Symposium addresses science of

What is sustainable forest management in the context of rapid climate change? Answering this question involves a number of challenges, including filling knowledge gaps on the rate and magnitude of climate change, determining which climate conditions are favourable to pest outbreaks, building the capacity of the plant community to adapt, understanding how forest pest species will adapt, and learning which forest pests could cause the greatest impacts.

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Considerable uncertainty regarding forest pests, evidence of accelerated or unanticipated changes in forest ecosystems, and awareness of a potentially short time span in which to react and adapt prompted the recent Forest Pests and Climate Change Symposium in Victoria. Organized by the Pacific Climate Impacts Consortium, the symposium was designed with the goal of initiating a dialogue on the scientific requirements for research on forest pests and climate change.

Attendees were given the opportunity to build new collaborative relationships, learn about new data sources, discuss the application of modelling and statistical methods, and explore the integration of economic impacts into detailed research studies. More than 30 experts from a number of different disciplines and organizations attended the symposium.

British Columbia's Chief Forester, **Jim Snetsinger**, opened with an overview of the problem from the perspective of the BC Ministry of Forests and Range. According to Snetsinger, one of the main questions facing foresters in British Columbia is: What is sustainable forest management in the context of rapid climate change? Answering this question involves a number of challenges, including filling knowledge gaps on the rate and magnitude of climate change, identifying which climate conditions are favourable to pest outbreaks, determining the capacity of the plant community to adapt, understanding how forest pest species will adapt, and learning which forest pests could cause the greatest impacts. As trees become stressed by changes in temperature and precipitation, pest populations and the existence and prevalence of non-native invasive pest species may increase. However, the rate and spatial scale of the anticipated pest response is not known.

Following the opening address, participants focused their discussions on the following five key topics:

- Models of economic impacts of forest pest outbreaks
- Biological models of pests and hosts in relation to climate
- Forest and pest outbreak databases and statistical methods
- Climate (historical and future) databases and methods for downscaling to a biologically meaningful scale
- Input for a strategy for a comprehensive analysis of impacts of climate change on pests in western North America

The following is a summary of the dialogue in each session.

In the first session, participants discussed economic modelling, with an emphasis on both monetary and non-monetary values. Carbon accounting and market diversification, including non-timber forest products, will increase the monetary value of future forests. However, key ecosystem services with no direct monetary value, such as water quantity and quality, are also essential for both a functioning ecosystem and for human benefit. The "triple bottom line" in this context is: (1) social values of the forests—significance to culture, recreation, and community; (2) biophysical values—functioning ecosystem processes and services; and (3) economic values. Risk management and maintaining resilient forest ecosystems will help to ensure all types of values are retained in BC's forests. Diversifying the species harvested and replanted for commercial use may be required to adapt to climate change as well as to changing market conditions.

The second session focused on biological simulation models of pests and their hosts. Process-based simulation models are based on the physiological response of the pest organism to weather events and climate patterns. Knowledge of pest phenology can be used to build simulation models that explore the effects of changes in temperature, precipitation, and other climate variables on pest outbreaks. These models can be used to approximate a species' fundamental niche (i.e., mapping the locations where it could possibly complete its life cycle). There are many areas related to simulation models which require further research, including: disturbance cycles, impact of climate change on the host species, effects of extreme events, modelling pest drivers other than weather, modelling the effect of pests on species other than the primary hosts (e.g., understorey species), biology of new pest species including invasive species, and the range of current pests in relation to hosts. More realistic representations of reproduction, dispersal, and survival should be developed and incorporated into future simulation models.

Session three gave participants an overview of available forest and pest outbreak databases and

researching forest pests, climate change

concluded with a discussion of statistical methods. There are two major sources of pest outbreak data: tree ring records and aerial survey data. Tree ring data are collected in the field for specific research projects. Aerial survey data are available for many pest species in BC through an ongoing monitoring program at the BC Ministry of Forests and Range. Some issues to consider with these types of data include limited spatial and temporal resolution and inconsistencies in recording procedures between agencies. Tree host-species data are available as forest inventories or vegetation plots (collected for the Biogeoclimatic Ecosystem Classification system). Major data gaps exist in these databases, especially in parks and other areas not managed for timber.

Statistical models can be used to explore the temporal and spatial relationships between pests, their host species, available site characteristics (e.g., drainage, soil), and climate. A simple approach develops independent climate envelopes for both the pest and the host species to forecast future ranges of pest outbreaks. Statistical models can also be used to appraise process-based models, quantify uncertainty, and for exploratory analysis during the initial stages of research. A statistical model is more useful if it directly incorporates biologically meaningful information based on scientific knowledge and an understanding of the pest or host itself.

The fourth session concentrated on climate databases and methods for downscaling to a biologically meaningful scale. Databases of historical and projected future climate variables are continually improving. In particular, data on the probability of occurrences of extremes is improving. Projections from Global Climate Models (GCMs) provide reasonable estimations of future climatic conditions. However, the fact that daily GCM output may not be used directly is a serious problem in situations where pest outbreaks are tied to sequences of weather events. Regional Climate Models (RCMs) offer potential improvements over GCMs in British Columbia, partly because of their superior representation of British Columbia's complex topography. Three important issues with historical climate databases were discussed: (1) sparse and uneven distribution of the climate stations; (2) high levels of spatial variability in precipitation; and (3) incomplete snow-depth data.

The final session discussed ways to move forward, including filling gaps in knowledge and suggesting solutions to some of the problems brought up in other sessions. Significant knowledge gaps identified by the participants included research on understorey species and other non-commercial tree species, pest biology, co-evolution between pests and their hosts, probabilities of extreme climatic events, and the cumulative impacts of disturbance events. Participants created a preliminary list of top pests that are expected to significantly impact British Columbia's forests in the future (see sidebar above).

British Columbia's top forest pests

Results ordered by number of votes from attendees at the Forest Pests and Climate Change Symposium:

Douglas-fir bark beetle (*Dendroctonus brevicomis*)

Western balsam bark beetle (*Dryocoetes confuses*)

Western spruce budworm (*Choristoneura occidentalis*)

Spruce bark beetle (*Dendroctonus rufipennis*)

Mountain pine beetle (*Dendroctonus ponderosae*)

Loopers, including Hemlock Looper (*Lambdina fiscellaria lugubrosa*)

Two-year cycle budworm (*Choristoneura biennis*)

Douglas-fir tussock moth (*Orgyia pseudotsugata*)

Warren's root-collar weevil (*Hylobius warreni*)

Spruce terminal (or leader) weevil (*Pissodes strobi*)

Western blackheaded budworm (*Acleris variana*)

Gypsy moth (*Lymantria dispar*)

Participants also suggested strategies for reducing the impact of future pest outbreaks, such as implementing facilitated migration through planting trees adapted to projected future climates, increasing the adaptive diversity of forest species, and maintaining forest resilience on an international level.

For a detailed summary of the symposium, see Forest Pests and Climate Change Symposium: 14–15 October 2007, by C.L. Abbott, K.E. Bennett, K. Campbell, T.Q. Murdock, and H. Swain. Available online at ***http://www.pacificclimate.org/resources/publications/***

Details of the Pacific Climate Impact Consortium's FSP-funded research on the influence of climate on pest outbreaks and host health can be found at ***http://www.pacificclimate.org/resources/climateimpacts/forests/***