are diminishing with time. To assist in assessing the risk of mountain pine beetle to Canada's boreal forest and provide guidance for forest managers in Alberta and Saskatchewan, the interaction between projected climate change and landscape-level susceptibility and habitat connectivity are explored.

SEMIOCHEMICAL DIVERSITY – A NEW DIMENSION OF BIODIVERSITY TO PROTECT CONIFER FORESTS: MECHANISMS AND MANAGEMENT OPTIONS

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Biodiversity lowers abundance of forest herbivores. The semiochemical diversity hypothesis (SDH), a new functional aspect of biodiversity, postulates a reduced searching efficiency of specialist herbivores in the face of non-host plant volatiles. A prediction from the SDH is that conifer specialists should avoid mixed habitats with non-host volatiles (NHV) from angiosperms (broad-leaf trees). Two European examples on

the habitat scale (rather than inhibition of attraction to point sources) now support the SDH for two insect orders. 1) We created “artificially mixed” spruce forest edges for *Ips typographus* beetles by application of a NHV blend + verbenone dispensers in central and north Europe. In Slovakia there was high tree mortality (untreated: 50 -63%) but still a reduction of killed trees. Regression analysis of dose-response to density of dispensers (720 trees) gave an effect estimate as correlation r= –0.6. In the Sweden attack rates were low while most attacks (99%) were found outside the experimental areas (mostly within 15-30 m), indicating an inhibitory range exceeding previous estimates. 2) We showed a population effect of density reduction in of pine processionary moth (*Thaumetopoea pityocampa*) by the EAD-active methyl salicylate, a synthetic birch volatile. The replicated dose-response study (600 trees) at a scale of 50m pine forest edge sections showed a dose-dependent reduction of larval winter nests and male pheromone catches (r= –0.6). The examples emphasise SDH as a functional aspect of biodiversity. The uses of NHV signals provide the only present method of direct protection of conifer forests under stress of climatic change.

MANAGING BARK BEETLES IN THE FACE OF CLIMATE CHANGE

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Bark beetles in the genus *Dendroctonus* have recently caused unprecedented damage to western North American forests. A series of large-scale studies has demonstrated the potential of pheromone-releasing laminated flakes to manage *Dendroctonus spp*. bark beetles in the face of climate change. The flakes, which will soon be available in a biodegradable formulation, can be applied using fixed-wing aircraft or helicopters. Alternatively, they can be broadcast from the ground using fertilizer-spreaders or can be sprayed directly onto tree trunks using a special hand-carried applicator. Area-wide tests were conducted using 150 grams of active ingredient (AI)/acre, and sprays onto individual trees were done using 15 grams AI/tree. Aerial application tests of verbenone-releasing flakes targeting *D. ponderosae* in whitebark pine and lodgepole pine stands showed reductions in attack rate of 60-70%, depending on stand conditions and beetle population levels. Rate of attack by *D. pseudotsugae* in Douglas-fir stands was reduced by 90% with aerial application of methylcyclohexenone-releasing flakes. When sprayed onto individual lodgepole pine trunks from ground level, verbenone-releasing flakes provided almost complete protection to trees baited with aggregation pheromone. We expect that efficacy of these treatments would be enhanced by proper silviculture, and recommend both sanitation of infested trees and maintenance of proper basal area as important components of an integrated approach to beetle management.

MANAGEMENT OF BARK BEETLE POPULATIONS IN ŠUMAVA NP AFTER STORM KYRIL

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Storm Kyril have damaged spruce forest in whole Czech Republic and particularly in Šumava Natianal Park (ŠNP) in January 2007. Volume of spruce trees damaged by wind reached 853 036 m3. GIS and remote sensing based risks analyze was done and management acceptable by nature conservation and also foresters was suggested in the middle of 2007. Approximately 116 th. m3 of spruce wood remained unprocessed in more strictly protected zones of ŠNP, forming food supply for *Ips typographus* populations. Standard methods of forest protection (salvage logging, pheromone trap barriers, trap trees) were widely applied in 2007-2008 and new methods of forest protection were tested (entomopathogenes, anti-atractants) in 2008. In 2007, bark beetle infested mainly wind blown trees. In early 2008, massive attack on forest edges started and had continued in 2008 and 2009. Now, large areas of mature spruce trees are killed by bark beetles outbreak.

ATTACK PREFERENCES OF BARK AND WOOD BORING INSECTS IN A DECLINING SCOTS PINE FOREST

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In a dry valley in Switzerland a pronounced dieback of Scots pine (*P. sylvestris*) has been observed since the 1990s. The role of beetles and woodwasps associated with pine trees of different crown transparency as a proxy for vigor was investigated. During five years 40 pine trees with different levels of needle loss were felled each year and sections of them were placed in emergence traps in the lab to catch the emerging insects. The proportion of trees that were infested by Anobiidae, Buprestidae, Cerambycidae, Curculionidae or by siricid woodwasps increased with increasing needle loss. Infestation density (insects per m2 bark surface) was highest in trees with 65-80 % needle loss. The transparency level at the time of infestation was related to the density of the emerged insects. There were species with a distinct preference for greatly weakened trees, e.g. *Acanthocinus aedilis* (Cer.) and *Orthotomicus longicollis* (Scol.) for trees of 70-85% needle loss. The bark beetle *Ips acuminatus* and the buprestid *Phaenops cyanea* were more aggressive and attacked trees with 30% or more needle loss. However, more than 50% of the greatly weakened trees were not colonized by either of the latter two species which suggests further factors involved in the tree dieback. Several potential pest species showed an infestation peak in 2003 when a hot spell hit Central Europe and induced a drought stress to the trees.

COLONISATION OF STORM GAPS BY THE BARK BEETLE *IPS TYPOGRAPHUS* - INFLUENCE OF GAP AND LANDSCAPE CHARACTERISTICS

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After storm disturbances there is a risk for degradation of the quality of fallen trees, and for subsequent tree mortality, caused by the spruce bark beetle *Ips typographus* (L.) (Coleoptera: Curculionidae). Models assessing the risk for bark beetle colonisation of storm-felled trees, and subsequent tree-killing, in different kinds of storm gaps would be a valuable tool for management decisions. The objective of this study was to determine which gap and landscape characteristics are correlated with the probability of colonisation of wind-felled Norway spruce trees by *I. typographus*. The

study included 36 storm gaps, varying in size from 3 - 1168 wind-felled spruces, created by the storm Gudrun in southern Sweden in January 2005. In the first summer on average 5% of the wind-felled spruces were colonised by *I. typographus*. The percentage of colonised wind-felled trees per gap was negatively correlated with the total area of storm gaps within 2000 m in the surrounding forest landscape. In the second summer the proportion of colonised trees increased to 50%. Both gap and landscape variables were significantly correlated with colonisation percentage. There was no relationship between gap area and colonisation percentage. This implies that landscapes with many large storm gaps, where logging resources will be most effectively used, should be salvaged first.

HOST-SELECTION BEHAVIOUR AMONG PRINCIPAL AND RARE SYMPATRIC HOSTS AS A FUNCTION OF LANDSCAPE DIVERSITY AND POPULATION DENSITY: SELECTION OF PINE VS. SPRUCE BY MOUNTAIN PINE BEETLES.

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The epidemic of mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Coleoptera: Scolytinae) in British Columbia, Canada now extends over 13 million hectares of lodgepole pine (*Pinus contorta* var. *latifolia*) forest. Within the central interior of British Columbia, mountain pine beetle are attacking interior hybrid spruce (*Picea glauca* x *engelmannii*) with increasing frequency, in some cases leading to successful colonization and reproduction. Spruce attack by mountain pine beetle has been reported occasionally within the published literature. The use of rare, alternate hosts by bark beetles, and other insects, has been hypothesized to have implications for the formation of “host races” that may ultimately lead to speciation events. Using populations of mountain pine beetle reared from interior hybrid spruce and lodgepole pine hosts, this study examined the effect of female developmental species and colonized host species on the reproductive capacity of this insect. Ovipositional gallery establishment, ovipositional gallery length, number of larval galleries, number of pupal chambers, and brood production were measured on a per-female pioneer basis. Two-factor ANOVAs analysed the effect of female developmental species and colonized host species on these reproductive measurements. The developmental history of female pioneers did not influence ovipositional gallery establishment or gallery length, number of larval galleries, number of pupal chambers, or brood production. Colonized host species had a significant impact on brood production, which was significantly lower in spruce relative to pine. All other measured parameters were not affected by the species of host colonized by mountain pine beetle.

DOES WATER LIMITATION INFLUENCE TREE DEFENSES AGAINST MOUNTAIN PINE BEETLE AND ITS FUNGAL ASSOCIATES? LINKING CHEMICAL ECOLOGY TO TREE PHYSIOLOGY AND GENOMICS

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The current outbreak of mountain pine beetle (MPB) in western Canada has killed lodgepole pine trees over several million hectares, comprising the largest known contiguous forest insect epidemic. Due to the recent host and range expansion of MPB in Alberta, many studies have sought effective means to predict, control and mitigate MPB populations. In the Tria project (http://www.thetriaproject.ca), an interdisciplinary team is investigating the genomics of the interacting MPB, its associated fungal pathogens, and host pines, aiming to link different scales and levels of biological associations from genetics to co-evolutionary interactions in MPB ecology. Water availability has been suggested to affect pine defense capacity, and is a factor that varies greatly across the historical and new range of MPB. Within the Tria project, our objective is to determine how water limitation affects pine defence responses against MPB. Metabolite and gene expression profiling is being carried out on trees subjected to simulated MPB attack, using both seedlings in growth chambers and mature trees in field experiments. We have taken physiological data (such as phloem thickness, phloem water content) and chemical measurements (such as phenolics and terpenoids) to characterize the role of water availability in tree defences. Microarray and quantitative RT-PCR analyses are planned to identify differentially expressed genes relevant to defence capacity or nutritional quality. Finally, the effects of these defences on MPB fitness parameters (such as growth and reproduction) are being measured. We will discuss our results to re-examine the plasticity and functionality of plant defenses against insect epidemics.

FROM CRITICAL CONSTRAINT TO UNREALIZED POTENTIAL: POPULATION-DEPENDENT MANIFESTATION OF HOST DEFENSE IN CONIFER-BARK BEETLE INTERACTIONS

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Understanding of conifer defense systems has increased dramatically in recent years. We have extensive information on how tree chemicals inhibit bark beetles and their associated microorganisms, and how trees respond actively to attack. However, we have limited understanding of how, or to what extent, these defenses influence population dynamics. Two of the major reasons are a) successful defense usually leaves no signal, i.e., beetles more commonly avoid entering resistant trees than are killed trying and b) resistance may be relative, i.e., properties that make a tree unavailable to a low population may be ineffective at higher populations. We tested the hypothesis that relationships between beetle population density and tree defense define a critical threshold separating endemic from eruptive dynamics. High constitutive resin flow, high induced monoterpene concentrations, and to a lesser extent total constitutive monoterpenes, separated lodgepole pines unattacked versus attacked by mountain pine beetle. However none of these relationships persisted in stands with incipient population levels, and eruptive populations actually preferred more vigorous trees by all three of these measures. Large-diameter trees had higher defensive ability than small-diameter trees, and beetles attacked progressively larger trees as populations rose. This suggests the long-observed correlation between tree diameter and beetle outbreaks does not occur because larger trees are more susceptible, but rather because higher-quality trees become available as populations rise, further contributing to outbreak dynamics. The percentage of attacks that succeeded ranged from 0-100%, indicating tree defense is an important determinant of whether outbreaks occur, but inconsequential once they do.

OPHIOSTOMA AND GROSMANNIA ASSOCIATES OF THE LODGEPOLE PINE BEETLE, *DENDROCTONUS MURRAYANAE*, AND THE DISCOVERY OF A SPECIES COMPLEX WITHIN *LEPTOGRAPHIUM TEREBRANTIS*

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Bark beetles are well known vectors of ophiostomatoid fungi including species of *Ophiostoma*, *Grosmannia* and *Ceratocystis*. While the fungi of common, economically important species are well characterized, fungal associates of rarer beetles remain mostly uninvestigated. This makes comparative studies of fungal function with host beetles difficult. In this study, the most common ophiostomatoid fungi associated with the non-tree killing, naturally rare, lodgepole pine beetle, *Dendroctonus murrayanae* were characterized. Pre-emergent and post-attack adult beetles were collected from lodgepole pines at four sites in British Columbia, Canada. Fungi were isolated from these beetles and identified using a combination of morphology and DNA sequence (ITS and tubulin) comparisons. In all four populations, *Grosmannia aurea* was the most common associate (74-100 % of all beetles) followed closely by *Ophiostoma abietinum* (29-75%). Other associates in order of their relative prevalence with individual beetles were *Leptographium terebrantis* (0-13%), *O. ips* (0-15%), *O. piliferum* (0-11%), *Pesotum sp.* (0-11%) and *O. floccosum* (0-1%). The *L. terebrantis* strains isolated in this study were compared with sequences in GenBank and from fungi in collections. This comparison revealed a species complex within *L. terebrantis* which we are currently describing.

SINGLE NUCLEOTIDE POLYMORPHISMS REVEAL CRYPTIC SPECIATION IN *GROSMANNIA CLAVIGERA*, A PATHOGENIC FUNGUS ASSOCIATED WITH THE MOUNTAIN AND JEFFREY PINE BEETLES

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The fungal pathogen *Grosmannia clavigera* and its bark-beetle associate, the mountain pine beetle (MPB), have affected over 16 million hectares of pine forests in British Columbia. The infestation is expanding in Alberta towards boreal forests, and in the western United States. *G. clavigera* also forms a close association with the Jeffrey pine beetle (JPB), which is the MPB sister species that inhabits only Jeffrey pines. Previous studies have identified *G. clavigera* using morphological characteristics and a limited number of genes, and suggested that natural populations consist of a single species. Recently, we generated a draft genome for *G. clavigera*, as well as expressed sequence tags (ESTs), which we aligned to the genome to support gene annotations. We used these resources to generate a multilocus sequence typing (MLST) assay for characterizing tree-inhabiting fungi. We first identified single nucleotide polymorphisms (SNPs) in 50 protein-coding genes across a panel of 15 isolates of *G. clavigera* and a few closely related pine-infesting fungi. We then selected 15 genes that showed the highest polymorphisms in the panel, and sequenced these genes in 65 more isolates from JPBs and MPBs. We identified a subset of SNPs that discriminated isolates from the two beetles, and resolved the isolates into two phylogenetic species, one associated with MPBs and the other with JPBs. The small overall sequence differences suggested that speciation occurred recently and that the fungi and their beetle vectors are co-evolving.

THE ROLE OF NUTRIENT USE IN NICHE PARTITIONING OF TWO BARK BEETLE MUTUALISTIC FUNGI

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The mechanisms that support coexistence of ectosymbiont assemblages with a single host are poorly investigated. This lack of knowledge extends to the coexistence of multiple species associated with bark beetle hosts. Bark beetles have had a long evolutionary history with filamentous fungi, some of which act as nutritional mutualists. The fungal species *Grosmannia clavigera* and *Ophiostoma montium* associated with *Dendroctonus ponderosae,* mountain pine beetle (MPB), are taxonomically related and ecologically similar. The similarity of the ecological roles of these fungi and the fact that they are restricted to exploiting the same limited and finite resource within the tree would suggest that they are likely to be involved in direct competition which is predicted to be destabilizing. However, the two fungi have coexisted for a long period of evolutionary time, indicating that a mechanism to reduce competition exists, permitting the stable association. One possible mechanism supporting stability is the partitioning of resources in a way that reduces competition. Fungi can vary substantially in their capacity to assimilate carbon and inorganic and organic nitrogen. Therefore, to begin to understand resource partitioning among fungal species, we will determine the nitrogen and carbon sources that these species are able to catabolize. To do this we are using phenotype microarrays (BIOLOG SN-F2 and PM- 3B plates). Results from these assays will be presented.

WOLBACHIA IN THE BARK BEETLE *PITYOGENES CHALCOGRAPHUS* (COLEOPTERA, SCOLYTINAE)

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Pityogenes chalcographus (Coleoptera, Scolytinae) is an important bark beetle in Europe, infesting mainly the branches and crowns of *Picea abies*. In the mid-seventies, studies that included crossing experiments and analysis of morphological features provided indications of separation among the European populations. It was thus hypothesized that populations of the six-toothed spruce bark beetle are clustered into a north-eastern and a central south-eastern race in Europe. Thirty years after building this hypothesis, *Pityogenes chalcographus* populations from all around Europe were analyzed once again. This time, a combined approach of modern molecular methods with crossing experiments, verified the formerly adopted hypothesis of genetic differentiation, supplemented by the detection of crossing barriers among the mitochondrial clades. *Wolbachia* are maternally transmitted, obligatory proteobacteria that have already been detected in a number of insects. Among several phenotypic manifestations, one of the most common is cytoplasmic incompatibility which imposes crossing barriers. Therefore, the presence of *Wolbachia* was tested in several populations of *Pityogenes chalcographus*, in order to reveal potential associations between infection pattern and mitotypes using a highly sensitive nested PCR technique, that enabled the detection of infection even in low titers, inaccessible to conventional methods. However, despite the fact that 35.5% of the individuals were found infected by one and/or two strains, no distinct pattern of infection was revealed, and infections were detected all over Europe, remaining uncoupled from mitochondrial clades. It can therefore be excluded that *Wolbachia* determined the current distribution of genetic diversity among the *Pityogenes chalcographus* populations in Europe by creating genetic barriers.

GEOGRAPHICAL DISTRIBUTION AND PREVALENCE OF PATHOGENS IN THE SPRUCE BARK BEETLE, *IPS TYPOGRAPHUS* (COLEOPTERA, CURCULIONIDAE), FROM DISTINCT EUROPEAN COUNTRIES

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The spruce bark beetle, *Ips typographus*, is probably the most important pest of Norway spruce in Europe. It is able to cause significant mortality to Norway spruce (*Picea abies)* in large areas of central and northern Europe. Spruce bark beetle populations, especially *I. typographus*, are permanently on a high population density in most parts of northern, western and central Europe at least since severe storms or gales during the last decades. Up to now, several studies were conducted on the description of pathogen species in *I. typographus,* but only few reports focused on the pathogen occurrence in specific regions of Europe giving evidence on the geographical distribution of these pathogens. In this study we show results from the years 1996 till 2005, presenting data from different regions of Europe. We found nine pathogen species in total, variable in species composition and in different prevalence in beetles from various locations, the *Ips typographus* Entomopoxvirus, the microsporidia Chytridiopsis typographi, Nosema typographi and Unikaryon montanum, the protozoan species Malamoeba scolyti, Gregarina typographi, Menzbieria cf. chalcographi and Mattesia sp. and an Ascomycete fungus Metschnikowia typographi.

SEASONAL CHANGES IN ABUNDANCE OF ROOT-FEEDING CURCULIONIDS AND OPHIOSTOMATOID FUNGI AT FORT BENNING, GA.

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Root-feeding curculionids and ophiostomatoid fungi have been associated with declining *Pinus spp*. in the southeastern United States, including *P. taeda* (loblolly pine) and *P. palustris* (longleaf pine). To assess the distribution of these beetles and their fungi in longleaf pine stands, pitfall traps baited with turpentine and ethanol were visited weekly for 62 weeks. Captured curculionids were identified, tallied, and rolled on selective and non-selective agar media to isolate ophiostomatoid fungi. *Hylastes spp*. captures peaked in spring and fall, while other important curculionid species peaked at other points during the sampling period. Ophiostomatoid fungi associated with these insects included *Leptographium procerum*, *L. terebrantis*, *L. serpens*, and *Grosmannia huntii*. Distribution of fungal isolates provided evidence of niche overlap between

Hylastes spp. and between regeneration weevils (Curculionidae: Molytinae). Black turpentine beetle (*Dendroctonus terebrans*) had a mycota dissimilar to either of these two groups, suggesting little niche overlap with the other beetles during the study period. Given the observed differences in seasonal peaks of insect and fungal abundance, climate change is likely to disrupt patterns of scolytine abundance and distribution in southeastern pine forests.

ROLE OF SYMBIOTIC BACTERIA IN THE REPRODUCTIVE SUCCESS OF BARK BEETLES

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Bark beetles that attack and colonize living pines encounter several barriers to survival: host defense, low nutrient availability, and antagonistic fungi. We investigated whether some bacteria are frequently associated with bark beetles, and if these associations benefit beetles in overcoming these barriers to survival. Culture-independent analysis of the bacterial community of *Dendroctonus valens* in sites ranging from Wisconsin to Oregon detected close similarity between beetles both within and between sites. To evaluate how bacteria may benefit bark beetles, we conducted a variety of assays with three systems, *D. valens*, *D. ponderosae*, and *I. grandicollis*. In bioassays that included combinations of beetle-symbiotic fungi, beetle-associated bacteria, and the monoterpene pinene, both the presence of a bacterium alone and a bacterium with pinene resulted in increased growth and sporulation of fungi. Next, screens for cellulose degradation activity were conducted on actinobacteria isolated from bark beetles, and genomic and proteomic analyses were conducted on select isolates. In each analysis there was strong evidence for the production of cellulolytic enzymes. In bioassays pairing bark beetle-associated actinobacteria with beetle-mutualistic and antagonistic fungi we detected strong evidence for inhibition of antagonists, while only minor inhibition was observed on growth of mutualists. We are currently testing whether bacteria associated with bark beetles detoxify host defense compounds. Preliminary data show high variation in the abilities of different bacteria to tolerate host terpenes. Collectively, our evidence suggests that some bacteria are frequently associated with bark beetles, and some appear to have specific activities that benefit beetle survival and development.

DOES THE MOUNTAIN PINE BEETLE HAVE ACCESS TO HOST RESOURCES STORED IN THE SAPWOOD?

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Unusually high mountain pine beetle (MPB, *Dendroctonus ponderosae*) activity in high elevation whitebark pine (*Pinus albicaulis*) forests is thought to be facilitated by global warming. Evidence also suggests that once trees are attacked whitebark pine is a better host for the MBP relative to lodgepole pine (*Pinus contorta*), the most common host. Contrary to the long held view that the MPB feeds exclusively from the phloem (including symbiotic fungi dispersed by the beetle), we propose that the MPB has indirect access to host resources stored in the sapwood where symbiotic fungi also proliferate. If so, differences in host physiology and stored resources may result in host-specific beetle performance, with potential implications for outbreak dynamics. Based on this hypothesis we expect a depletion of sapwood stored resources following beetle attack due to fungal colonization and growth. Here, we test whether beetle attack causes NSC depletion in the sapwood and whether such depletion is due to fungal growth. Sapwood samples from healthy and recently attacked whitebark pine and lodgepole pine trees in the Pioneer Mountains, MT showed a significant depletion of sapwood NSC in attacked trees with extensive fungal colonization relative to healthy trees or trees with minimal fungal colonization. We propose that proliferation of symbiotic fungi in the sapwood enhances resource foraging and subsequent transfer to the phloem and beetles. Ongoing work will test whether the MBP ultimately benefits from access to sapwood stored resources and whether beetle performance depends on host-specific stored resources and nutritional quality.

USE OF LOCAL STRAINS OF ENTOMOPATHOGENIC FUNGI AS COMPONENTS OF IPM AGAINST SPRUCE BARK BEETLE *IPS TYPOGRAPHUS* (COLEOPTERA, SCOLYTIDAE) IN NATIONAL PARK SUMAVA.

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A survey of entomopathogenic fungi associated with spruce bark beetle *Ips typographus* was undertaken in 82 *Picea abies* forests sites in National Park Sumava, Czech Republic. In each site, samples of bark and soil were taken and analyzed for presence of entomopathogenic fungi using various methods, including isolation from adult cadavers, selective artificial media and alive baits (larvae of *Galleria mellonella* or *Tenebrio molitor*). *Beauveria bassiana*, *B. brongniartii* and *Isaria fumosorosea* were the most frequently detected species, with B. bassiana as most important species assciated with adult cadavers. More then 200 isolates were found within this survey. *Beauveria bassiana* (87 strains) was used to demonstrate its potential for IPM. Each strain of *B. bassiana* was characterized by radial growth, sporulation, spore vitality and virulence, including strain-specific morphological and DNA markers. Fifteen strains of *B. bassiana* were produced and formulated for application in water suspension or as sporal dust concentrate. Each strain was reintroduced in to site of its origin only. Local strains of B. bassiana induced significant mortality in population of *I. typographus* when reintroduced by application as low or high volume water suspensions, including site-aimed application with helicopter. However, the most effective was reintroduction of spores in dust applied on tree trunks when synchronized with bark beetle activity. Use of local strains of *B. bassiana* became key component of IPM designed with special respect to site-specific managements in Natural Park Sumava.

SPATIAL DISTRIBUTION OF AN INTRODUCED AND NATIVE *LARICOBIUS* SPECIES IN HEMLOCK WOOLY ADELGID INFESTED HEMLOCK STANDS

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Laricobius nigrinus Fender continues to show promise as a biological control agent for hemlock woolly agelgid, *Adelges tsugae* Annand, in the eastern United States. Understanding the dispersal potential of this introduced predator in its newly established range may facilitate strategic planning of future release locations. A native predator of pine bark adelgid, *Laricobius rubidus* LeConte, can also complete its life cycle on HWA and was commonly recovered on infested hemlocks. The morphologically indistinguishable larvae of both predators were recovered from HWA infested hemlock branch samples and identified using molecular diagnostic assays. In spring of 2007 through 2009 up to 16 points at various distances from four *L. nigrinus* established release sites were sampled for dispersal of the F2-F3 through F4-F5 generations. In addition, four newly colonized release sites were sampled in 2008 and 2009 to represent dispersal of the parent and F1 generations. The parent generation dispersed approximately 10 meters from the release areas while the F2-F3 and F3-F4 generations dispersed approximately 100 and 300 meters from the release areas, respectively. Where eastern white pine was a forest component, *L. rubidus* was abundant on hemlocks with building HWA populations, and absent from stands lacking eastern white pine. The dispersal dynamics of the congeners provide an estimate of predator populations over time.

HISTORY AND DYNAMICS OF RED OAK BORER IN ARKANSAS

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In 2000 tens of thousands of dead and dying red oaks were discovered in the forests of northern and western Arkansas. A significant cause of mortality in this "oak decline event" was a population explosion of a previously innocuous, native wood-boring beetle, the red oak borer, *Enaphalodes rufulus* (Haldeman). We initiated research in 2001 to investigate causes of this insect outbreak. We felled and intensively examined more than 240 oak trees from a variety of stands in the Ozark National Forest and Ouachita National Forest. We gained knowledge on beetle life history and behavior, examined tree response to infestation and investigated the relationship of forest site, stand and tree conditions to the distribution and abundance of the red oak borer outbreak. We extended our sampling to historical analysis of red oak borer populations over the past 70 or so years by tree ring analysis. We know now that from 1940 until 1992 red oak borer populations were present in red oak trees at consistently low levels. The current outbreak on the Ozark National Forest appears to have begun in 1994, peaked from 2000 to 2002, with population levels more than 100 times higher than at the beginning of the outbreak. In 2001, rough population estimates suggest about 174 emerging red oak borer adults per tree. The emerging population in 2003 decreased to 32 per tree, and in 2005 was only 1.6 per tree, and the 2007 emergence was 1 adult per tree sampled, suggesting that the outbreak is over.

STAND CHARACTERISTICS AND DOWNED WOODY DEBRIS ACCUMULATIONS ASSOCIATED WITH A MOUNTAIN PINE BEETLE OUTBREAK IN COLORADO

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Lodgepole pine forests in north-central Colorado are undergoing rapid and drastic changes associated with tree mortality from a mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak. To characterize stand characteristics and downed woody debris loads during the first 7 years of the outbreak, 221 plots (0.02 ha) were randomly established in infested and uninfested stands distributed across the

Arapaho National Forest, Colorado. Mountain pine beetle initially attacked stands with higher lodgepole pine basal area, and lower density and basal area of non-host trees compared to uninfested plots. Mountain pine beetle-affected stands had reduced total and lodgepole pine stocking and quadratic mean diameter. The density and basal area of live overstory lodgepole declined by 62% and 71% in infested plots, respectively. The mean diameter of live lodgepole pine was 53% lower than pre-outbreak in infested plots. Downed woody debris loads did not differ between uninfested plots and plots currently infested at the time of sampling to 3 or 4–7 years after initial infestation, but the projected downed coarse wood accumulations when 80% of mountain pine beetle-killed trees fall indicated a four fold increase. For trees 2.5 cm in diameter at breast height, the density of live lodgepole pine trees in mountain pine beetle-affected stands was higher than Engelmann spruce, subalpine fir, and aspen, (*Populus tremuloides* Michx.), in diameter classes comprised of trees from 2.5 cm to 30 cm in diameter, suggesting that lodgepole pine will remain as a dominant overstory tree after the bark beetle outbreak.

DOES WILDFIRE LEAD TO SUBSEQUENT MOUNTAIN PINE BEETLE OUTBREAKS? SEPARATING THE ROLES OF HOST RESISTANCE, HOST SUITABILITY, AND INTERSPECIFIC COMPETITION IN FIRE-INJURED AND NEIGHBORING LODGEPOLE PINES

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Wildfire and bark beetle outbreaks are important natural disturbances in Rocky Mountain conifer ecosystems. However, little is known about how and to what extent they interact to affect the population dynamics of tree-killing eruptive species. This study addressed whether fire injury increased the susceptibility of lodgepole pine (*Pinus contorta var. latifolia*) trees to the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), and whether low population sizes transition to outbreak population sizes as a result of build up in fire-injured trees. Four sites in the Greater Yellowstone Ecosystem (Wyoming) that burned during summer 2006 were studied in the summer of 2007, and four sites that burned during summer 2007 were studied in the summer of 2008. Four 100m x 5m belt transects at each site were used to determine the number of lodgepole pines per fire injury category (none to low, moderate, high), the presence or absence of *D. ponderosae* in each tree, and the presence or absence of *D. ponderosae* competitors. Our results indicate that fire injury predisposes trees to *D. ponderosae* colonization, but the extent to which this occurs varies in a nonlinear fashion with the severity of injury. Both colonization and reproduction are further modified by host resistance, host suitability, the presence of competitors and beetle population density. Ongoing studies are complementing these tree-level analyses with stand-level analyses evaluating beetle population responses to burned areas, and underlying measures of tree resistance and substrate quality to natural and controlled fire injury.

A HISTORICAL PERSPECTIVE ON COLLAPSE OF GREATER YELLOWSTONE WHITEBARK PINE ECOSYSTEMS

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Weather and climate have long been recognized as the major constraint on the success and distribution of mountain pine beetles; and appropriate weather conditions were generally understood to be a necessary condition for outbreak development. Recognizing this importance, considerable effort was expended in development and verification of a mechanistic model that related population success to seasonal weather patterns. This work resulted in methodology capable of evaluating the potential impact of climate warming on mountain pine beetle outbreak potential at the time the first IPCC report on global warming became available in 1990. Simulation results indicated the potential for range expansion of populations beyond the historic northern limits of distribution, and the increased probability of outbreak populations developing in high elevation pine forests. These hypothetical results were well within the ranges of warming predicted in the first and subsequent IPCC reports. It was further noted that mountain pine beetle, because of a direct physiological response to temperature uncomplicated by a physiological timing mechanisms such as diapause, was an ideal indicator species for the ecological effects of climate warming. Unfortunately, subsequent events have proceed much as these early model simulations predicted, with two major exceptions; population response to a warming climate occurred earlier than model simulations predicted, and the consequences have been more devastating for whitebark pine than anticipated. These historical considerations and the subsequent impact on Greater Yellowstone Ecosystem whitebark pine are the subject of this presentation.

USING AN INNOVATIVE AERIAL SURVEY METHOD, TO MONITOR MOUNTAIN PINE BEETLE OUTBREAKS IN WHITEBARK PINE OF THE GREATER YELLOWSTONE ECOSYSTEM

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Historically, the range of mountain pine beetle in the Greater Yellowstone Ecosystem (GYE) was limited to lower elevation forests because of the unfavorable climatic conditions found at higher elevations. For this reason, whitebark pine forests which are located above 2600 meters in elevation in the GYE, have largely avoided past mountain pine beetle outbreaks. With the recent advent of anthropocentric global warming, the ecological relationship between mountain pine beetle and whitebark pine has undergone a fundamental shift. The harsh environment that served to protect these forests has moderated to the extent that it is no longer a deterrent to outbreak beetle populations resulting in an alarming number of mountain pine beetle outbreaks taking place in these previously inhospitable whitebark pine forests. In the summer of 2009, in an effort to better understand the extent and severity of these outbreaks, we conducted aerial surveys across the entire whitebark pine distribution within the GYE. Our method used airplane over-flights in conjunction with Global Positioning System technologies and digital photography to map whitebark pine conditions. The results reveal a widespread ecological collapse of the whitebark pine ecosystem. In certain areas essentially the entire whitebark pine overstory is dead and in other areas only a minor component of living whitbark pine remains. Only portions of the Wind River, Beartooth and Lemhi ranges remain in a healthy condition. In this presentation we will present detailed data from our 2009 aerial survey and will discuss the potential future of whitebark pine in the GYE.

MOUNTAIN PINE BEETLE ADAPTATION TO LOCAL ENVIRONMENTS

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The mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae, Scolytinae) (MPB), is widely distributed across western North America spanning 25 degrees latitude and more than 2500 m elevation. In a common garden experiment, Bentz *et al.* (2001) observed that MPB populations from a southern location required significantly more time to develop than individuals from a population in the northern part of the range, although both populations exhibited univoltinism. Adults from the southern population were also significantly larger, even when reared in a common host and temperature. These results suggest that local selection plays a role in MPB adaptation to temperature which can vary dramatically across the broad range of MPB. A subsequent line-cross analyses revealed that complex epistatic interactions control development time and adult size. In addition, a potential reproductive incompatibility was observed when MPB populations from southern California and central Idaho were crossed. Geographic differences among populations in response to temperature and the influence of these differences on population success in a changing climate will be discussed.

WHAT IS A MOUNTAIN PINE BEETLE ANYWAY? A SYNTHESIS OF RECENT RESEARCH INVOLVING DIVERGENT POPULATIONS.

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Several recent studies involving multiple *Dendroctonus ponderosae* populations have discovered substantial genetic differences in life history traits. Investigations aimed at understanding these differences revealed postmating reproductive isolation between several key populations. Results from a rangewide molecular genetic analysis of *D. ponderosae* imply that the reproductive isolation observed in our studies is recent, and most likely occurred in combination with a broad, somewhat fragmented distribution. I

will describe and synthesize results from several cross-population mating studies and investigations of body size and development time differences, and discuss adaptation and divergence within the context of the evolution of postmating incompatibilities. Our results suggest that *D. ponderosae* is made up of multiple populations that produce reproductively compromised male hybrids when crossed. Furthermore, partially incompatible populations do not always differ in host use, body size, or development time, while some fully compatible populations do. Hybrid male sterility is widely known to be the first postmating incompatibility to develop between diverging taxa, and *D. ponderosae* is providing us an ideal system for examining the forces underlying speciation.

LIFE CYCLE DEVELOPMENT OF BARK BEETLES UNDER CLIMATE CHANGE

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Completion of the different developmental stages of bark beetles is temperature-driven to a large extent. We exploit a threshold-based degree-day model, based on daily temperature measurements or simulations, to conclude on the timing of swarming, reproduction and possible completion of a second generation in a given year (bivoltinism). For the case of *Ips typographus* (European spruce bark beetle), the parameters of the model are well constrained based on rearing cage studies. However, beetles also undergo reproductive diapause, depending on photoperiod, to reduce winter mortality, requiring an extension of the model. In addition, the microclimatic conditions, e.g. temperature under bark, are more relevant than daily mean air temperature at 2 m height. Thus, we perform a sensitivity analysis of the extended model to conclude on the range of responses under current conditions (based on a large network of meteorological stations) and in different climate scenarios using a highly resolved spatial grid. Results indicate that boreal forests are close to a regime shift from mainly univoltine to bivoltine behaviour in the next few decades, increasing the risk and severity of attacks. We also discuss whether a similar developmental model applies to *Dendroctonus ponderosae* (the Mountain Pine Beetle), and try to constrain the corresponding parameters also in this case.

THE SOUTHERN PINE BEETLE: WHETHER WEATHER FAZES PHASES

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The southern pine beetle (SPB), *Dendroctonus frontalis*, has three population phases: latent, intermediate, and outbreak. Outbreak populations are generally defined as having one or more expanding infestations per 1000 acres of susceptible host type. Latent populations occur when SPB are rare or absent, and the intermediate phase includes all other population levels. Biotic, management, and climatic factors can help trigger population movement between phases. Biotic factors (competitors and natural enemies) and temperature extremes may cause infestation collapse and population declines. Outbreaks have been associated with wet springs in the Western Gulf Coastal Plain, while drought may fuel SPB population increases in the eastern portion of their range. SPB prevention and suppression programs (or lack thereof) significantly impact population fluctuations and can minimize or exacerbate the effects of climatic conditions on SPB infestations.

CLIMATIC CHANGE AFFECTS PHENOLOGY OF THE SPRUCE BARK BEETLE *IPS TYPOGRAPHUS* (COLEOPTERA CURCULIONIDAE) IN THE SE ALPS

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Spring drought associated with high temperatures recorded in the last years may give rise to outbreaks of bark beetles developing in weakened host trees. The effects of environmental change on the biology of the spruce bark beetle *Ips typographus* were investigated in the southeastern Alps, where the species is usually bivoltine. The study was carried out recording temperature, precipitation, and damage caused by *I. typographus*. In addition, data from pheromone-baited traps provided information on insect phenology and voltinism. In the last 47 years (1962-2009), mean temperature observed in March-July, the period of main spruce growth and flight activity of I. typographus, has increased of about 2°C (+13%). Increases in March-July temperature did not affect the development timing of the first generation, but only changed its onset, starting and ending sooner (about 20 days over the last 10 years). The early start of the second generation allowed a more complete development of the second brood, reducing the winter mortality. The occurrence of a third generation, however, was never observed suggesting that in SE Alps the voltinism of *I. typographus* is limited by summer photoperiod rather than temperature. Previous investigations report that I.

typographus needs to emerge a day length of at least 15 h. In SE Alps, such day length becomes shorter around end of July, before the complete development of the second-generation offspring. In conclusion, warmer spring affects insect phenology but not voltinism.

EFFECTS OF CLIMATE CHANGE ON THE INTERACTION BETWEEN *IPS TYPOGRAPHUS* AND NORWAY SPRUCE

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Under current climatic conditions *Ips typographus* is always univoltine in Norway and completes a single generation between May and August. Further south in Europe, including Denmark and probably S-Sweden, development is bivoltine, with the completion of two generations in most years. By using a temperature-driven developmental model we have demonstrated that by 2070-2100 the voltinism of *I. typographus* in Norway will change dramatically. In a future climate where summers are only about 2.5°C warmer than today bivoltinism can be expected every single year in the most important spruce growing areas in S-Norway. This will probably have dramatic effects on forestry since two generations per year will give two, instead of one, attack periods each summer. In addition to increasing the number of attacked trees the effect of the attacks may also be more severe, as Norway spruce seems to be more susceptible to beetle attacks later in the summer. However, the susceptibility of Norway spruce to attack by *I. typographus* and its phytopathogenic fungal associates is also likely to change in response to climate change. Thus, we are currently modelling how tree resistance varies with temperature and tree phenology in order to provide more well-founded advice to forest managers on the interaction between bark beetles and tree in a future climate.

***MELOLONTHA SPP*. AND CHANGES IN ENVIRONMENT**

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In recent years, cockchafers *Melolontha* spp. (Coleoptera, Scarabaeidae) have become a major problem in forestry and agriculture in Poland and other countries of Europe (Germany, Austria, Slovenia, Hungary, etc.). Historically, *Melolontha* populations have peaked on a roughly 24-30 year cycle. Their populations had almost been eradicated in the middle of the 20th century through extensive use of heavy pesticides. However, in recent years their numbers have been observed to be on the increase, e.g. in Poland there has been a 100-fold increase of the area of *Melolontha* adults' occurrence in forests since early 1990s. In 2006, economic loss in Polish forestry caused by *Melolontha* grub damage of young plantations and costs of reforestation reached about 30 million PLN (ca. 9.4 million USD). Basing on data provided by regional forest protection service units during the autumn of 2008, the Polish Forest Research Institute estimated that 2009 spring damage by *Melolontha* grubs would exceed levels that would justify the cost of initiating protective control measures on more than 1750 ha of conifer and broadleaved forest nursery and young forest plantations. At present, the only *Melolontha* grub control method approved for use in EU member countries are entomopathogenic nematodes (*Steinernema spp.* and *Heterorhabditis spp.*). However their efficacy is erratic due to the effect of soil moisture and other factors. The author will discuss the possible effects of climate warming and changes in agriculture' and silviculture' systems on *Melolontha* populations.

CLIMATE WARMING IN ALASKA: EFFECTS OF CLIMATE CHANGE ON FOREST INSECT POPULATIONS

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Historically, the boreal forest has experienced major changes and even today appears to be on the brink of further significant change in composition and function triggered by recent changes that include ecosystem disturbance and climatic warming. Ecosystem disturbance by a variety of insects over several years can lead to reduced annual growth and even tree mortality. In interior Alaska, high populations of the spear-marked black moth on paper birch and the large aspen tortrix on quaking aspen occurred at 10-year intervals prior to 1980. However, high populations of these two defoliators have not occurred since 1980 when mean annual temperatures in Alaska began to increase. In comparison, other species of defoliating insects such as the spruce budworm and spruce cone moth on white spruce, larch sawfly on tamarack, and aspen leaf miner on quaking aspen had negligible populations prior to 1990, but since then have defoliated thousands of hectares of forests. From 1990 to 1996, 1.5 million hectares of white spruce were infested and killed by the spruce beetles. During this 6-year period, 30 million trees were killed and 60% of the spruce forests were decimated. This massive outbreak was related to the relatively high densities of large-diameter spruce in an aging forest and to a warming trend which increased spruce susceptibility to beetle attack and reduced the life cycle of many spruce beetles from a two-year to a one-year life cycle, thus increasing the number of maturing beetles in a given year.

THE SOUTHERN PINE BEETLE II

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The southern pine beetle has been studied extensively from a variety of perspectives since the early 1960s. Thatcher et al. (1980) published an interpreted synthesis of the state of knowledge on the southern pine beetle [Thatcher, R. C., J. L. Searcy, J. E. Coster, and G. D. Hertel (Eds.). 1980. The Southern Pine Beetle. USDA For. Serv. and Sci. and Educ. Admin. Tech. Bull. 1631]. In the ca. 30 years since the last synthesis of knowledge on the southern pine beetle, the insect has continued to be a significant pest organism and consequently the object of considerable investigation. In this interim, the nature of the research arena and the forest environment changed significantly. The tools and technologies from the “digital age” were mainstreamed into scientific inquiry and new discoveries followed. The nature of the forest changed dramatically as industrial ownership diminished substantially, human populations encroached into the forest environment, and recreational demands on the forest landscape expanded. These changes affected the economic, ecological, social, and political impacts of the southern pine beetle in unique and undefined ways. Consequently, the USDA Forest initiated project to provide a contemporary and freshly interpreted summary of the state of knowledge of the southern pine beetle. The new volume, The Southern Pine Beetle II, was produced from the labors of a suite of knowledgeable authorities representing both scientists and practitioners. We provide an overview of the revision.

THE SOUTHERN PINE BEETLE DATA PORTAL & SPATIAL WEB APPLICATION

Anthony Courter

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The Southern Pine Beetle Data Portal is an inter-state, inter-agency web based data application to track infestations of *Dendroctonus frontalis* Zimmermann (Coleoptera: Curculionidae: Scolytinae) on federal, state, and private forest lands throughout the US Forest Service Southern Region (Region 8). State and US Forest Service entomologists have individual user/password protected logins to a robust data entry interface that validates data values in real time. Standardized reports, custom data query, GIS mapping and an automated data (*.csv file) upload utility are included. The data structure is designed to accommodate the informational needs of the thirteen Southern States and the US Forest Service by tracking individual southern pine beetle infestations from initial detection via aerial detection or ground check on to treatment and suppression. Minimum required core values are Latitude and Longitude (in decimal degrees NAD83), Unique Spot Identifier, Date of Detection, State, County, Total Affected Acres, Total Affected Volume (in Cubic Feet), and Total Value ($). Core values are validated, and sometimes calculated, based upon other supporting information such as Market Size Class, Basal Area and Average Height. Reasonable values for standing timber are determined with an interface to the most recent timber market data. This reporting system represents the first time that standardized operational data on southern pine beetle suppression programs will be recorded in real time across all land ownerships throughout the Southern Region.

RESOURCES TO SUPPORT FOREST INSECT AND FOREST HEALTH RESEARCH AND EDUCATION WWW.BUGWOOD.ORG

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Scolytine bark beetles and other forest insects are important components of forests around the world and often function as change agents in those systems. As we try to understand their population dynamics and their role in forested systems around the globe, it is essential that not only the scientists working on them, but also the managers, practitioners and the general public are able to properly identify them as well as to find accurate information about them. The Center for Invasive Species and Ecosystem Health continues to operate The Bugwood Network suite of 30 web sites provides images and information that can be used to further education. The Bugwood Image and Database Systems make 100,000 images on a wide array of topics, taxa and subject matter available at no cost for educational uses. Other Bugwood systems provide access to management and identification information that can be used directly or as “tools” by educators to carry out their own research and educational programs. This presentation will provide an overview of Bugwood systems available, including www.ForestryImages.org; www.Invasive.org, and www.Barkbeetles.org that received over 180 million hits and served a global audience during 2008.

Poster Presentation Abstracts

PARASITOIDS ASSOCIATED WITH *IPS ACUMINATUS* (GYLLENHAL) IN THE SOUTH-EASTERN ALPS

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Since 2004, many outbreaks of the bark beetle *Ips acuminatus* (Gyllenhal) have been reported throughout Scots pine (*Pinus sylvestris*) stands growing in the South-Eastern Italian Alps. Infestations show a characteristic pattern: each spot includes a number of infested trees ranging from 10-20 ("small" spots) to 80-100 ("large" spots), although in other Alpine forests a single spot may involve hundreds of trees. Spots do not enlarge with time and infestation continues to grow with the manifestation of new spots close to the old ones. We hypothesize that natural enemies might have an influence on the pattern of spot development. In the outbreak area of San Vito di Cadore (Eastern Dolomites) the number of attacked trees was surveyed since 2005 and emergence of bark beetles and natural enemies was assessed. A sanitation felling was carried out by the Forest Service in autumn 2007. Nineteen hymenopterous parasitoids were found, represented by Pteromalidae (72%), Braconidae (19%), Eurytomidae (8.5%) and Eupelmidae (0.5%). *Metacolus unifasciatus*, *Dendrosoter hartigii*, *Rhopalicus quadratus*, *Roptrocerus xylophagorum*, *Tomicobia acuminati*, *Dinotiscus colon* and *Eurytoma arctica* were the most common species. All species overwinter on the host tree. Except for *Tomicobia acuminati*, they are larval and pupal ectoparasitoids. Overall parasitism by larval and pupal parasitoids was not density dependent, as well as for the adult parasitoid *Tomicobia acuminati*. Individual species of larval and pupal parasitoids responded differently to the change of host density (data not shown). Competition among parasitoid species may explain their low regulation capacity.

THE EVOLUTION OF BARK AND AMBROSIA BEETLE-ASSOCIATED FUNGI USING PHYLOGENETICS

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Ambrosia beetles vector fungi in the Ophiostomatales and Microascales including species of *Ophiostoma*, *Ambrosiella*, *Dryadomyces*, and *Raffaelea*. Ambrosia beetle-associated fungi have been relatively poorly studied despite their ecological importance and close relationship to bark beetle-associated fungi. In 2002, a *Raffaelea* species of wilt fungus vectored by an introduced ambrosia beetle, *Xyleborus glabratus*, began causing extensive mortality of red bay magnolia (*Persea borbonia*) in the Southeastern United States. This has increased interest in ambrosia beetles, however few studies have focused on exploring the diversity or relationships of the fungal associates of ambrosia beetles. These groups of fungi have many taxonomic problems such as polyphyly, undescribed species and a lack of sampling. An understanding of the evolution of scolytid fungi will give us insight into mechanisms responsible for their evolution and stability such as cospeciation and host switching. We propose to do this by creating a phylogeny including the ambrosia and bark beetle fungi. Future work will include mapping key innovations that have led to significant morphological and biological changes in the fungi. We have collected 140 isolates of ambrosia beetle fungi from Taiwan, South Africa, and the USA and are currently identifying these fungi using a combination of morphology and DNA sequences (LSU, ITS and tubulin). Using these, existing strains from culture collections and Genbank sequences our goals are to 1) determine the evolutionary relationship between ambrosia and bark beetle-associated fungi 2) resolve polyphyletic genera of ambrosia beetle-associated fungi 3) identify and characterize new species of ambrosia beetle-associated fungi.

CLIMATE CHANGE EFFECTS ON REGIONAL POPULATION DYNAMICS OF THE SOUTHERN PINE BEETLE

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Southern pine beetle (SPB) is a major pest of pine forests of the South Eastern United States. Its pestilence is characterized by regional (ca 2500 mile2) outbreaks lasting one or two years, followed by extended periods of little or no damage. Its life-history processes (development, survival, fecundity and dispersal) have been shown to be strongly driven by temperature. In addition, the interaction between SPB and its host, competitors and predators may be affected by a number of other climatic events such as rainfall (drought and flooding) and extreme temperatures (low and high temperature mortality). In this paper we will critically review the role of climate in characterizing the two dimensions of SPB pestilence: 1) The frequency of outbreaks and 2) The severity of outbreaks. In turn, we use these insights to project the likely impacts of climate change on SPB activity.

SOUTHERN PINE BEETLE OUTBREAKS ASSOCIATED WITH CLIMATE CHANGE IN HONDURAS

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Pine forests, consisting primarily of *Pinus oocarpa* and *P. caribaea*, cover some 2.5 million hectares and are one of the principal natural resources in Honduras. Historically, these forests have been subjected to ecological impacts and economic losses caused principally by wildfires and outbreaks of the southern pine beetle (SPB), *Dendroctonus frontalis* (Coleoptera: Curculionidae: Scolytinae). To explore the relationship between SPB outbreaks and environmental conditions in Honduras, we developed a model relating periodic SPB outbreaks to climatic variables and occurrence of wildfires. We found that increases in mean ambient temperatures in the month of June, reductions in mean monthly precipitation in June and July, and climatic anomalies in warm months that influence the annual frequency of wildfires were positively correlated with the occurrence and extent of southern pine beetle outbreaks since 1982. The linear model was used to predict future trends in SPB activity in Honduras as a function of expected changes in climate. Results suggest that SPB outbreaks in Honduras and other Central American countries are likely to become more frequent and severe as the climate changes.

SPATIAL DISTRIBUTION OF TREE MORTALITY CAUSED BY THE SPRUCE BARK BEETLE IPS TYPOGRAPHUS IN THE MANAGED FOREST OF SWEDEN

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Spatial distribution of tree mortality caused by the Spruce bark beetle *Ips typographus* in the managed forest of Sweden; Large storm disturbances are known to trigger outbreaks of the spruce bark beetles *Ips typographus* (L.) (Coleoptera: Curculionidae). In January 2005, Southern Sweden experienced the largest storm-felling recorded so far. In 2006 an outbreak of *I. typographus* started that during the following three years have resulted in an estimated mortality of 3 million m^3 of Norway spruce (*Picea abies*). I will, as a part of my PhD-project, study the large scale spatial distribution of killed trees during different phases of this outbreak. The study will be based on data from helicopter surveys of groups of killed trees. Factors that could influence the spatial distribution of attacks are: (1) the spatial distribution of stands with suitable host trees, (2) beetle population densities, (3) the spatial distribution of the beetles in spring before the start of the flight period and (4) tree vitality.

COMPARISON OF WHITEBARK AND LODGEPOLE PINE DEFENSES AGAINST MOUNTAIN PINE BEETLE

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Large-scale outbreaks by mountain pine beetle can only occur when a combination of conditions, including favorable temperature, suitable forest structure, and host susceptibility, coincide to allow transition from endemic to eruptive dynamics. Such conditions occur intermittently in low-elevation pine forests of western North America. In contrast, low temperatures in high elevation stands have historically allowed only infrequent, short-duration outbreaks. Recent warming conditions have permitted higher survival and reproduction by mountain pine beetle at high elevations. We compared the chemistry of two host species in the Greater Yellowstone Ecosystem of the US, one (lodgepole pine) with a long history of continuous association with mountain pine beetle, and the other (whitebark pine) a partially naïve species now experiencing an intensifying relationship due to recent elevated temperature. We also conducted bioassays with beetles in the field. The terpene composition of whitebark pine appears more conducive to the pheromone communication system that mountain pine beetle

uses to coordinates mass attacks. Total constitutive terpene concentrations in lodgepole and whitebark pines are similar, but induced responses to natural attacks appear more substantial in lodgepole pine. Preliminary assays also suggest differences in beetle responses to host resin. If host susceptibility is continually present in whitebark pine, rather being a response to external stresses in more adapted species, then high elevation stands appear likely to experience severe mortality whenever temperatures are high, a condition being met with increasing regularity. Additional information on inter-regional variation in whitebark pine defense physiology is needed to understand the long-term implications.

NATIONAL INSECT AND DISEASE RISK MAP

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The National Insect and Disease Risk Map (NIDRM) is a USDA Forest Service project which provides estimates of potential future tree mortality across the USA for a wide range of forest insect and disease agents. The mapped projections are based on spatial data representing current tree species' sizes and densities and other physiographic and climate data, combined with models for a large combination of pests and locations. Climate change impacts were not considered in the 2006 update, but there is widespread interest in it being considered in the production of the next (2011) update. Several analyses will be presented which have been undertaken to support this need. A database of the potential aspects of climate change and their likely insect guild impacts provides insight into the different ways that current interactions may change. An analysis has been done of the variables in 500 hazard and risk rating NIDRM models and other published models; in regards to how related the variables may be to predicted climate changes. A review of phenology models provides information on how and where changes in voltinism and host-insect synchronicity can be expected. Because the time horizon (15 years) in the current NIDRM version is too short to meaningfully reflect differences in climate projects, future site-climate relationships are being estimated by multiple means. One involves using outside models of climate and CO2 impacts on future forest "carrying capacity", expressed as maximum Leaf Area Index. This will be displayed as a relative value of current LAI potential.

WILL MAJOR BARK BEETLES BECOME INVASIVE AND WHAT WOULD BE THE OUTCOME?

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Pre-emptive measures to lower the risk of introductions are important, as post-establishment management is often extremely costly and has a low chance of successful eradication. In this presentation, we focus on some of the most aggressive bark beetle species of *Dendroctonus* and *Ips* occurring in North America and Eurasia. Despite frequent interceptions at the ports of entry, none of these beetles have been established as exotics on either continent. Simulation models are used to understand the outcome of potential interactions if an invasive and a native aggressive beetle species became sympatric due to an introduction. When highly aggressive species are forced to interact on the same host, our simulations show strong inter-specific facilitations that could result in more frequent and severe outbreaks than produced by each species alone. Colonization experiments are used to determine whether *Ips typographus* can successfully colonize and produce viable broods in cut bolts and living trees of some North American spruce species. Differences among spruce species do not appear to be an absolute obstacle for establishment of *I. typographus* in North America, as both dead and live host materials were successfully colonized in the experiments. Results from a generic invasion model suggest that introductions of bark beetles are likely, given present timber import practices, and that immigration may often go undetected by pheromone traps. However, reduced offspring productivity due to a suboptimal host tree species along with low local beetle populations may contribute to Allee effect that reduces the possibility of establishment.

SEMIOCHEMCIALS FOR MONITORING AND CONTROL OF CONOPHTHORUS SPP. CONE BEETLES (COLEOPTERA: SCOLYTINAE) IN MICHOACAN

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Semiochemicals were shown to be effective for monitoring and control of *Conophthorus michoacanae* (*Pinus michoacana*), *C. conicolens* (*Pinus pseudostrobus*), and *C. teocotum* (*Pinus teocote*) in the state of Michoacan, Mexico. Forest stands were located in rural indigenous communities, which are especially appropriate for this type of pest management. Seed sources of these pine species may be important for assisted migration in the face of global climate change.

THE INFLUENCE OF MOUNTAIN PINE BEETLE OUTBREAKS ON CARBON AND NITROGEN DYNAMICS IN LODGEPOLE PINE ECOSYSTEMS

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In lodgepole pine (LPP) forests, maximal volumes of C storage occur among mature stands whereas the highest rates of C uptake occur in relatively young stands. A similar, age-dependent dynamic occurs for N and other nutrients. Thus, the loss of the mature overstory during a mountain pine beetle (MPB) outbreak can substantially alter the flux and storage of C and N within the affected ecosystem. Moreover, killed trees become part of the detrital pool, further affecting C and N cycling. Over several centuries of repeated MPB disturbance, resulting in replacement of mature trees with young ones, cumulative C uptake should be significantly greater compared to a chronosequence with no disturbance. Also, live and detrital C storage may be regulated at a relatively high level (regulated in the sense that MPB outbreaks are quasi-cyclical). A cycle of MPB outbreaks may also contribute to accelerated N cycling and retention. N bound in the dead stems may be immobilized by decomposers and eventually released

to the available pool. Meanwhile, N demand by the new and surviving trees should increase with accelerated biomass increment. I will investigate these hypotheses through empirical data and chronosequence simulations using a growth and yield model (Forest Vegetation Simulator, FVS). Furthermore, I will assess landscape-scale affects of MPB disturbance on C flux using a process-based model initialized with remotely-sensed data (Physiological Principles Predicting Growth from Satellites, 3PGS). Understanding these dynamics will enhance managers' ability to match vegetation management with desired outcomes.

FORECASTING THE RESPONSE OF SPRUCE BUDWORM DEFOLIATION TO CLIMATE CHANGE IN CENTRAL CANADA

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The spruce budworm (*Choristoneura fumiferana* Clem.) is the most important insect disturbance in Canada’s boreal forest. We used a process-oriented climate envelope model to forecast plausible future responses of the spatial distribution of SBW defoliation in Ontario to different climate change scenarios for 2011-2040. Forecasts were made for 6 scenarios: CGCM2-A2, CGCM2-B2, HadleyCM3-A2, HadleyCM3-B2, CSIRO Mk2-A2, and CSIRO Mk2-B2. All the scenarios predict an increase in temperature variables relevant to SBW biology. Overall, the model explains 88.5% of the variance of historical defoliation frequency and reproduces fairly well the spatial patterns of defoliation at large and medium scales. Winter temperatures (min and max) and spring and summer minimum temperatures are the most important variables. Projected patterns of defoliation appear considerably different from historical patterns. The models suggest a northward expansion of the defoliation belt whereas in the south, they do not predict the disappearance of the defoliation as it has been predicted by other authors for the north central and north eastern United-Sates. This difference is due to our assumption that host species will remain at the southern limit of defoliation during the next outbreak and to the predictions that the warmer temperatures predicted during this period will remain in the “acceptable range” for spruce budworm. Overall, while the latitudinal range of spruce budworm is predicted to increase, the overall severity of the outbreak may decrease due to the decrease in areas of high frequencies of defoliation.

RESOURCES TO SUPPORT INFORMATION EXCHANGE AND EDUCATION ON INVASIVE FOREST INSECTS: COOPERATION BETWEEN CISEH (CENTER FOR INVASIVE SPECIES AND ECOSYSTEM HEALTH, TIFTON, GEORGIA USA) AND UWH-FF (UNIVERSITY OF WEST HUNGARY, FACULTY OF FORESTRY, SOPRON, HUNGARY).

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Invasive forest insects are important factors in forest ecosystems and often function as change agents there. As we try detect them as early as possible, it is essential that not only the scientists working on them, but also broader audience (like forest managers, practitioners and the general public) are able to properly identify them. To understand the role of these new pests in the newly invaded area, accurate information about them is required. The Center for Invasive Species and Ecosystem Health operates The Bugwood Network (www.bugwood.org) suite of web information systems to provide images and information that can be used from researchers to the general public. The Faculty of Forestry at UWH offers different courses in undergraduate, graduate and outreach education in the field of invasion biology. With this poster we provide an overview how the Bugwood systems could be linked to European educational and research systems to provide adequate information for peoples working in quarantine, research and educational organizations.

THE TRIA PROJECT: MOUNTAIN PINE BEETLE SYSTEM GENOMICS

Nadir Erbilgin, J Bohlmann, J Cooke, B Aukema, C Breuil, D Coltman, M Evenden, R Hamelin, R Holt, D Huber, J Jones, C Keeling, M Marra, B Murray, and F Sperling

The current mountain pine beetle (MPB) epidemic in British Columbia is the largest bark beetle outbreak in recorded history. Warmer winters are thought to have permitted the beetle to invade regions in which it has never been previously recorded. The epidemic has now crossed the Rocky Mountain barrier into Alberta, from which it may spread further into Canada's vast boreal forest. Major factors in the spread of the MPB epidemic are climate and forest resource management. Bark beetles, beetle-associated tree-killing fungi, and pine trees are three of the major interacting biological components of the MPB epidemic. Despite the epidemic dimensions of the current MPB outbreak, very little is known about the molecular mechanisms and the population genomics of the interacting bark beetles, fungi and trees. This lack of knowledge of the biological systems of the MPB epidemic affects ecological risk models which are used to address the MPB epidemic in government and industry. Harvesting decisions made by government, for example, rely on simulation-based risk assessment models. These models do not include some important aspects pertaining to the biological systems of the MPB epidemic, and as such they encounter limitations, particularly when applied to regions where MPB have rarely or never been recorded. Genomic information generated first at the sequencing level and further advanced to the functional and population levels will be incorporated in models that will test scenarios involving beetle, fungi and tree population variation in biological traits relevant to, for example, fungal pathogenicity, beetle fitness, or host switching.

FLIGHT ACTIVITY AND DEVELOPMENT OF THE SPRUCE BARK BEETLE *IPS TYPOGRAPHUS*

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The outbreak of *Ips typograhus* in southern Sweden after the storm in January 2005 killed 2-3 million m^3 of spruce forest during 2005-2009. Since 2005 we are studying flight activity and development of *Ips typograhus* at two field stations in southern Sweden, Asa and Tönnersjöheden. The biology of *Ips typograhus* is relatively well studied except from the over wintering and different behaviours of the sister brood. Thus it is needed to find out more about factors effecting different developmental stages of *Ips typograhus*. To study development, bark beetle infested logs are put into emergence bags in May, June and July and emerging beetles are collected weekly. In all years, first (F_1) generation started to emerge in early July, and callow beetles showed up in traps together with old sister-brood flyers. Most of the *Ips typographus* flying after 1 July is 1st generation. Hence 1st (F_1) generation flight occurred in all years, but a completed second (F_2) brood development only occurred in the exceptionally warm and dry summer of 2006. Predictions based on the Austrian PHENIPS-model (Baier et al 2007) are made and data collected during 2005-2009 will be used for adapting the model for Swedish conditions.

STRAIN SPECIFIC CHARACTERIZATION OF ENTOMOPATHOGENIC FUNGUS *BEAUVERIA BASSIANA* ISOLATED FROM SPRUCE BARK BEETLE *IPS TYPOGRAPHUS* IN THE SUMAVA NATIONAL PARK, CZECH REPUBLIC

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Large scale monitoring of the occurrence of entomopathogenic fungi associated with spruce bark beetle *Ips typographus* (Coleoptera, Curculionidae, Scolytinae) population was realized in cooperation between Faculty of Agriculture, University of South Bohemia and management of the Sumava National Park during period 2008 – 2009. Monitoring was realized in three experimental systems: 1) isolation of entomopathogenic fungi from infected cadavers of I. typographus; 2) from niches under/in the spruce bark, and 3) from the soil under the trees damaged by spruce bark beetle. During the period of monitoring, 225 samples were collected and evaluated from 75 sites. The assortment of mitosporic fungi isolated from adults, bark and soil samples is represented by entomopathogenic species *Beauveria bassiana*, *B. brongniartii*, *Isaria farinosa*, *I. fumosorosea* and *Lecanicillium muscarium*, while *Metarhizium anisopliae* was isolated from soil samples only. Monitoring of the occurrence of entomopathogenic fungi in spruce bark beetle population was followed by strain specific characterization based on criteria generated by set of standard in vivo and in vitro laboratory assays. Methods of surface cultivation of selected strains of *B. bassiana* was also developed to ensure production of uniform fungal biomass for reintroduction of particular fungal strain to the site of its origin with aim to induce focus of new epizootics within a frame of an IPM program. Funded by Ministry of the Education of Czech Republic, Project No.: SP/2d1/41/08.

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