MPBSpread: a spatially explicit cellular model

A tool to evaluate the efficacy of current and alternative management actions to control the spread of Mountain Pine Beetle

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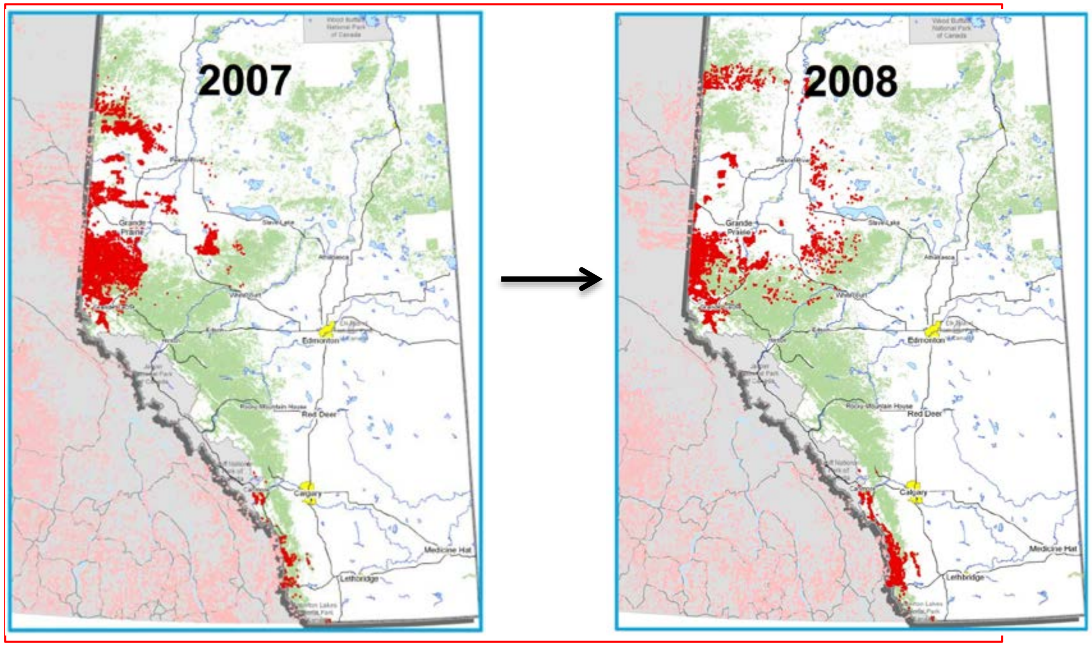
MPBSpread
Model structure

A spatially explicit model designed to simulate the spread of MPB across a large forested landscape over a 10 to 20-year time horizon. It has a cell-based representation of the landscape. Each cell is 400m*400m (16-ha) in size.

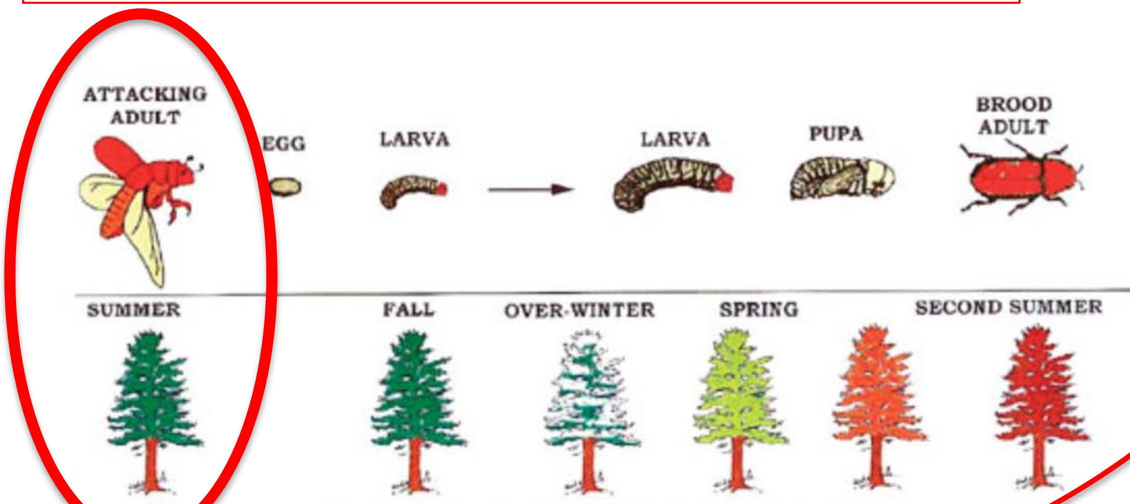
The model calculates from one year to the next:

(a) MPB reproduction and associated pine mortality within a cell, and
(b) The probability of colonization from an occupied cell to suitable but unoccupied 'recipient' cells.

MPBSpread is also stochastic: Actual colonization events are triggered as binary events (colonized, or not) by a randomization process. It is this between-stand spread that is the main focus of the model.



Dispersal between and within stands



MOUNTAIN PINE BEETLE LIFE CYCLE

Mortality

Model structure

The model is used to calculate $P_{i,t}$, the probability of successful MPB colonization of a given unoccupied cell, *i*, in year, *t* :

$$P_{i,t} = HQ_i \sum_{j=1}^{n} (BEF_{j,t} \cdot G_{j,t} \cdot W_{i,j})$$

HQ_i is the habitat quality of an unoccupied cell.

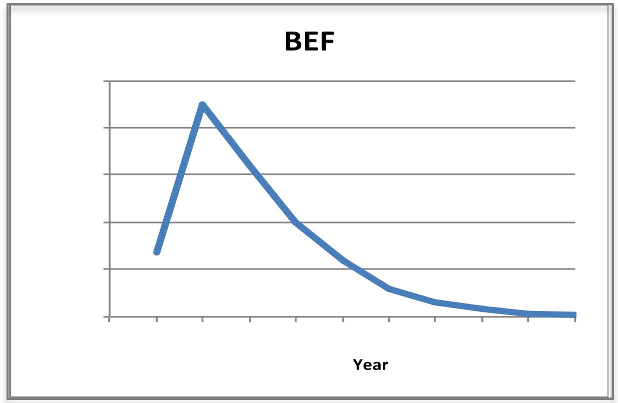
Collectively, the terms inside the summation represent the probability of beetles from an occupied cell, *j*, infesting an unoccupied cell within a given year:
$BEF_{j,t}$ is a Beetle Export Factor, an index of annual dispersal from an occupied cell;
$G_{j,t}$ a directional scalar accounting for wind direction; and
$W_{i,j}$ a distance weighting factor between an occupied cell and a given unoccupied cell. All terms are scaled between 0 and 1.

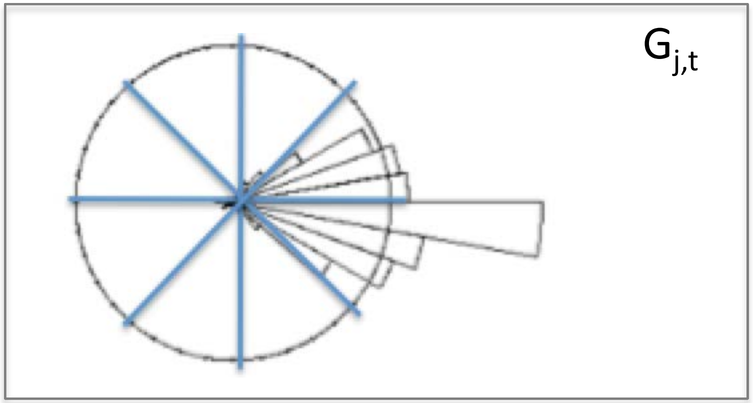
Model structure: $$P_{i,t} = HQ_i \sum_{j=1}^{n} (BEF_{j,t} \cdot G_{j,t} \cdot W_{i,j})$$

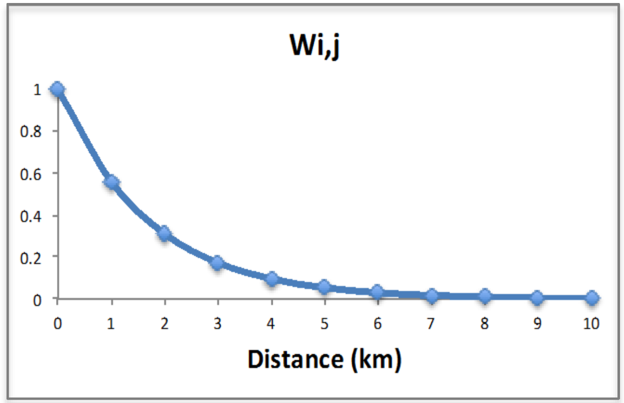
The model is used to calculate $P_{i,t}$, the probability of successful MPB colonization of a given unoccupied cell, *i*, in year, *t* :

$HQ_i = P \bullet A \bullet D \bullet L$

- P = Percentage of susceptible pine
- A = Age
- D = Density
- L = Location factor



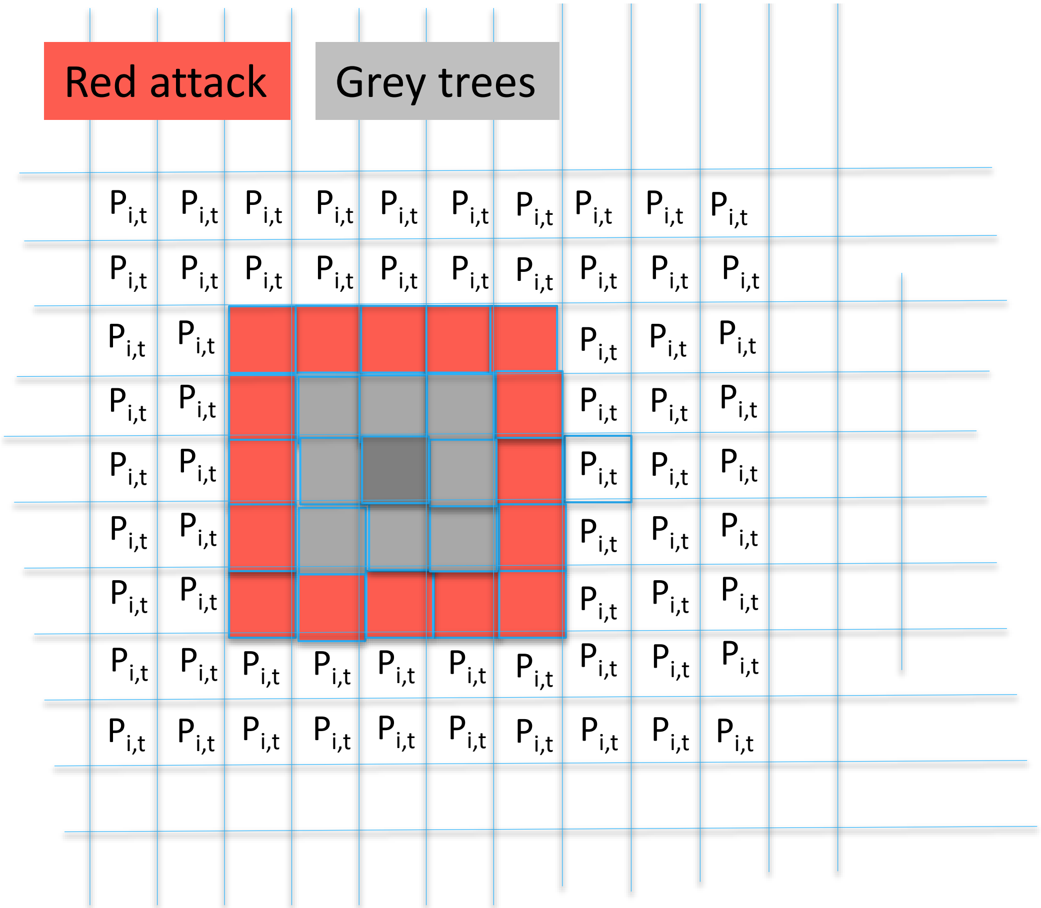


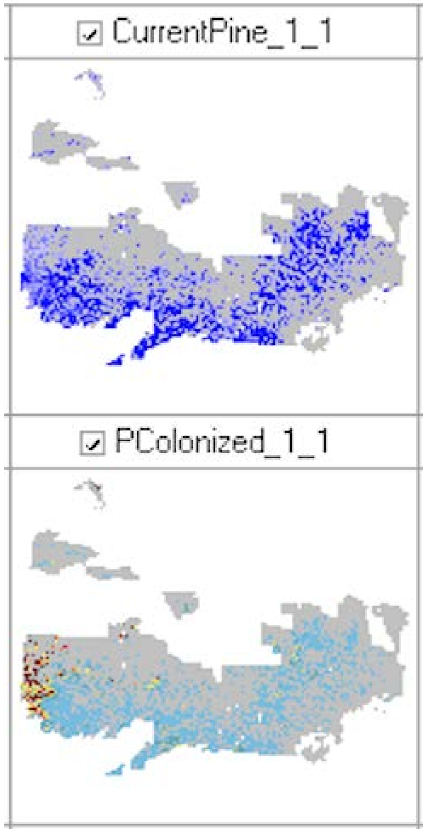


The basics of MPBSpread

1. Calculate the probability of infestation for all cells in a given year, $P_{i,t}$

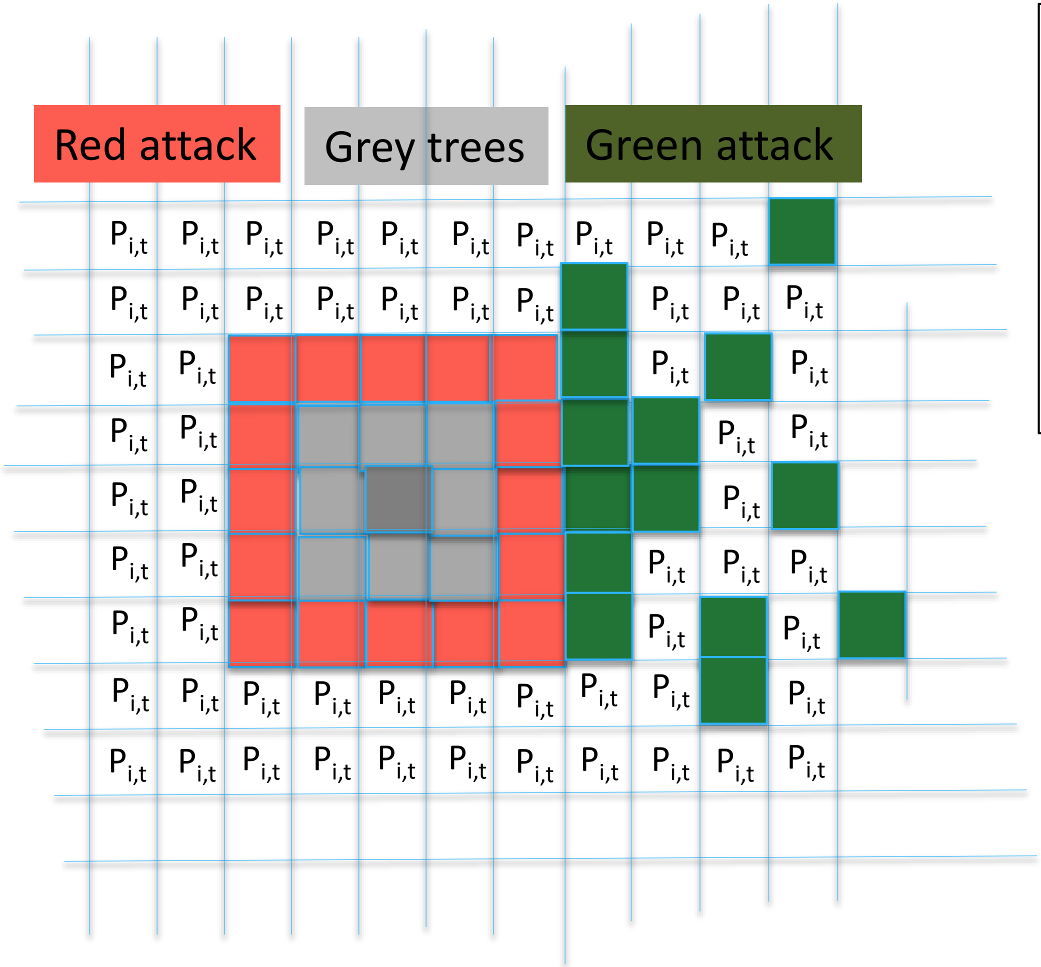
$$P_{i,t} = HQ_i \sum_{j=1}^{n} (BEF_{j,t} \cdot G_{j,t} \cdot W_{i,j})$$

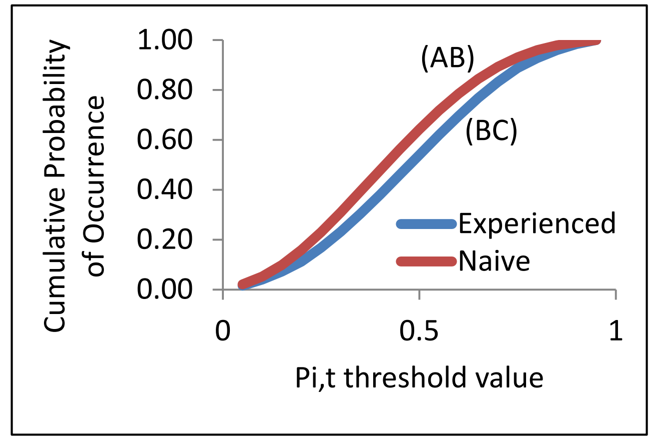


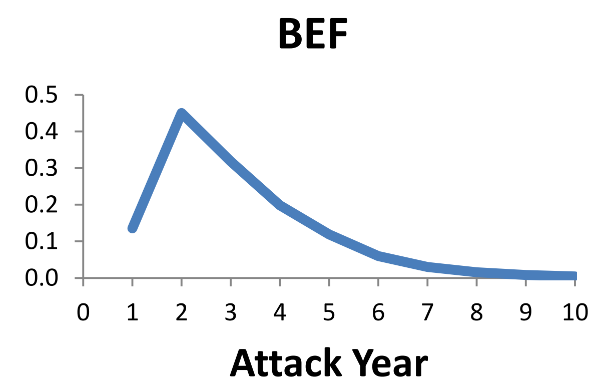


The basics of MPBSpread

2. Translate probabilities ($P_{i,t}$ values) into actual colonization events

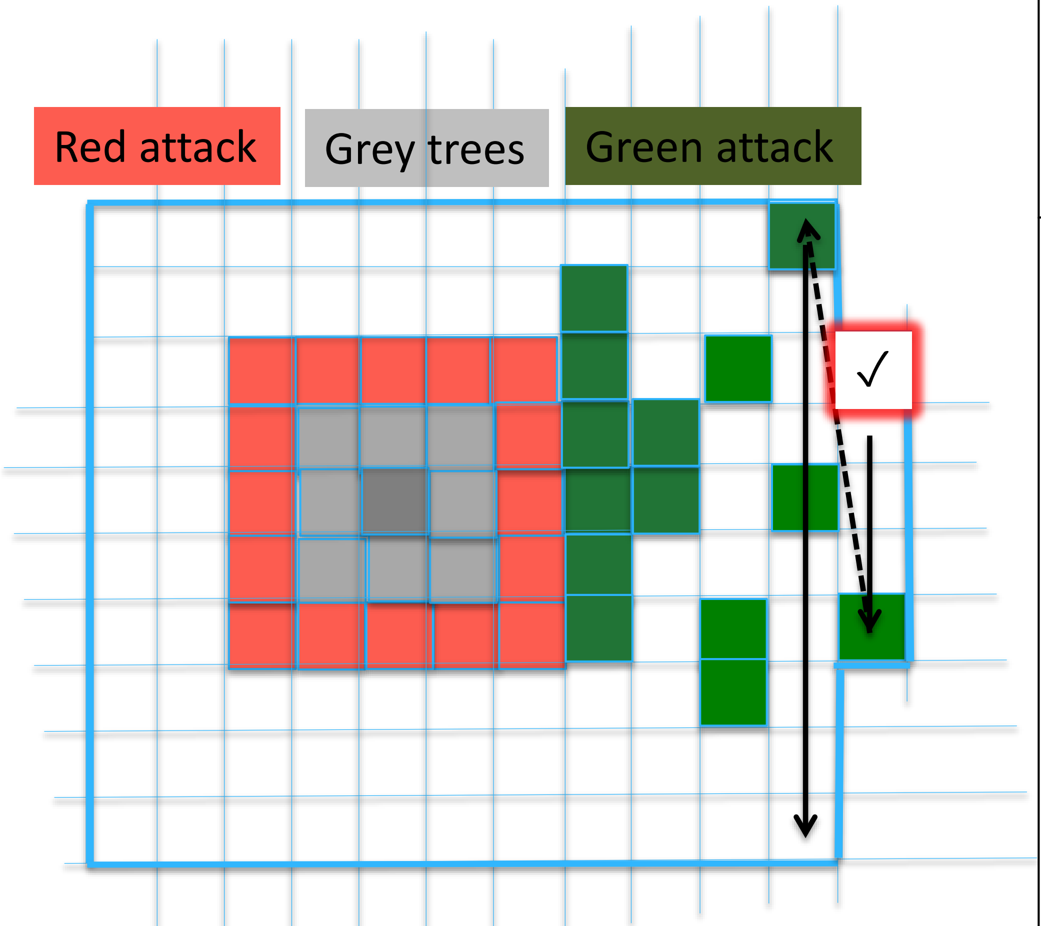






The basics of MPBSpread

3. Implementing controls



With Level 1 control, either all or a proportion of green attack is removed, depending on $P_{eradicate}$. <u>All</u> trees are removed within a cell under Level 2 control.

Implementation rules

<u>Level 1</u>: Cells where an infestation is detected $\leq$ 2 years of establishment.
<u>Level 2</u>: Cells with infestations of $\geq$ 3 years duration and $\leq$ 7 km from a road. Else, no treatment.
Note: infested cells may not be detected.

Application rules (leading edge focus)

Begin with the cell at the easternmost longitude and corresponding highest latitude within the study area. Proceed sequentially by longitude to the southernmost cell within the area and then onto the northernmost cell to the immediate west.

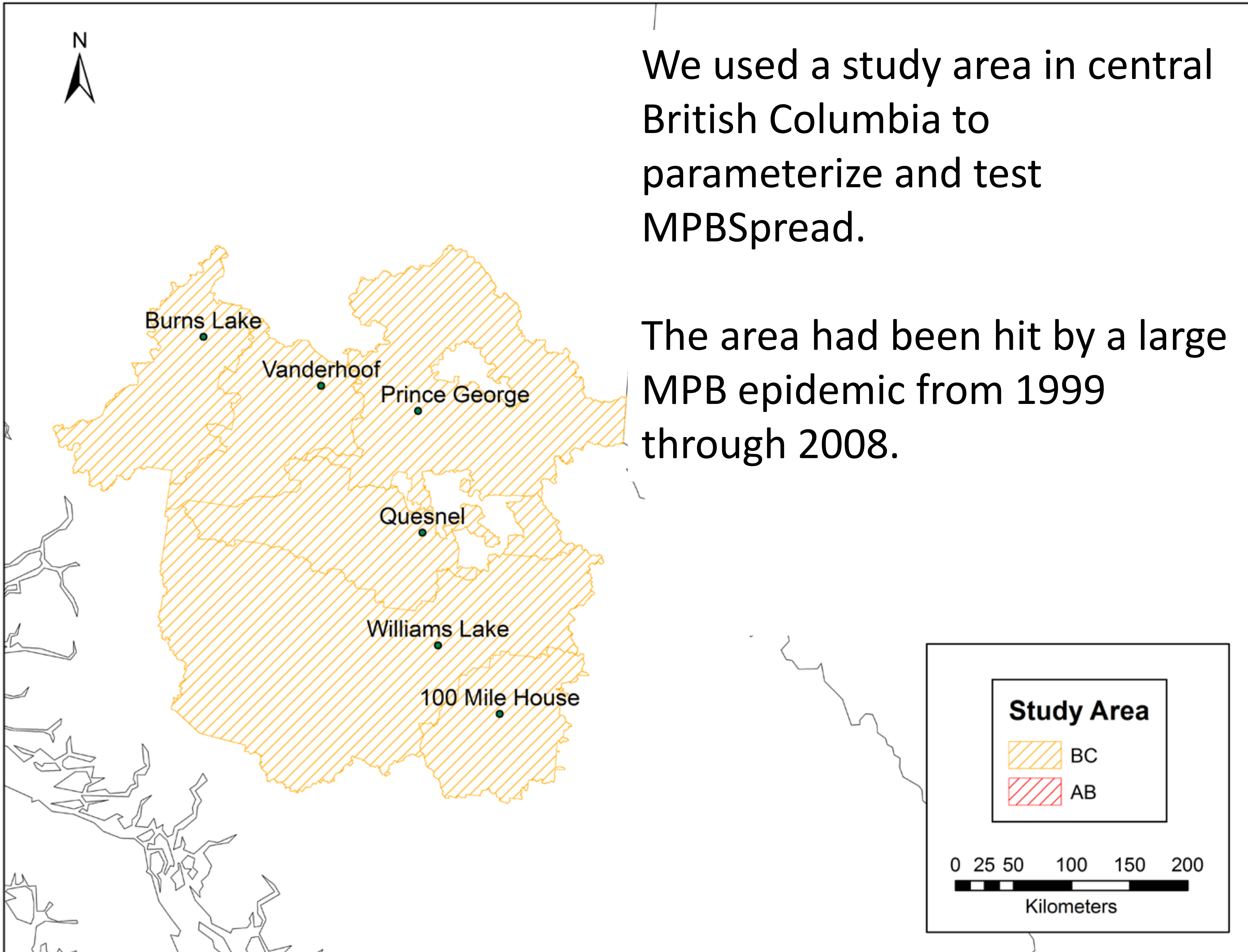
<u>Continue process until all cells within the study area have been sampled or the total area allocated for control in a given year is reached</u>

Each infested cell has a <u>probability of being detected</u>, and a subsequent <u>probability of successful eradication</u> ($P_{eradicate}$).

In summary, MPBSpread accounts for:

- Infested trees at the stand and landscape level
- Stand susceptibility
- Mortality
- MPB reproductive output (including climate effects)
- Habitat connectivity
- Dispersal
- Beetle control

Model validation



We used a study area in central British Columbia to parameterize and test MPBSpread.

The area had been hit by a large MPB epidemic from 1999 through 2008.

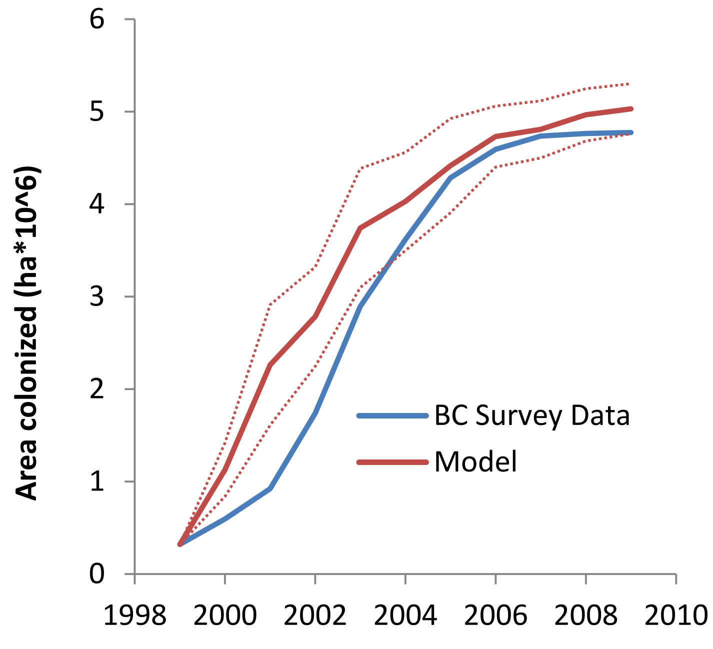
- BC survey data from the beginning of the epidemic (1999) were used to seed the model.

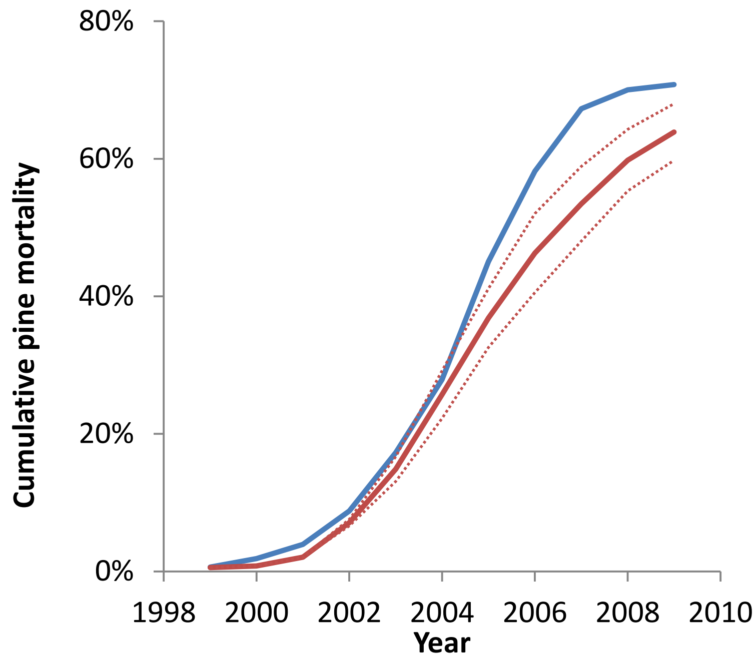
- The spread of MPB was then projected for the subsequent 10 years (to 2009).

- 10 model runs were conducted using experienced pine. This gave 10 projections of MPB spread (total area infested, and total pine killed), from which means and 95% confidence intervals were derived.

- Spread projections were compared with empirical data.

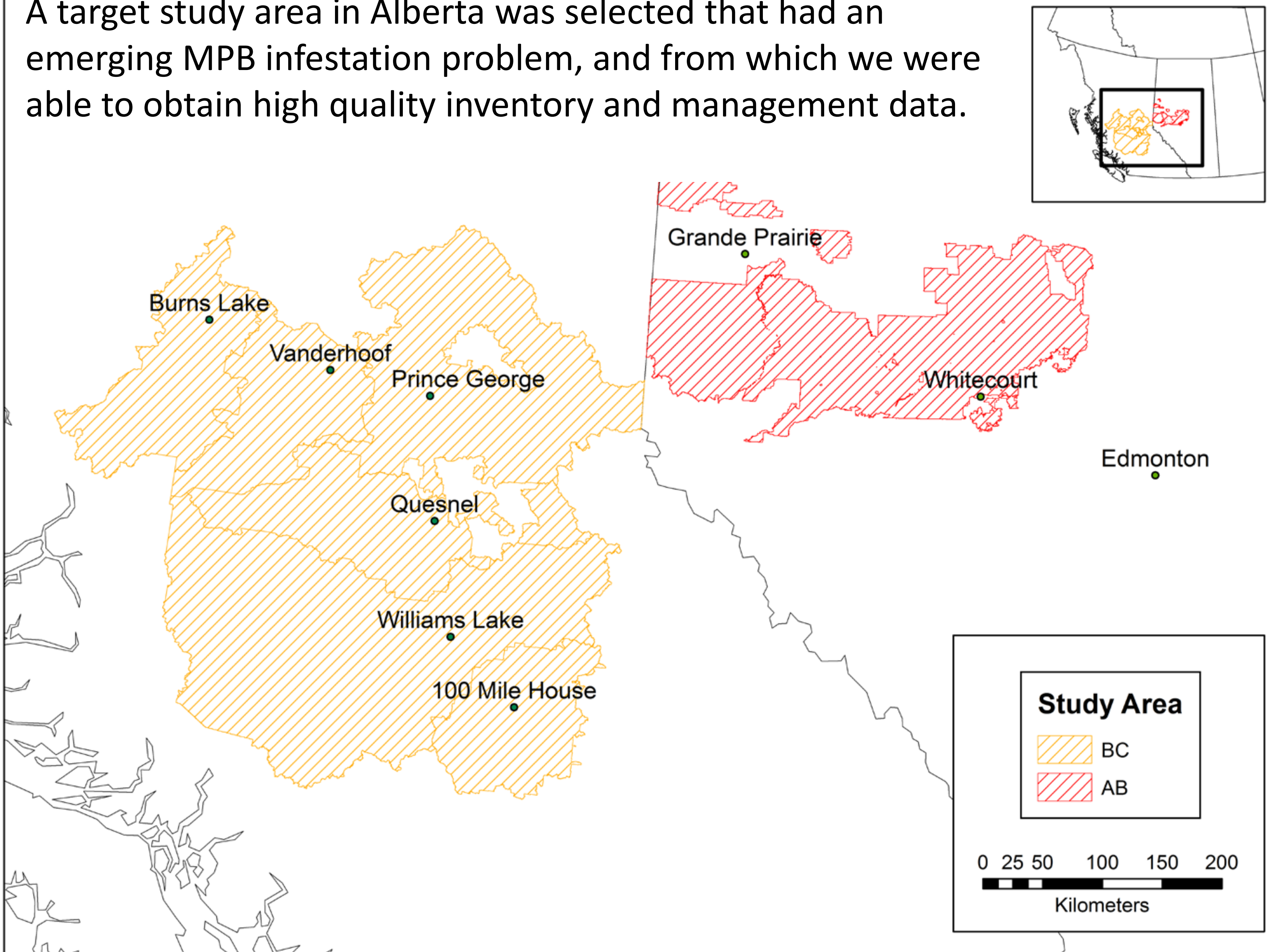
Comparison of predictions from MPBSpread and empirical data on colonization.





Assessing the efficacy of MPB control in Alberta using MPBSpread

A target study area in Alberta was selected that had an emerging MPB infestation problem, and from which we were able to obtain high quality inventory and management data.



- Annual MPB survey data from 2008 through 2015 were provided by Alberta Agriculture and Forestry.

- Using inventory data and parameters utilized in the BC validation exercise (with small adjustments to represent “naïve” pine in Alberta) we applied MPBSpread to the study area.

- The model was ‘seeded’ with infestation data from 2008 and then run forward for 10 years.

- To begin, the following two scenarios were evaluated with MPBSpread, with each scenario subject to 40 replications.

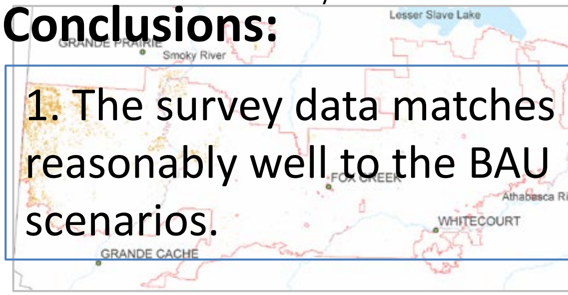
No.	Description	Level 1 (ha)	Level 2 2008 (ha)	Level 2 2017 (ha)	P_{Detect}	$P_{Eradicate}$	Host
0	Do nothing	-	-	-	-	-	Naïve
1	BAU*	10000	1500	3000	0.9	0.65	Naïve

*BAU = “Business as usual”; treatments derived from empirical data

The impact of control relative to ‘do nothing’

Conclusions:

2008 Survey Data

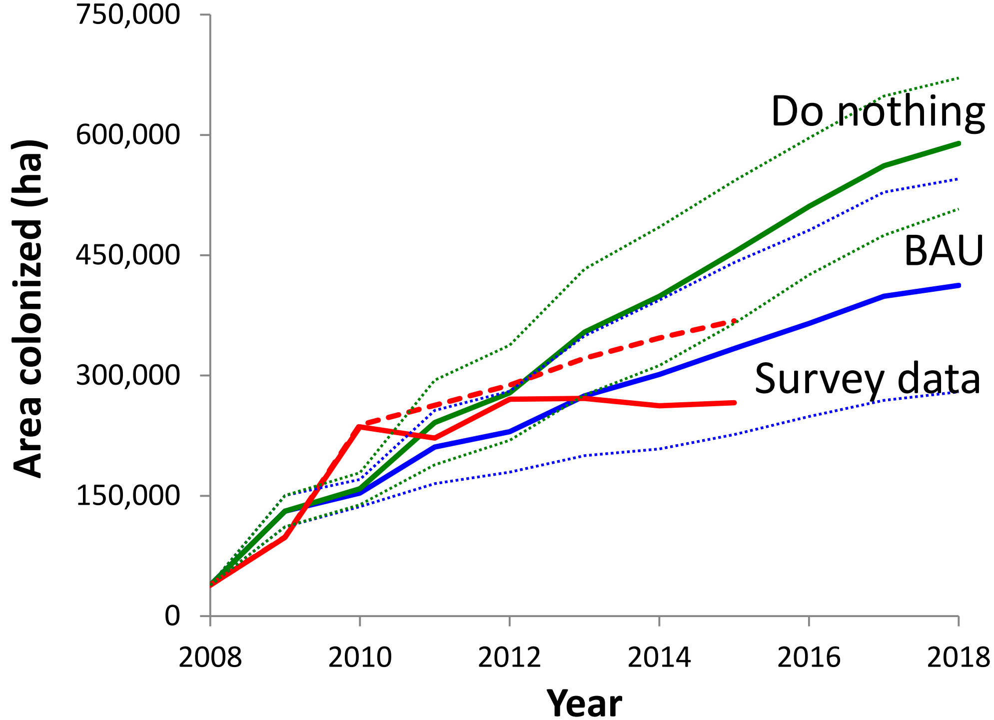


1. The survey data matches reasonably well to the BAU scenarios.

2018 Projected (do nothing)

2. Control does make a difference.

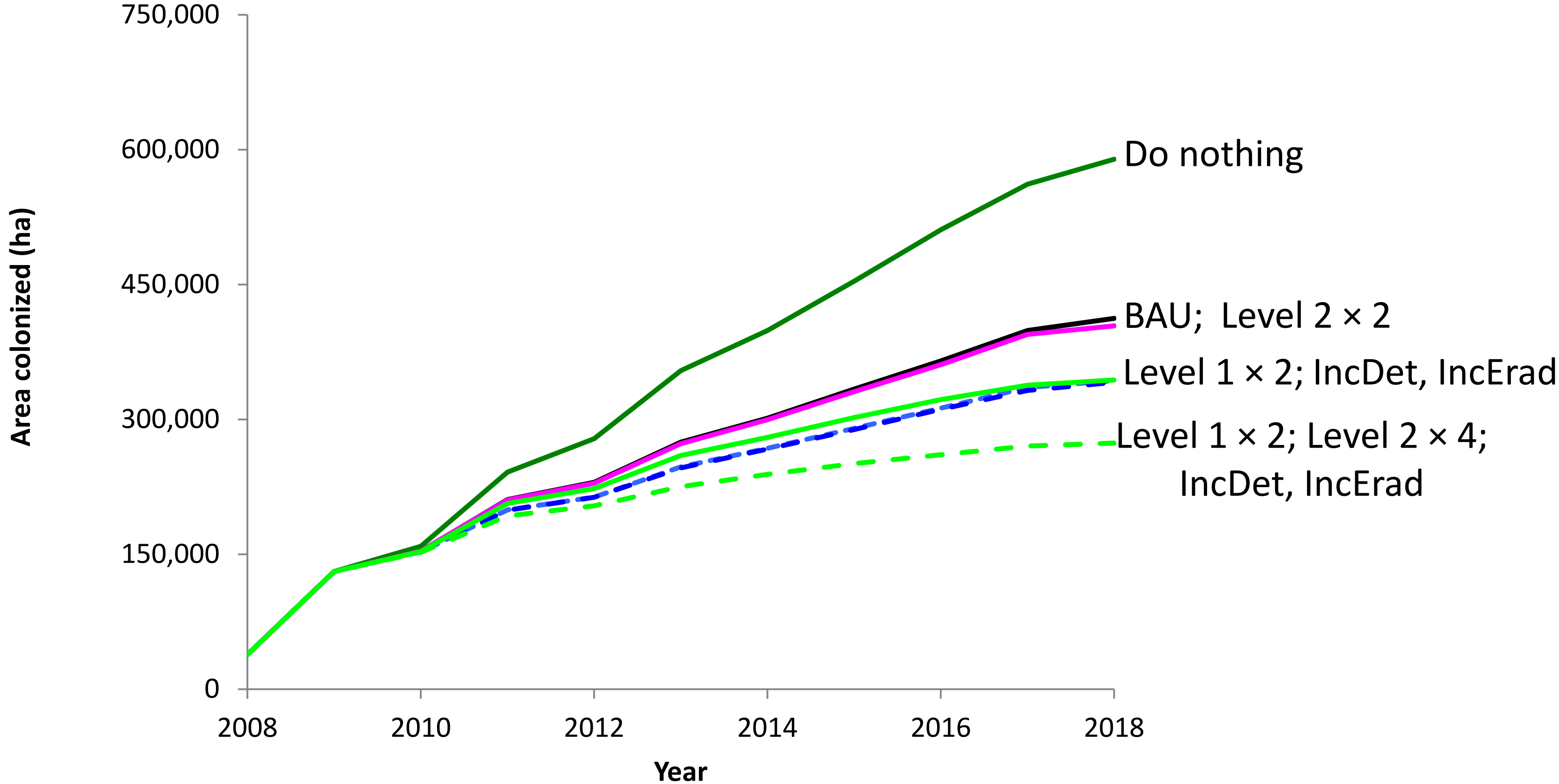
3. Control efficacy is not immediately apparent – it takes time to manifest itself.



A range of scenarios was created to illustrate both the flexibility of MPBSpread and explore the impact of variation in control effort:

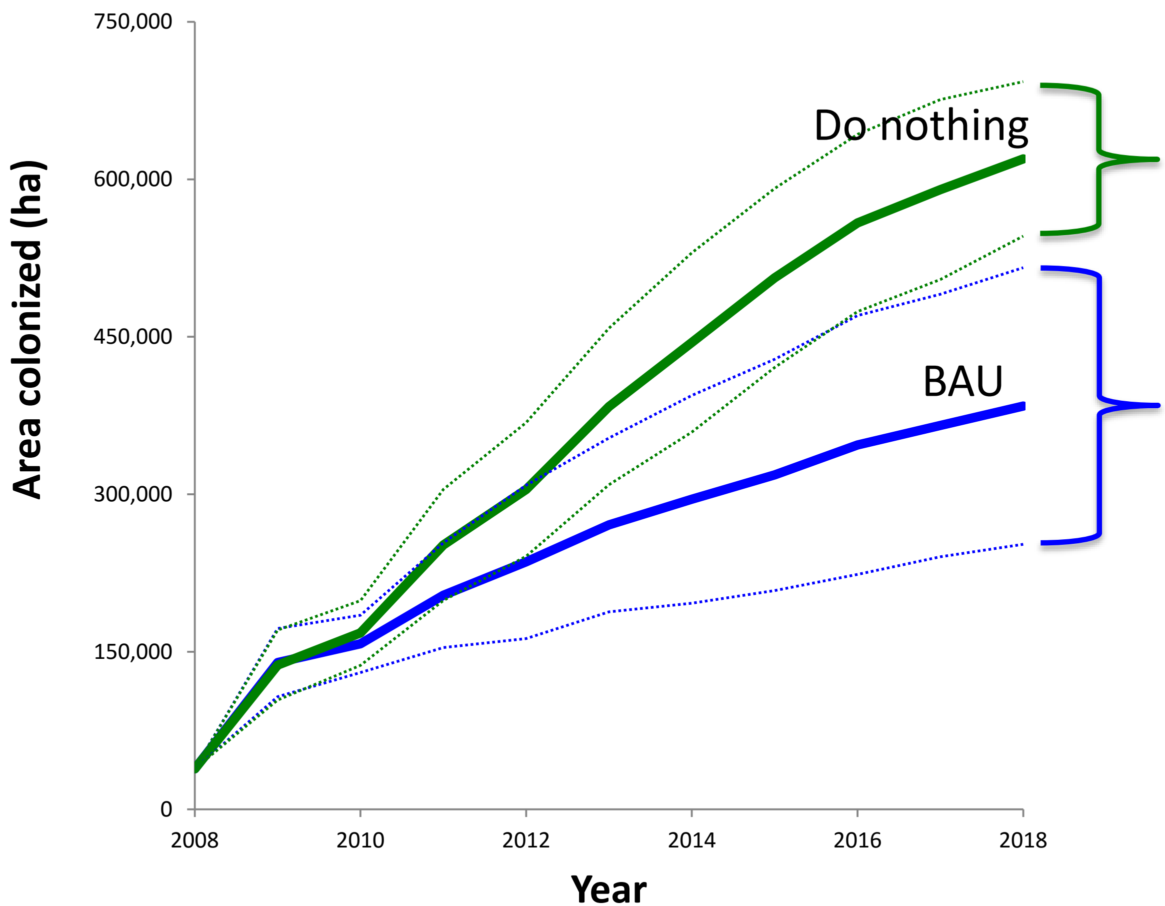
No.	Description	Level 1	Level 2-2008	Level 2-2017	PDetect	Peradicate (Level 1)	Host
0	Do nothing	-	-	-	-	-	Naïve
1	BAU	10000	1500	3000	0.9	0.65	Naïve
2	L1*2;L2➔2	20000	1500	6000	0.9	0.65	Naïve
3	L2*2	10000	3000	6000	0.9	0.65	Naïve
4	L1*2	20000	1500	3000	0.9	0.65	Naïve
5	L1*0.5;L2*2	5000	3000	6000	0.9	0.65	Naïve
6	IncDet, IncErad	10000	1500	3000	0.95	0.8	Naïve
7	Experienced	10000	1500	3000	0.9	0.65	Exp
10	L2*4	10000	6000	12000	0.9	0.65	Naïve
11	L1*2; L2*4	20000	6000	12000	0.9	0.65	Naïve
12	L1*2; L2*4; IncDet; IncErad	20000	6000	12000	0.95	0.8	Naïve

Comparing alternative control tactics



Conclusion: Allocating greater resources to control efforts needs to be selective.

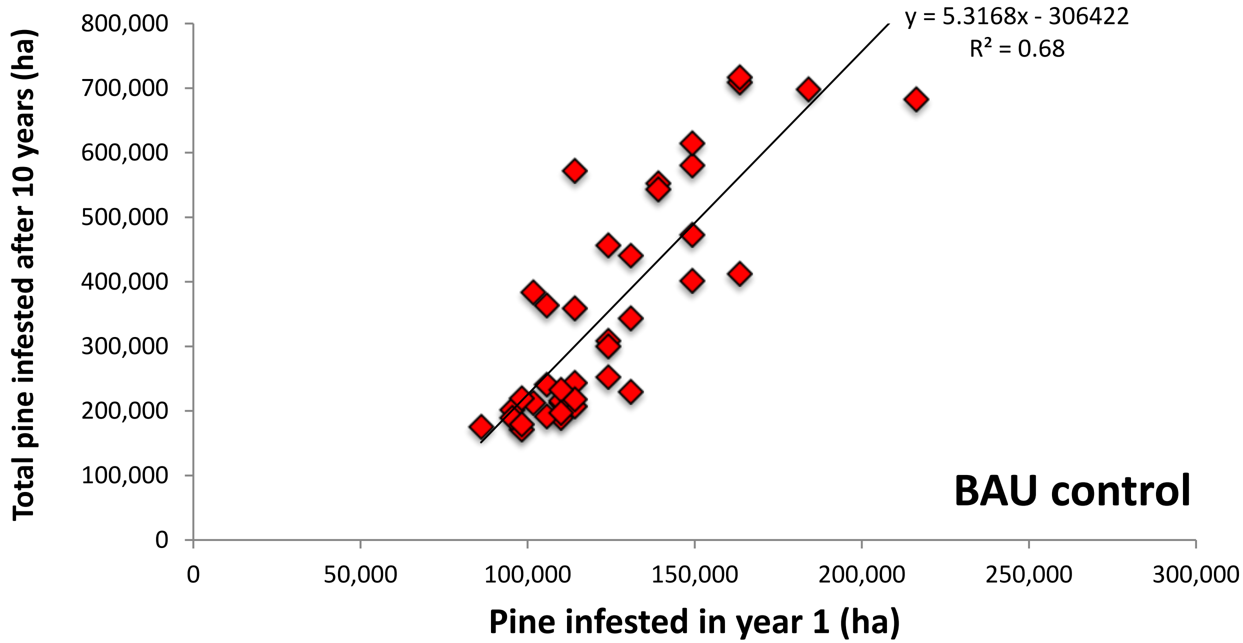
How important is early control in dictating long-term outcomes?



What is the source of this variation?

Conclusion

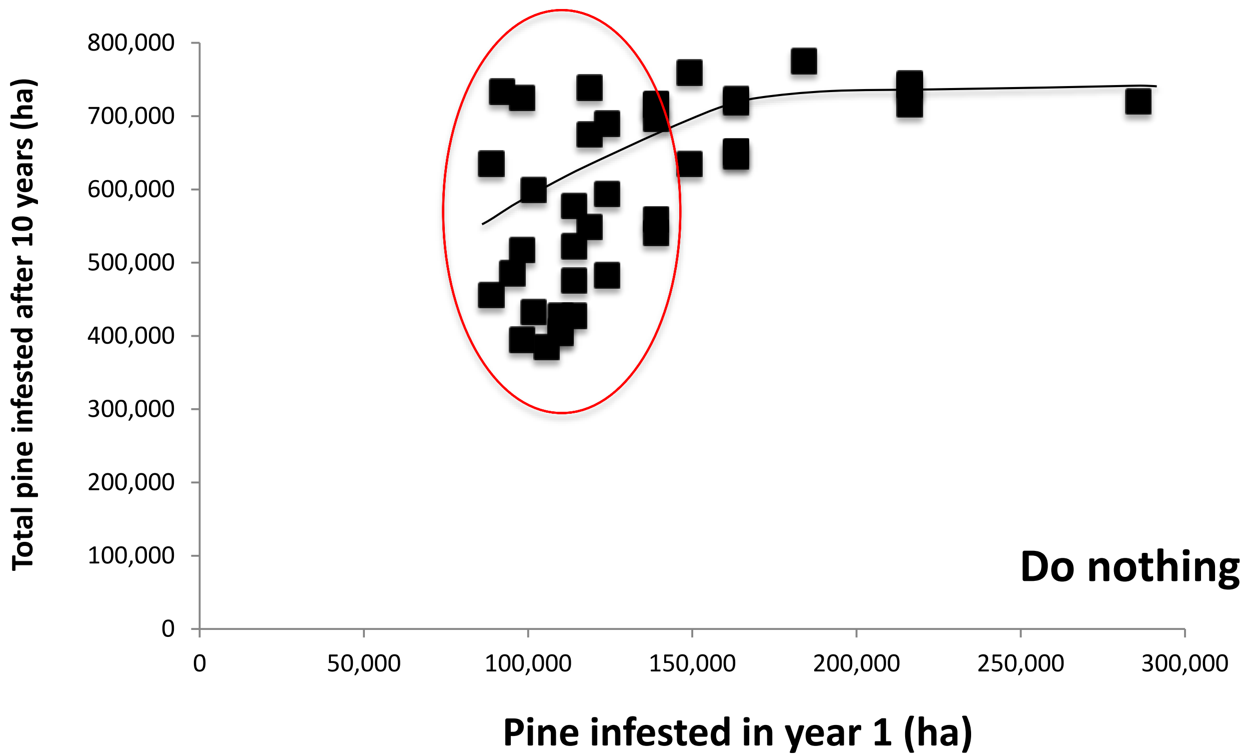
Under BAU control, much of the variation in total infested pine (after 10 years) is due to variation in early infestation.



Is that also the conclusion in the 'Do nothing' case?

Conclusion: Not really.

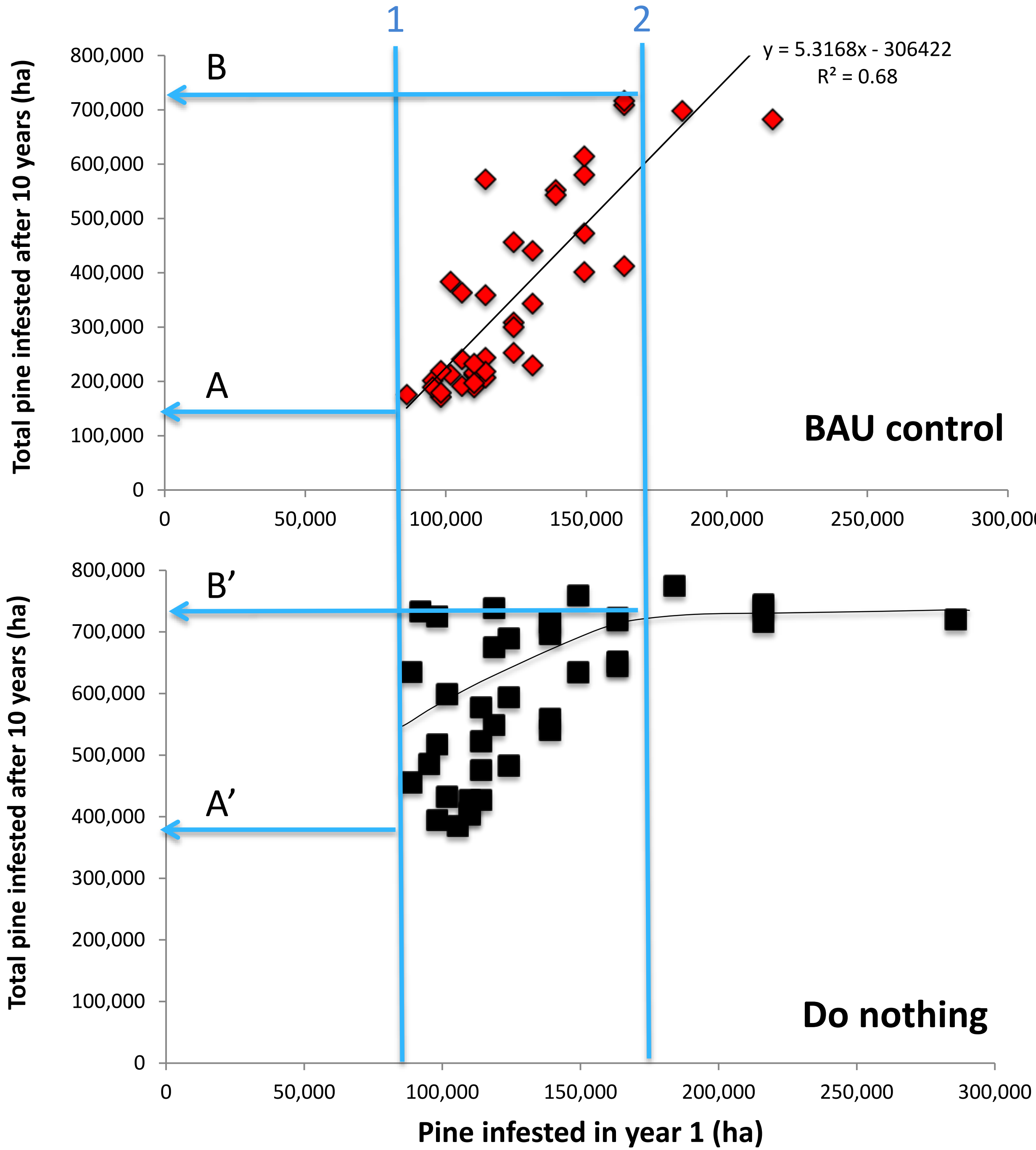
Under no control, there is a weak relationship between the variation in total infested pine (after 10 years) and early infestation.



Learnings

1. Early intervention is important to limiting beetle spread ('buying time'). A decision to 'wait and see' could be costly.

2. At some point (~ 175,000 ha), control has no impact on subsequent spread.



Conclusions

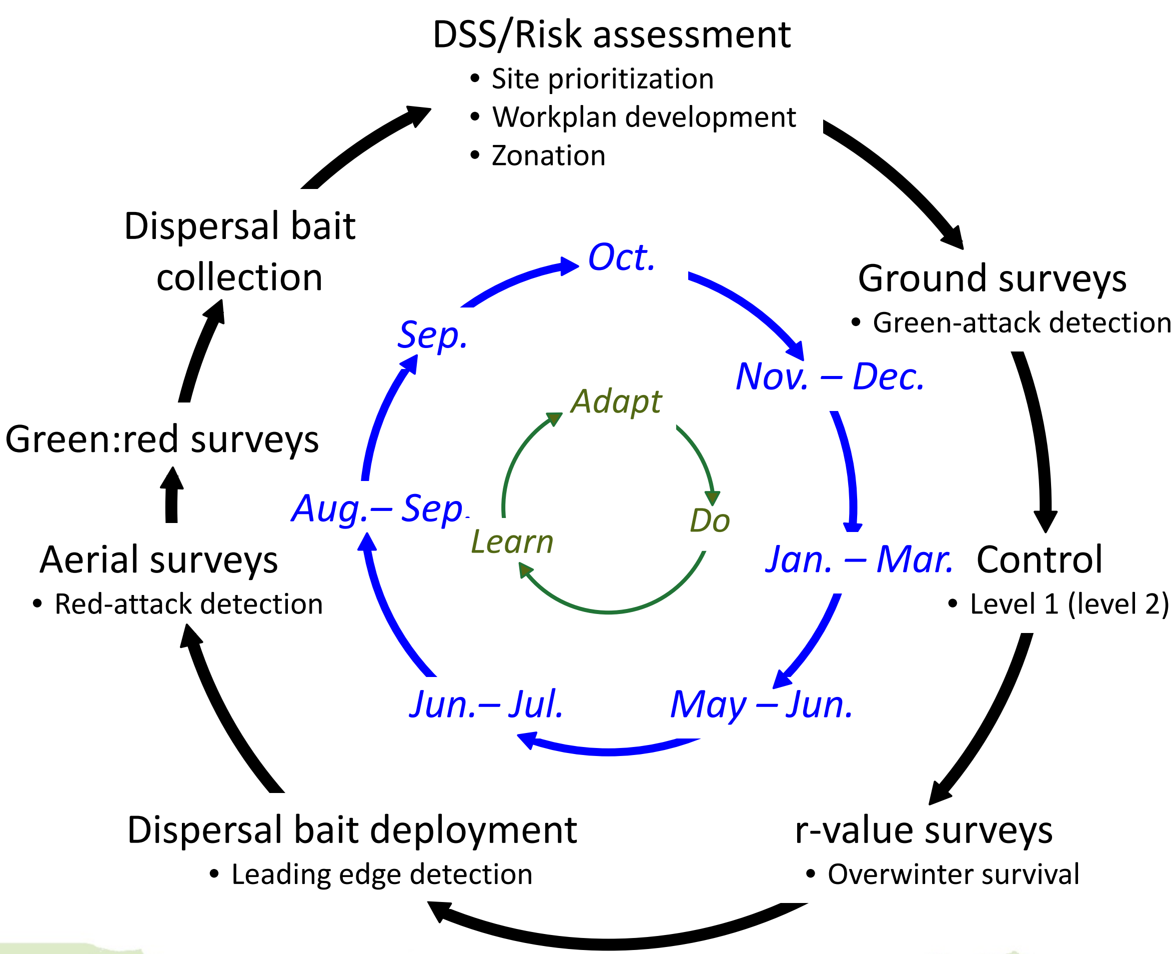
1. BAU reduces infestation area relative to ‘Do nothing’.
2. Increasing Level 1 control reduces infestation, whereas increasing Level 2 control has relatively little impact.
3. Increasing Levels 1 and 2 controls, along with increased detection and eradication, generates the greatest decline in infestation area.
4. Under ‘Do nothing’ low early infestation is a poor predictor of 10-year outcomes.
5. Control can be very effective when initial infestations are low.
6. Control effectiveness diminishes in direct relation to initial infestation size but is still useful in limiting total infestation (how much pine is killed).
7. Control measures are largely ineffective when early infestation exceeds ~ 175,000 ha.

Remaining work under current funding:

1. Develop a Decision Support Tool to evaluate the full suite of runs conducted with MPBSpread.

1. Add economic metrics and assess the relative benefits of the scenarios.

MPBSpread scenario evaluation: relevance and integration



1. The "slow the spread" strategy (BAU) is effective in mitigating the spread and impacts of MPB across the study area
2. Significant improvements through increased application of Level 1 (but not Level 2) treatments accompanied by increased levels of green attack detection
3. Regardless of strategy, early intervention in all affected areas is critical

Discussion