Epidemiological models reproduce cyclic insect outbreaks

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THANK YOU

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Spruce budworm is a forest defoliator

≈ 15% of Canadian forests damaged
≈ $bn 8 in revenue losses

Natural Resources Canada 2013, National Forest Service 2013
SPRUCE BUDWORM DISTRIBUTION

Boulanger and Arseneault 2004
LANDSCAPE DATA FOR SPRUCE BUDWORM OUTBREAKS

1968

Ministère de l'Énergie et des Ressources Naturelles Québec
A model to manage Spruce Budworm outbreaks

- Process-based and tractable
- Landscape-scale
- Dispersal
Objective

- Create a model of spruce budworm outbreaks to improve decision-making
HOW DO WE MAKE A LANDSCAPE OUTBREAK MODEL?

- Insects
  - Ecology
HOW DO WE MAKE A LANDSCAPE OUTBREAK MODEL?

- Insects
  - Ecology
- Forest patches
  - Epidemiology
FIR model

Forest

Infected

Recovering

spontaneous

dispersal
FIR model

\[ \frac{dF}{dt} = \gamma_1 R - \beta F - \alpha f(l)F \]
\[ \frac{dl}{dt} = \beta F + \alpha f(l)F - \gamma_2 l \]
ADD SPRUCE BUDWORM BEHAVIOUR - ALLEE EFFECT PRODUCES DENSITY-DEPENDENT DISPERSAL

Régnière et al. 2013
ADD SPRUCE BUDWORM BEHAVIOUR - ALLEE EFFECT PRODUCES DENSITY-DEPENDENT DISPERSAL

\[ f(l) = ll^p \]

Régnière et al. 2013
**RESULTS: FIR model with density-dependent dispersal has cyclic outbreaks**

- **Spatially implicit, \( p = 0 \)**
  - Proportion: 0.5
  - Time: 500

- **Spatially implicit, \( p = 0.4 \)**
  - Proportion: 1
  - Time: 500

\[ \beta = 0.0001 \]
\[ \alpha = 0.2 \]
\[ \gamma_1 = 1/40 \]
\[ \gamma_2 = 1/3 \]
HOW DO WE MODEL A LANDSCAPE?
HOW DO WE MAKE A SPATIALLY-EXPLICIT MODEL?
Infections spread locally in spatially-explicit FIR model
Results: Spatially-explicit FIR model has cyclic outbreaks.
RESULTS: DENSITY-DEPENDENT DISPERSAL PRODUCES LARGE OUTBREAKS
RESULTS: WEAK DISPERSAL RATE PRODUCES LARGE OUTBREAKS
SUMMARY: USE THE FIR MODEL TO STUDY LANDSCAPE INSECT OUTBREAKS

Propose new hypotheses:
- Density-dependent dispersal
- Spatially-explicit dispersal
- Landscape-scale
**CONCLUSION: USE THE FIR MODEL TO MANAGE LANDSCAPE INSECT OUTBREAKS**

- Harvesting = Spatial vaccination

![Diagram showing the Fir model with states: Infected, Forest, Recovering, and the process of harvesting as spatial vaccination.](image-url)
USE OUTBREAK DATA TO PARAMETERIZE MODEL - $\beta$, SPONTANEOUS OUTBREAKS AND $\alpha$, DISPERAL

![Graph 1: Probability of start vs. Climate](image1)

![Graph 2: Probability of spread vs. Number of infected neighbours](image2)
RESULTS: DENSITY-DEPENDENT DISPERSAL PRODUCES LARGE RARE OUTBREAKS
RESULTS: WEAK DISPERSAL RATE PRODUCES LARGE RARE OUTBREAKS

Spatially-implicit

Spatially-explicit

Proportion Infected

dispersal, \( \alpha \)

Years

Y ears

dispersal, \( \alpha \)
\[ \frac{dF}{dt} = \gamma_1 R - \beta F - (1 - [1 - \alpha f(I)]^{24})F \]
\[ \frac{dl}{dt} = \beta F + (1 - [1 - \alpha f(I)]^{24})F - \gamma_2 l \]
## Summary of Results

<table>
<thead>
<tr>
<th>Model</th>
<th>Density-dependence</th>
<th>One out-break</th>
<th>Cyclic out-breaks</th>
<th>Self-organized landscapes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatially-implicit</td>
<td>$p = 0$</td>
<td>yes</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$p &gt; 0$</td>
<td>yes</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Spatially-explicit</td>
<td>$p = 0$</td>
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</tr>
<tr>
<td>- immigration</td>
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<tr>
<td>- emigration</td>
<td>$p &gt; 0$</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
Analytical Results: FIR model with Allee Effect has outbreaks

- Negative real parts
- Negative real parts, imaginary
- Positive real parts, imaginary

Spatially-implicit $p > 0$

- $\alpha$
- $\beta$

Graph showing the relationship between $\alpha$ and $\beta$ with different markers for different types of real and imaginary parts.
RESULTS: PATCH SIZES AND POWERLAW SLOPE

Spatially-explicit, immigration

- A
- B

Spatially-explicit, emigration

- C
- D

- 0 stands
- 4.6 stands
- 9.2 stands
- 13.8 stands
- 18.5 stands

- $\beta$
- $\alpha$

- $-2.34$
- $-2.62$
- $-2.9$
- $-3.18$
- $-3.46$