Translating Mountain Pine Beetle Genomics Outputs into Genomics-Enhanced Environmental and Economic Risk Models

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BACKGROUND

A sustainable, predictable, optimally allocated supply of forest feedstock for traditional and new products is crucial for continued viability of Alberta's forest industry. Mountain pine beetle (MPB) affects both sustainability and predictability of Alberta's pine inventory, and also impacts end use of this timber supply. This devastating forest pest is typically associated with lodgepole pine and had primarily been restricted to British Columbia in Canada, but has recently spread beyond the lodgepole – jack pine hybrid zone into the jack pine forests of north central Alberta (Cullingham *et al.* 2011). Consequently, even more of Alberta's pine inventory is now at risk of mortality (ASRD 2011). While the climate of these northern Alberta forests was once considered marginal or unsuitable to sustain MPB populations (Nealis and Peter, 2008), the magnitude and range of the current outbreak suggests that this may not be as valid an assumption as previously thought (James *et al.* 2011).

Surprisingly, there are no published predictive MPB spread models that take into account both path and rate of spread, which is key to developing efficacious management strategies. We propose to develop a MPB spread model that will provide predictive capacity for assessing risk of MPB spread in Alberta's forests. Lack of robust MPB spread models also limits the ability to develop optimal allocation economic models for forest inventory during MPB outbreaks. We propose to use the MPB spread model in developing economic risk models that allow for determination of optimal allocation of forest inventory under scenarios of MPB outbreaks. These economic models will also examine the impact of spread control measures.

Central to development of an effective MPB spread model is understanding the role that climate plays in MPB population dynamics. While many models employ a climatic suitability index, this index does not take into account the genetics of MPB or the pine host, both of which could influence MPB population dynamics. For example, northern and southern populations of MPB are genetically distinguishable (Samarasekera *et al.* in revision); do these populations show different migration patterns or respond differently to climate variables? Is MPB undergoing genetic selection within any geographic portion of the current outbreak to become more adapted to cold? Similarly, it is possible that stresses imposed upon the tree by environmental factors such as drought may affect MPB dynamics by affecting host defenses against attack by this forest insect pest (Lusebrink *et al.* 2011). The distribution of lodgepole pine, jack pine and their hybrids could also affect MPB spread. Recent research indicates changes in the environment may modify ranges for many forest tree species in Alberta (Gray & Hamann 2011). These possible range shifts could generate uncertainties in long-term management and reforestation strategies, even in the absence of future MPB outbreaks.

We are currently generating large-scale genetic (i.e. genomic) datasets within the presently-funded Tria 2 project. This project is scheduled to end in September 2012. These data are uniquely suited to address the question of how the genetics (genomics) of MPB and pines might influence MPB spread, which will inform development of the proposed MPB spread model, and in turn, the economic risk models. Many of the outputs arising from the tree genomic analyses are also expected to directly inform the economic risk modeling process. New funding would enable us to fully exploit these fundamental genomics data, translating the outputs into novel, integrated genomics-enhanced spread risk and economic risk assessment tools for more effective forest resource management. Importantly, these tools will account for variability in climate and the environment. In addition to producing the next generation of integrated management tools, we aim to facilitate knowledge transfer to industry and government representatives of the forest sector through enhanced outreach activities.

PURPOSE AND OBJECTIVES

There are three main goals within this project. (1) Determine if genetic variation in MPB or pines influences risk of MPB spread eastward across the boreal forest, particularly under different climate scenarios. (2) Develop MPB spread risk and economic risk models that incorporate outcomes from the genetic analyses, and are in turn used to inform a comprehensive MPB risk assessment strategy. (3) Transfer knowledge to stakeholders and end users.

These goals will be addressed through five major objectives:

OBJECTIVE 1: Assess genetic variability in pine and MPB over the range of current and potential spread, and the potential influence of signatures of selection and/or adaptation on MPB spread.
OBJECTIVE 2: Identify whether species and/or water limitation affect pine tree defense capacity, and thus influence MPB spread.
OBJECTIVE 3: Develop genomics-informed MPB spread models that can be used to assess risk of MPB spread across Alberta and invasion into additional provinces.

OBJECTIVE 4: Develop economic risk models that focus on issues arising from continued eastward invasion of MPB.
OBJECTIVE 5: Develop and deliver an outreach programme.

METHODS OVERVIEW

This proposed project leverages large scale genetics (i.e. genomics) datasets being generated through the currently-funded Tria 2 project. Here, we propose to conduct comprehensive multivariate analyses of these data to ensure that these rich, complex datasets are fully exploited, and that outputs inform spread and economic model development.

OBJECTIVE 1: Datasets for hundreds of MPB and pine individuals that quantify genetic variability at hundreds of genes for each individual will be analyzed using Bayesian and Fst outlier approaches (Narum & Hess 2011). Analyses will focus on MPB and pines collected at the leading edge of the outbreak, as well as jack pine sampled across a region spanning from Alberta to Ontario. The analyses will reveal signatures of selection and/or adaptation; such signatures are indicative of spatial genetic heterogeneity in the host. Spatial correlations between these data and climatic, geographic and environmental factors will be assessed (e.g. James *et al*. 2011) to estimate adaptive potential across the range.

OBJECTIVE 2: Analysis of microarray datasets profiling expression of thousands of genes in jack and lodgepole pine comparing responses to MPB vectored fungi under different water levels will be analyzed to determine if there are key differences between species in their defense responses and/or resource utilization, particularly under water stress. Data will be analyzed as described by El Kayal *et al*. (2011), and then integrated with existing physiological data. Multivariate approaches will then be used to identify relationships between these datasets.

OBJECTIVE 3: The pattern of invasive spread from 2001 to 2011 will be described using a Bayesian Conditional Autoregressive model of annual rates of population growth and spread as a function of key landscape variables, including climate, forest structure, topography and host tree and MPB genetics.

OBJECTIVE 4: Monte Carlo simulation/decision tree models will be developed to examine spread control effects on forest sector timber supply and expected net present values under different scenarios, with a focus on eastward spread through jack pine.

OBJECTIVE 5: A communications director will (a) establish linkages with representatives of key end user groups, particularly from industry and provincial government; (b) arrange regular face-to-face and computer-assisted meetings with these end-users for feedback on scientific progress, (c) organize regular meetings for dissemination of key outcomes from the research, (d) as possible, arrange technology transfer.

RESEARCH OUTCOMES

1. Answers to the following:
(a) is genetic variation associated with spatial heterogeneity in pine susceptibility to successful MPB colonization, reproduction and/or fitness;
(b) are there genomic signatures that suggest rapid adaptation of MPB to marginal habitats, such as on the leading edge of the current outbreak;
(c) are there relationships between pines, MPB, climate and/or environmental features that could affect MPB population dynamics now or in the future?
2. Arising from outputs of (1), recommendations on appropriate genetic pine stock for reforestation within specific MPB impacted regions, and user-friendly diagnostic genetic markers to facilitate identification of appropriate stock.
3. Genomic-enhanced MPB spread risk models that more accurately predict MPB spread in Alberta, based on inputs from (1).
4. Economic impact on forest sector due to MPB spread and potential benefits/costs of spread control based on inputs from (1-3).
5. Together, (2-4) constitute an integrated suite of MPB impact mitigation tools to present to industry and government for informed forest management.

Commercialization: We currently have genetic markers that distinguish between lodgepole, jack and hybrid pines. These and any additional pine genetic markers identified during the proposed study that are associated with potential adaptation and could therefore inform reforestation stock suitability will be provided to our industry partner, IgY, for development of patentable, cost-effective, user-friendly, diagnostic marker chips. These chips can be commercialized for use by nonspecialists in research, government or industry.

BENEFITS

This proposal has a very favourable risk-reward margin: the data will have been obtained by the outset of the project, shortening the timetable for translation to useful outputs for industry and government. Our team will continue to break new ground through innovative analyses of these complex genomics datasets, positioning AB as a leader in landscape-level genomics. Short term benefits to industry and the province include a direct method to assess feedstock suitability for reforestation given changes in environmental suitability and potential for insect pest outbreaks, resulting in a long term forest management strategy that is adaptable to changes in landscape and supply parameters. This progressive approach will maintain AB as a leader in sustainable forest management. Environmental and social benefits will result through maintenance of healthy ecosystems and by ensuring the security and future of an important livelihood for many Albertans.

Economic risk models will allow the forestry sector to remain profitable in changing and challenging economic conditions. This cutting edge approach to feedstock assessment will put AB at the forefront of forest management, taking the lead in development of inter-jurisdictional forestry issues. The economic risk models will allow for realistic estimations of the expected range of possible losses in profitability and future benefits from the forest sector in Alberta due to the invasive spread of MPB. The model will identify uncertainties about MPB impact on timber supplies and market uncertainties. These analyses will give an estimation of the range and distribution of possible outcomes in forest sector losses rather than single point estimates, providing a more realistic picture. Spread control costs and effectiveness models will be linked to the economic risk model. An outcome of this modelling will be a chart of the minimum spread control effectiveness rates and maximum costs that can pass basic economic criteria for sound investment. The spread control model can be linked to the rest of Canada so that forest sector values threatened by MPB can be modeled as MPB spreads eastward. This will allow us to account for potential extra-jurisdictional costs of MPB spread and benefits of MPB spread control in our model. This is vital because economic justification for invasive spread control resources may not be possible based on threatened Alberta forest sector values alone.

Given the value and the direct benefits of this research to the forest industry, we will employ a communication director who will enhance connections with industry and as well as connections that we already have with government. The applicability of research outcomes to stakeholders can be improved when the community provides feedback to ongoing efforts. Through their outreach efforts, the communications director will provide an avenue for ongoing dialogue with stakeholders allowing such feedback to be incorporated. Avenues will also be developed for dissemination of this knowledge to stakeholders and end users. Ultimately, this enhanced connection will allow for a direct translation of knowledge to a broad end-user community and bridge the gap between research and industry.

LINKAGES WITH OTHER FRI MBPEP-FUNDED PROJECTS

We have developed preliminary linkages with two FRI MBPEP-funded projects; one lead by Dr. Kathy Lewis and another led by Dr. Kathy Bleiker. We intend to strengthen the linkages between this proposed project and these funded projects if we are invited to submit a full proposal.

Dr. Kathy Lewis. Dr. Lewis is a formal collaborator on the Tria 2 project. Her research on post-mortality pine decay following MPB attack is a central input into the economic risk models developed by Dr. G. Hauer and his team, and helps to link the population dynamics models developed by Dr. B. Cooke and his group with the economic risk models. If this project is funded, it would enable us to further strengthen the linkages between Dr. Lewis' research and the modeling proposed here.

Dr. Kathy Bleiker. Dr. B. Cooke is a formal collaborator with Dr. Bleiker on her Alberta-based research project. We have also discussed the possibility of genotyping materials for Dr. Bleiker using the genomics tools described in this research proposal to support her research project. We intend to explore these linkages in more detail.

TIMELINE

Project year			Y1				Y2				Y3			
MM/YY to MM/YY			04/12 to 03/13				04/13 to 03/14				04/14 to 03/15			
Start Date	**End date**	**MILESTONE RESULTS**												
ACTIVITY 1: Pine population genomics (J. Cooke, Coltman)														
04/12	03/14	1.1 Pine sequence analysis	■	■	■	■	■	■	■	■				
04/12	03/14	1.2 Pine genotyping analysis	■	■	■	■	■	■	■	■				
04/13	12/14	1.3 Integrated analysis with outputs from pine functional and MPB genomics					■	■	■	■	■	■	■	
ACTIVITY 2: Pine functional genomics (J. Cooke)														
04/12	03/13	2.1 Gene expression analysis (microarray and qRT-PCR)	■	■	■	■	■							
10/12	06/13	2.2 Integration with physiological data			■	■	■	■						
ACTIVITY 3: Mountain pine beetle population genomics (Sperling, Coltman)														
04/12	03/14	3.1 MPB sequence analysis	■	■	■	■	■	■	■	■				
04/12	03/14	3.2 MPB genotyping analysis	■	■	■	■	■	■	■	■				
ACTIVITY 4: Development of genomics-enhanced ecological risk models (B. Cooke, Lewis)														
04/12	03/15	4.1 Incorporation of genomics information for development of improved MPB spread risk models	■	■	■	■	■	■	■	■	■	■	■	■
ACTIVITY 5: Development of improved resource utilization models (Hauer)														
04/12	03/15	5.1 Development of improved resource utilization models	■	■	■	■	■	■	■	■	■	■	■	■
ACTIVITY 6: Outreach, communication and research translation to end users (Cooke, communications director)														
04/12	03/14	6.1 Identify and approach representatives of key end user groups	■	■	■	■	■	■	■	■	■	■	■	■
04/12	03/14	6.2 Translation/outreach meetings with representatives of the end user community				■		■		■		■		■

BUDGET

Breakdown by Funding Partner:

Eligible costs	(A) Applicant / Other contributions		(B) Foothills Research Institute MBPEP		(A+B) Total Cost
	Cash ($)	In-kind ($)	Cash ($)	In-kind ($)	
1. Salaries and benefits	$ 775,750	$ -	$ 100,000	$ -	$ 875,750
2. Consumables	$ -	$ -	$ -	$ -	$ -
3. General and Administrative Costs	$ 74,250	$ -	$ -	$ -	$ 74,250
4. Equipment	$ 40,000	$ -	$ -	$ -	$ 40,000
Totals	**$ 890,000**	**$ -**	**$ 100,000**	**$ -**	**$ 990,000**

Funding requested from the Foothills Research Institute MPBEP will support salary of one postdoctoral fellow involved in risk modeling and of the project manager/communications director to pursue outreach activities and engage the stakeholder and end user communities. The postdoctoral fellows will advance research on five strategic themes in direct support of project objectives: 1) Pine population genomics, 2) Pine functional genomics, 3) MPB population genomics, 4) Environmental risk modeling, and 5) Economic risk modeling. The project manager/communications director will coordinate scientific and financial reporting to the funders and co-funding agencies and undertake research translation activities by directly engaging stakeholders (e.g. one-on-one meetings, hosted workshops).

Detailed justification:

1. Salaries and benefits **$875,750**

a. 5 postdoctoral salaries: 11.75 FTE x $49,000/FTE $575,750
(Year 1: 5.0 FTE; Year 2: 4.5 FTE; Year 3: 2.25 FTE. Total of 11.75 FTE)
b. Project manager/communications director: 3 FTE x $100,000/FTE $300,000

2. Consumables **$0**

3. General and administrative costs **$ 74,250**

a. Travel (conference/outreach), networking, and workshop hosting costs $ 49,250
b. Publication costs $ 25,000

4. Equipment **$ 40,000**

a. Software support (annual site licenses, support packages) $ 40,000

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