FORESTS, FIRES and STOCHASTIC MODELLING

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Statisticians have an important role to play in the study of various aspects of forestry. The objective of the BIRS workshop was to facilitate interaction between statisticians and researchers that study forest fires and forest ecology.

One theme that emerged in several of the keynote talks as well as in the roundtable discussions was the importance of melding science with statistics. In some of the talks, physically reasonable differential equation models as well as other types of deterministic models were augmented to incorporate the natural variability inherent in some of the systems observed (e.g. animal trajectories, weather, fire behaviour). It is likely that advances in forestry science and statistics will be made rapidly, if these types of approaches are emulated in other situations.

As this report will indicate, the outcome of this meeting was enhanced collaboration among these groups of researchers and an increase in energy and enthusiasm to solve open forestry-related statistical problems.

This report begins with a brief overview of the field (forest fire and forest ecology research). The next section gives summaries of the main presentations. The subsequent section highlights some of the progress made during the workshop; summaries of four roundtable discussions are contained there. This report concludes with an outline of the collaborations that are emerging as a result of this highly inter-disciplinary workshop. A brief bibliography is given at the end; a more extensive bibliography can be obtained from `http://www.stat.sfu.ca/~dean/forestry/BIRSBibliography.pdf`.

1 Overview of the Field

Forest fires are a natural component of many of Canada's forested ecosystems but they also pose threats to public safety, property and forest resources. Every year, forest fires cause millions of dollars worth of damage and force the evacuation of some communities. Such problems will be exacerbated as people establish more homes and cottages in and near forested areas and climate change alters forest vegetation and weather.

The forest fire research community has made steady progress over the past four decades, in increasing our understanding of the nature of forest fires. Mathematical models for predicting fire occurrence have been developed. Deterministic fire spread models are being implemented for planning purposes and for use in computer simulations to aid in prediction of the future behavior of existing and potential fires. Such models are used in conjunction with queueing models in the strategic management of fire-fighting resources such as aircraft and fire fighters. Although much has been learned about the interactions of weather and fuel-types and their effects on fire spread and intensity, a large number of questions remain. For example, how can jump-fires ignited by burning bark and other firebrands carried by the wind, in advance of a spreading fire, be modelled as a stochastic process? How can the fire hazard in particular areas be assessed reliably? What are the potential impacts of climate change on fire regimes and fire management systems? What are the effects of multiple interacting threats (e.g., insects attacks or pollutions levels) on fire risk?

The development of methods for mapping species abundance and diversity is important for forest management and conservation. It is important to understand how the conversion of old-growth forests to managed forests affects the structure, function, and species diversity of ecosystems and whether converted forests will eventually recover to a state that mimics many of the traits of old-growth stands. Methods for the development and dynamics of the ecosystems from a newly disturbed to an old-growth stand and the development of tools for predicting vegetation succession are of importance. In the short term, reliably projecting some specific important stand features is of importance. However, evolution to a substantial scale which will investigate stand dynamics for exploring environmental changes and for forest management is of essence.

2 Presentation Highlights

To ensure that there was sufficient time for formal and informal discussions of emerging and ongoing research collaborations, the number of long formal presentations was kept to a minimum. These talks are summarized in this section. It should be noted that there were also some shorter talks which were a part of the roundtable discussion. Some of the material presented in those talks is discussed in that section.

2.1 A stochastic space-time model for annual precipitation extremes – Jim Zidek

This talk began with a discussion of what is extreme. The answer depends on the context: engineering of bridges and dams might have a different notion than the EPA which monitors particulate concentrations. In all contexts, the notion of ‘return value’ is important. Return values are effectively extreme percentiles. For example, a 100-year return value corresponds to the 99th percentile.

The talk then centered on a Coupled Global Climate Model (CGCM) which combines ocean and atmosphere models, taking in various greenhouse gas scenarios as input. The response of interest is annual maximum precipitation levels in Canada (gridded at a resolution of 312 cells) based on data simulated from the CGCM. A spatially coherent distribution over the grid is required.

Data consisted of three independent simulation runs of hourly precipitation (mm/day) in 21-year windows (to look for trends):1975-1995, 2040-2060, and 2080-2100. This gives $21 \times 3 = 63$ annual precipitation maxima per grid cell.

Two approaches were considered to analyze these data: using multivariate extreme value theory; and using hierarchical Bayes.

For a single grid cell, the Fisher-Tippett generalized extreme-value distribution could be used to model precipitation extremes. The generalized Pareto was also suggested as a possible model. Other alternatives were also considered, but some were dismissed as unduly complex. All of these extreme value models possess shortcomings for this application. In particular, extending Fisher-Tippett to the multiple cell case leads to a large class of possible limit distributions, and extremes must be asymptotically dependent for large return periods. A point process approach was also considered but rejected because of difficulties in extending to the multiple cell case.

The hierarchical Bayes approach showed more promise, though it would not be effective for very extreme data. The idea was to approximate the joint distribution of (transformed) cell maximum precipitation data by a multivariate t-distribution. Specifically, the log-transformed data were assumed to have a multivariate normal distribution, conditional on their mean vector and variance-covariance matrix. Prior distributions were placed on these parameters: a multivariate normal for the mean vector and an inverted Wishart for the variance-covariance matrix, giving rise to a t-distributed posterior.

A cross-validation technique was used to assess the appropriateness of the model, in particular, the normality assumption. Using the hierarchical Bayes technique, contour plots of 10-year return values could be obtained, for example.

2.2 On Using Expert Opinion in Ecological Analysis: A Frequentist Approach – Subhash Lele

Many ecological studies are characterized by a paucity of hard data. Statistical analysis in such situations leads to flat likelihood functions and wide confidence intervals. Expert knowledge about the phenomenon under study is often available. Such expert opinion may be used to supplement the data in these situations.

One approach to incorporate expert opinion in statistical studies is via the Bayesian framework. This approach, aside from subjectivity in choosing prior distributions, faces operational problems. For example, it is difficult to formulate a precise quantitative definition of what characterizes an expert.

A frequentist approach to incorporating subjective expert opinion in statistical analyses can be taken. It may be easier to elicit data than to elicit a prior. Such elicited data can then be used to supplement the hard, observed data to possibly improve precision of statistical analyses. The approach suggested here also leads to a natural definition of what constitutes a useful expert. A useful expert is one whose opinion adds information over and above what is provided by the observed data. This can be quantified in terms of the change in the Fisher information before and after using the expert opinion. One can, thus, avoid the real possibility of using an expert opinion that adds noise, instead of information, to the hard data.

This approach was illustrated using an ecological problem of modeling and predicting occurrence of species. An interesting outcome of this analysis is that statistical thinking helped discriminate between a useful expert and a not so useful expert; expertness need not be decided purely on the basis of experience, fame or such qualitative characteristics.

2.3 A process approach to predicting tree mortality in surface fires – Sean Michaletz and Ed Johnson

This talk was concerned with predicting tree mortality using a heat transfer model of crown scorch. The model commonly used is due to Van Wagner (1973) which is an empirically-based model. It predicts that necrosis (death) height should be related to the $2/3$ power of the fireline intensity.

By considering physical characteristics of plume buoyancy and employing a lumped capacitance heat transfer model, a new heat transfer model can be derived which scales with fireline intensity in the same way as Van Wagner's model, but with no reliance on empirical data for its derivation.

Validation of components of this new model was demonstrated using empirical data from several experiments including wind tunnel measurements.

The proposed model is an example of how process models can be used to improve upon logistic models, which are empirically-based.

2.4 Synthetic Plots – David Brillinger

This talk began with the assertion that science needs appraisal methods. The idea of the synthetic plot goes back to Neyman who used it to assess the appropriateness of various models for the distribution of galaxies.

The synthetic plot is based on simulated data. Such a plot is set beside a plot of the observed data. Differences highlight problems with the model.

Sometimes a visual comparison is not adequate. It is preferable to base the comparison on some relevant statistic or set of statistics.

A first example involved Saugeen River (Ontario) monthly flow data to which a first order periodic autoregressive model was fit. The synthetic plot indicated some differences, but a spectral ratio revealed the difference more concisely.

Monthly numbers of fires in subregions of Oregon were next studied using a spatial logit model. Synthetic plots were then visually inspected. Nearest neighbour distance distributions for both the simulated and observed data were then compared to see any discrepancies.

Final examples concerned trajectory tracking for seals and elk. In these examples, Newtonian differential equations were used:

$$dr(t) = v(t)dt$$

where r denotes location and v denotes velocity.

$$dv(t) = -\hat{a}v(t)dt - \hat{a}\nabla H(r,t)dt.$$

$H(r,t)$ denotes a potential function and $\hat{a}$ is a coefficient of friction.

$$dr = -\nabla H(r,t)dt = i(r,t)dt$$

if $\hat{a} >> 0$.

Different choices of H can be used to model attraction or repulsion.

By appending a diffusion term, these equations can be made stochastic. Using an Euler scheme, they can be solved, and an approximate likelihood can be set up. Again, synthetic plots could be used to compare the observed data with simulated data from these models. The bagplot of Rousseuw et al (1999) was used to assist in the comparison.

2.5 The Use of Deterministic and Stochastic Fire Growth Models in Alberta – Cordy Tymstra

This talk was an introduction to the Prometheus project which is centered on a deterministic fire spread model which has been programmed and used to make predictions for fire growth in the Canadian Boreal forest as well as in other parts of the world.

The model is based on a set of differential spread equations which are derived from Huygens' principal of wavefront propagation. The equations are solved using a discrete Euler approximation where discretization points define certain ellipses; the envelope containing these ellipses defines the advancing fire front.

Mathematical difficulties involving choice of time step and vertex crossing were demonstrated. These difficulties were the basis for several discussions held after the talk (see the roundtable discussion section below, as well).

2.6 Empirical Modeling of Insect Wildfire Interactions in the Forests of the Pacific Northwest, USA – Haiganoush Preisler

In 2005 over 3 million hectares of U.S. federal lands were lost to wildfires, and there was a large amount of insect damage as well.

The combination of drought and bark beetle infestations in the southwest may make the 2006 fire season particularly devastating.

The hypothesis that insect-caused mortality increases fire risk has been around for almost a century (Hopkins 1909). It is not without controversy. Fleming (2002) suggested that more large fires occur within 3 to 9 years after a Spruce budworm outbreak. Bebi (2003) showed that areas affected by 1940 Spruce beetle showed no higher susceptibility to subsequent fires. Lynch (2004) showed that areas affected by Western Spruce budworm showed significant decrease in risk of forest fires.

This talk explored the relationship between insect infestation and fire size and frequency in the U.S. Northwest. A spatial multinomial distribution was used to model fire size class. Multinomial cell probabilities (at each spatial location) were estimated using semiparametric likelihood methods where covariates such as temperature, Palmer drought severity index and spruce budworm and/or bark beetle infestation levels. Maps of cell probability estimates were displayed for each of three size classes.

A multinomial model with ordinal categories was also considered, where the latent variable can be thought as a critical level of flammability. This technique seems to indicate that the probability of fires in the two larger size classes is related to area defoliated by insects; recent bark beetle infestations seem to increase the probability, while budworm infestations in 3-9 years in the past seem to have the opposite effect.

2.7 Modeling wildfire probability and impacts in British Columbia – Steve Taylor

This talk began with a review of the use of logistic regression in studying fire occurrence and its relation to several covariates including fuels, topography, weather and ignition sources.

Fires at the wildland urban interface were also discussed, using a modified Buffon's needle problem as a simplified model for interface fire risk.

This talk highlighted several issues and opportunities for statisticians to engage with the forest fire research community.

2.8 Introduction to Point Processes – Bruce Smith

Point processes are recognized as an important vehicle for beginning to understand and predict lightning and fire ignitions.

Within the group at BIRS were experts in the area of point processes. These processes can be used as models for fire events in time and space as well as for covariates such as lightning strikes. The key quantity that needs to be physically modelled is the point process intensity which is a generalization of the hazard function. Once this is specified, it is possible to use likelihood methods to fit point process models to data. Using a simple transformation involving the integrated intensity (compensator) leads to a useful diagnostic tool for assessing model adequacy.

There is interest in modelling compensators with covariates. Applying point process techniques to fire data is a goal of several of the participants.

This talk introduced the basics of point processes. It was pitched to the graduate students in the audience as well as the forestry researchers who might benefit from knowledge of some of the key concepts. The focus was on homogeneous and inhomogeneous Poisson processes and the Meyer-Papangelou transformation. The use of this transformation in assessing goodness of fit was demonstrated.

2.9 Fire History Evidence from Natural Recorders – Rick Routledge

Recent uncontrollable fires in such places as the Okanagan Valley in British Columbia and the mountains above San Diego, California have cast doubt on the wisdom of universal suppression of forest fires. By attempting to eliminate fire from the landscape, we may simply be allowing the fuel supply to build to the point where a major conflagration becomes virtually inevitable. It is widely believed that minor fires were once common in dry forests, and that aboriginal populations may have used deliberate broadcast burning to manage the landscape. Yet quantifiable evidence on fire history is elusive.

Natural recorders, specifically fire-scarred trees and lake sediments, in generate evidence on the fire history of the dry ponderosa pine forests of western North America. Statistical challenges in interpreting this evidence were highlighted.

2.10 Statistical concepts and methods in forest fire history studies – Bill Reed

This talk began with a review of some of the fire history concepts and definitions, noting ambiguities and contradictions in some cases and revising certain definitions. The use of scar data (from surface fires) and time-since-fire-map data in estimating historical fire interval was discussed. Change point identification and testing was also considered.

Concepts considered were hazard of burning which corresponds to the usual hazard rate at a given location; the fire interval which is the expected time between fires at a point (reciprocal of the hazard if constant); annual percent burn; and fire cycle – the time to burn an area equal to that of a study area.

The notions of fire cycle and fire interval are frequently interchanged in the literature, but this is due to deterministic thinking. The two concepts are really quite different. The annual percent burn is a random variable; thus, the time to burn an area equal to that of the study area, is also a random variable. Hence, fire cycle not well defined.

An attempt to rescue the fire cycle definition by means of its expected value was considered. Other revised definitions were an area-wide hazard of burning

$$\Lambda = \lim_{\Delta \to 0} \frac{1}{\Delta} P(\text{fire in the study area in } (t, t+\Delta))$$

A temporal homogeneity is required for this definition to make sense, i.e. to be independent of t. A local hazard of burning is defined as

$$\lambda(x) = \lim_{\Delta \to 0} \frac{1}{\Delta} P(\text{fire at location } x \text{ in } (t, t+\Delta))$$

Assuming spatial homogeneity, one can write

$$\text{FI} = \frac{1}{\lambda}$$

for the definition of the fire interval (FI).

Assuming a Poisson process $N(t)$ for the times of fires in the study area, the time to burn an area equal to that of the study area A is

$$\min(t : S_t \geq A)$$

where $S_t = X_1 + \cdots + X_{N(t)}$. The X's are assumed to independent and identically distributed fire areas. Applying Wald's theorem, it can then be shown that

$$E[T] \geq FI.$$

Note that $E[T]$ is the revised definition of the expected fire cycle (EFC).

For exponential fire sizes, it can be shown that

$$EFC = FI1/\Lambda$$

which means that if fires are fairly infrequent (small Λ) the expected fire cycle (time to burn an area equal to study area) could be considerably larger than the expected fire interval (time between fires at any location). Thus, fire cycle and fire interval do not coincide except for constant sized fires.

The upshot of this discussion is that the notion of fire cycle is not well-defined and should be abandoned. Notions of local hazard of burning and its reciprocal, the fire interval, are preferable measures of fire frequency.

The second part of the talk demonstrated quasilikelihood estimation of a fire interval using scar data, assuming a constant area-wide hazard of burning. Using an overdispersed binomial model for the number of scarred trees (stratified by time epoch), it is possible to set up an EM algorithm to estimate the fire interval. The method was demonstrated on data from Mexico.

The third part of the talk was devoted to considering what happens when the local hazard of burning is clearly not temporally homogeneous. In that case, piecewise constant local hazards were considered within a penalized likelihood framework, in which the Bayesian Information Criterion was used. The method was applied to several data sets from Alberta and Montana.

3 Scientific Progress Made

A unique feature of this workshop was the extensive use of the roundtable format. There were roundtable discussions on four themes: fire ignition and spread, forest management, forest inventory data and ecology.

3.1 Fire Ignition and Spread

Specific Projects

1. Work has begun on a 2-D renewal process which was proposed by Ivanoff and Merzbach (2005). A statistics graduate student has begun to simulate the process for simple cases using the algorithm described in a recent paper of Ivanoff (2006). Her next goal will be to fit this model to various data examples using a likelihood approach. Ultimately, a flexible model may be fit using local likelihood methods.

2. Some statisticians are considering a simple Poisson cluster model for lightning. It involves a nonlinear curve which specifies a lightning track and point events which are located according to a bivariate Gaussian distribution centered at Poisson locations on the track. The track can be estimated using smoothing methods, and the bivariate distribution can be estimated from the residuals. The model has been applied to a small amount of data from the Province of Ontario with mediocre results (using the synthetic plot idea of Neyman, and updated by Brillinger). More meteorological information is required to improve upon this model. Forestry researchers are starting to collaborate on this project and will provide additional lightning data as well as covariate data (e.g. 500 mb measurements).

Fire Perimeter Modelling

Work is proceeding on fluid queue approximations to fire perimeters. These approximations are convenient and are potentially operationally useful. In particular, relations between perimeter predictions and resource allocation will be studied in future.

3.1.1 Fire Spread – Prometheus

Cordy Tymstra is the project leader of the Prometheus fire growth model. This is a deterministic model based on differential equations derived from Huygens' principle of wave propagation. Points of an ellipse are propagated forward according to covariate information including wind direction and speed.

There are a number of issues connected with this model which need to be addressed:

1. **incorporating stochasticity.**

   There are a number of proposals here to be followed up on.

   (a) Conversion of DEs to SDEs.

   (b) Using computer modelling experiments to calibrate the model and estimate standard errors (or their analogue in this setting).

2. **generating spotfires.**

3. **an algorithmic geometry problem.**

   The movement of vertices on the ellipses can sometimes cause awkward cross-overs which can lead to unrealistic patterns. Handling these anomalies is related to a classic problem in geometry related to winding numbers and a point in polygon problem. Cordy Tymstra is giving Tanya Garcia instruction on the background of this problem. This problem will be presented at the PIMS Industrial Problem-Solving Workshop in Vancouver at the end of June. A graudate student in statistics will pursue this problem as part of her MSc project this summer.

3.1.2 Fire Spread – Markovian Lattice Model

A group of statisticians are working on a stochastic spread model based on a continuous time Markov chain. Neighbours 'infect' each other with fire. The principal advantage to this approach is the more natural way of allowing for fire spotting.

Model validation is required. One way that this will be done is through comparisons with simulations coming from Prometheus.

The spotting mechanism will be refined upon using data from Cordy Tymstra and his group.

Incorporating some of the ideas from the lattice model to Prometheus to achieve stochasticity is an emerging goal from this workshop.

3.1.3 Fire Spread – Percolation Model

There was a suggestion that a subcritical percolation model for fire spread may be useful for studying certain ecological questions. These models are time-independent which means that they cannot be used for real-time spread prediction. Their value would be in providing a 'mean-type' measure of fire activity for a given fire.

Opposition to this idea stemmed from the idea that such a model would not be of management interest. Process-driven models may be ultimately of more use in scientific work, but the percolation model may be easier to fit to existing data.

[Note: There was considerable discussion regarding the potential uses of such models. There was also warning that these models are not necessarily accurate across varying time-scales.]

3.1.4 Prescribed Burns

Causal modelling of prescribed burns is a difficult problem. An ignorability assumption is required in order for the methodology to work; this assumption is likely not reasonable. There are likely unmeasured confounders, but what are these?

Propensity score analysis provides a possible way around these problems.

3.2 Forest Management

The focus of this discussion was on problems in estimating the economic value of fire suppression, though other aspects of management were addressed as well. There were three short presentations followed by a general discussion.

The first presentation was concerned with spatial planning incorporating uncertainty. Spatial harvest scheduling presents a tough combinatorial problem. The solution presented was to use a stochastic programming model to generate scenarios. Even a deterministic approach is difficult.

The second presentation was concerned with resource-sharing among government provincial, federal and territorial fire fighting agencies. Resources include equipment and personnel. Risk sharing models were discussed; a balance is sought between sharing and keeping fire fighting resources at the home location. Balancing mitigation and suppression is also an objective.

The third presentation focussed on fire suppression. An important question to study: for the fires that we know happened, what would have happened if fire suppression had not been practiced? Observations made during the presentation:

1. Considering arrivals (fires detected and reported) vs year (about 1968-1998), there is an increasing trend, but with extremes and high annual variability.

2. Fire suppression effectiveness in Alberta: The relation between escape probability versus year appears to have a discontinuity at 1983 due to a change in strategy involving a specialized technique for allocation of resources (crews located in areas of high risk). Generally, there is a decrease over time due to increased effort.

3. Estimating the area preserved: there appears to be a strong positive linear relationship between log(area burned) and log(# escaped).

Discussion centered around questions of whether the record was long enough to take climate change into account and whether covariates would help in answering the guiding question. In particular, the surface water temperatures in the North Pacific would help to account for the Pacific decadal oscillation (dragged out El-Nino effect). More analyses could be done.

In evaluating the effect of fire suppression, the role of the type of area where suppression is practiced and the role of other covariates were further considered. For example, different strategies of fire suppression are practiced in Northern and Southern Saskatchewan. Studies in a homogeneous region of Ontario which straddles the intensive/extensive fire suppression boundary will help to clarify the question about the role of suppression since confounding variables do not come into play. A reminder was given of the importance of thinking about how fires get started, how they go out, the use of extinction models, and taking into account covariates.

3.2.1 Other questions to consider

If we were to look afresh at the specific topic for the roundtable we might ask questions such as: What are the indicators of economic value? How should the high and low priority areas that are an integral part of suppression strategies be taken into account? If a higher number of fires is part of the scenario of climatic change, does this change the definition of priority area?

3.2.2 The role of statistics education

Impediments to progress for each of the two groups (broadly classified) who are participating in the workshop were stated to be:

- An impediment for statisticians working on these problems is data related. There is a need for a reasonably good set of data to use in developing models. This could be seen as providing the opportunity to develop a suite of techniques that could be broadly applied.
- An impediment in forestry is the question of how to link analyses provided by the models to the real questions of interest. The answer to this would seem to be networking. Partnerships are important. Statisticians working alone cannot ask the right questions for formulating the models. The discussion took several directions: Developing the collaborative ethic.
- One model for getting the interaction needed are the workshops run at NCAR which brings young investigators together, since early in the career the scientist is provided with a collaborative experience.
- Encourage Statistics PhDs to do Post Docs in other areas, when appropriate, jointly supervised by a specialist in the chosen area and a statistician.
- The idea of a new training environment, bringing together epidemiology and statistics, is being put forward in health area and has been received positively by CIHR and NSERC. Comments on the issues related to teaching statistics:
- Sometimes it is the way the course is taught. We would like to have scientists excited about statistics and statisticians excited about science.
- There has been a move towards statistical science, a broader definition of the discipline.
- A proper mathematical statistics background is still important. The message should be that you cannot understand statistics without understanding the math and you can understand the math.
- The sciences, including applied science, are having difficulty keeping quantitative methods in the curriculum.
- Math is the problem. Without it students cannot go beyond the first introductory course.

Two big gaps in representation of the disciplines in forest fire research were identified: statisticians and social scientists.

3.3 Use of Forest Inventory Data for Assessing Historical Fire Regimes

Most of the discussion here centered on the objective of assessing historic fire regimes so as to inform management decisions regarding attempts to generate a 'natural' mosaic of stand ages in the forest landscape.

Forest inventory data can provide relevant information, but there are major concerns associated with inaccuracies in estimates of stand age from aerial photo interpretation. Not only are the ages of stands often substantially in error, but the stands themselves can be incorrectly delineated. These difficulties could cause major errors in estimates of historical fire regimes.

Ideas for developing solutions:

- Supplement the inventory data with spot checks for accuracy.
- Rely more heavily, possibly exclusively, on random sampling for spot data.
- Adapt methodology for misclassification errors developed elsewhere, e.g. in epidemiology.
- Make particular use of more reliable data on locations of more recent fires.

Several participants questioned the appropriateness of the goal. The 'natural' landscape has evolved over time, and a failure to recognize this has led to confusion. In addition, this misconception could well lead to inappropriate targets since changes to uncontrollable factors such as the climate may render the problem of attaining such a goal ill-posed.

Further discussion centered on the value and achievability of the alternative goal of managed forests with a uniform distribution of stand ages.

3.4 Ecology

Ecology problems under investigation include modelling of forest succession, species occurrence including interacting disturbances: fire, mountain pine beetle, timber harvest and climate change.

A number of researchers are investigating the problem of Mountain Pine Beetle infestation in BC and Alberta. A number of questions are under study:

- How can future infections be mitigated?
- How have the structure and value of wood changed after infestation?
- How does the fire hazard change over time?
- How does the beetle spread?
- What are the important factors determining spread?
- What underlying mechanisms determine spread?

It was noted that planting of trees outside their natural distribution boundaries is being considered carefully in Germany with regard such infections; it was also noted that there is some evidence with regard to long-distance dispersal by wind, and fair evidence that climate is a relevant factor; small-particle dispersal models may be helpful.

Another important problem under investigation is that of modelling beetle/fire interactions.

A major challenge in the statistical modelling of forestry ecology data is the use of different spatial resolutions when data have been collected. Work is proceeding on the spatio-temporal modeling when response and covariate data are at different spatial scales.

4 Outcome of the Meeting

The goal of the meeting was to foster collaborations among forestry researchers and statisticians. The following is a partial list of emerging collaborative initiatives:

- Lightning tracking. Potential collaborators: Cordy Tymstra, Mike Wotton, Rolf Turner, Doug Woolford, and John Braun. A follow-up meeting was held in Toronto in July, 2006.
- Fire spread. Potential collaborators: Cordy Tymstra, Mike Wotton, Reg Kulperger, Dave Stanford and John Braun are studying possible linkages between the Prometheus fire growth model and the stochastic growth model. A follow-up meeting has been scheduled for Toronto in June, 2007.
- Related to the project above is a mathematical problem which has been submitted to the PIMS Industrial Problem Solving Workshop to be held in June, 2007 at Simon Fraser University.
- Wildfire Analysis: Dave Martell and Haiganoush Preisler.
- Modeling of fire and insect risks and modeling of dual risks of fire following insect outbreaks. Potential collaborators Steve Taylor, Subhah Lele, Charmaine Dean, Haiganoush Preisler and Farouk Nathoo.
- Spatial covariance analysis of historic fire weather, Potential collaborators Steve Taylor, Sylvia Esterby.
- Morphometric modeling for forest fire spread. Potential collaborators: Subhash Lele, John Braun.
- Boreal Bird-Habitat Study. Potential collaborators: Steve Cumming, Charmaine Dean, Subhash Lele, Laurie Ainsworth, Jason Nielsen, Farouk Nathoo. A followup meeting will be held in the Fall, 2006.

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