Application of Value of Information to Inform Optimal Invasive Species Management

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Introduction

- **Invasive pests pose serious threats to both ecosystems and economies**, making timely and effective management essential to prevent widespread and lasting damage.
- Following initial detection of an invasive species, **resource managers must evaluate response options – ranging from no action to eradication – to minimize damages and costs**.
- **Effective decision-making is hindered by complex system dynamics and uncertainty**, including regarding pest spread, distribution, impacts, and control efficacy.
- Bioeconomic models can provide important decision support for invasion management response.

Objectives

- Develop a bioeconomic tool to support natural resource managers' selection among potential post-detection management for a new invasive species, considering three option: no management, slow-the-spread, or eradication.
- Evaluate the extent to which uncertainty hinders cost-efficient management and value of resolving uncertainties

Bioeconomic Model

- Bioeconomic model that identifies the management response that **minimizes the net present value of expected costs and damages for a newly detected pest.**
  a. **Simple model of invasion spread:** invaded area *A(t)* increases over time until the invasion reaches its maximum range size

$$A(t) = \pi\left[r_0 + \sum_{s=1}^{t} g(s)\right]^2 \qquad g(t) = \frac{g_{\max}\cdot r(t-1)^m}{h^m + r(t-1)^m} \qquad r(t) = r(t-1) + g\big(r(t-1)\big)$$

  - Pest population (initial radius at detection r_0) expands radially at an increasing rate (*g*) and approaching a maximum, asymptotic radial rate of spread (g_{max}). m is the population growth shape parameter; and *h* is the radius at which the population reaches half of its maximum radial growth rate.

  b. **Damages and control costs depend on the extent of the invaded area.**

  c. **Management options**

  - **No control**: damages accrue across entire infested area each period, with damages per unit area invaded.

$$TC_{nc} = \sum_{t=1}^{T} MC_{dam}\cdot A(t)\cdot(1+\delta)^{-t}$$

  - **Slow the spread**: control efforts reduce spread rate by a proportion and incur costs based on the buffer area (A_{buffer}) treated over time. Total damages are reduced by slower rate. Select the optimal stopping time of the management strategy to minimize the total costs and damages.

$$TC_{slow} = \min_{t^*}\left[\sum_{t=1}^{t^*}\left(MC_{dam}\cdot A(t) + MC_{slow}\cdot A_{\text{buffer}}(t)\right)\cdot(1+\delta)^{-t}\right]$$

  - **Eradication**: Eradication has a probability of success and incurs costs proportional to treated area. Unsuccessful eradication incurs eradications costs and management costs from switching to the next best option.

$$TC_{erad} = [MC_{erad}\cdot A_{e0}] + (1-p_{erad})\cdot\min(TC_{slow}, TC_{nc})$$

- **Parameter uncertainty accounted for with user-inputted distributions**

Value of Information (VOI)

- **New invasions are highly uncertain. How costly is that uncertainty? Does it hinder management selection?** Value of information (VOI) analysis can address these questions.
- We apply **VOI analysis** to examine the sensitivity of the optimal management choice to invasion uncertainty, and identify which uncertainties most hinder cost-effective management selection.
- The Expected Value of Perfect Information (EVPI) is the difference in total expected costs under uncertainty vs. if that uncertainty were resolved.

$$\mathbf{EVPI} = \underbrace{\max_{M}\sum_{w} p_w \times TC_{wm}}_{\text{Total expected costs under uncertainty}} - \underbrace{\sum_{w}\max_{M}\left(p_w \times TC_{wm}\right)}_{\text{Total expected costs with uncertainty resolved}}$$

M denotes the best strategy: {No Control, Slow the Spread, Eradication}.

W denotes the parameter value scenarios.

Case Study: Species

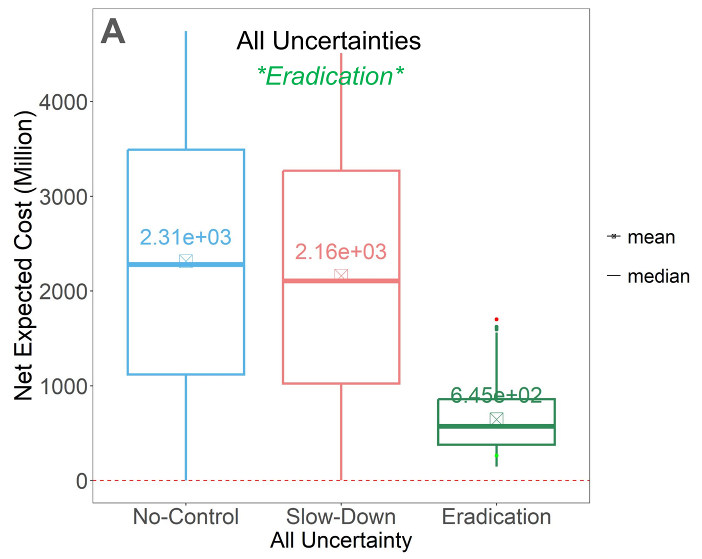
European Grapevine Moth

The European Grapevine Moth (EGVM; *Lobesia botrana*), originating from Italy, was first detected in California in 2009. It poses a significant threat to California's grape industry by damaging fruit and hindering exports. However, relatively effective control and eradication strategies are available. We examine optimal response for a large detected population (1000 km^2).

Spotted Lanternfly

The spotted lanternfly (*Lycorma delicatula*), native to Asia, was first detected in Pennsylvania in 2014 and now infests at least 18 U.S. states. It threatens agriculture and forestry by feeding on grapes, hops, fruit trees, and hardwoods. Control strategies are generally costly and relatively ineffective. We examine management for detection of a small, satellite population (3 km^2).

Management Optimization



Box plots shows distribution of total expected costs under three strategies: No Control, Slow-Down-Spread, and Eradication.

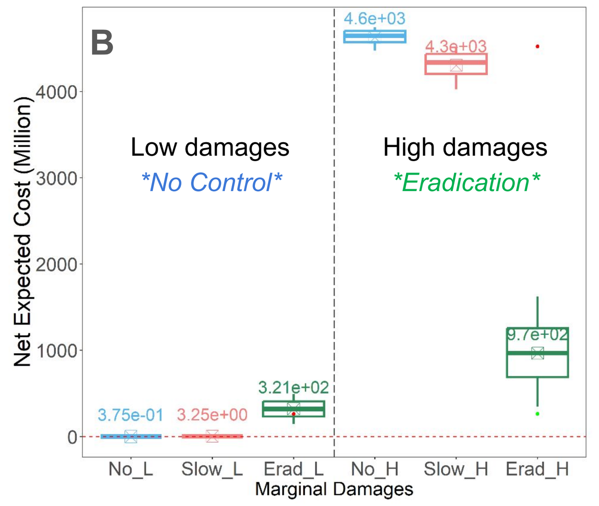
A. Eradication is optimal strategy (i.e. has lowest expected costs) when all parameters are uncertain [left].

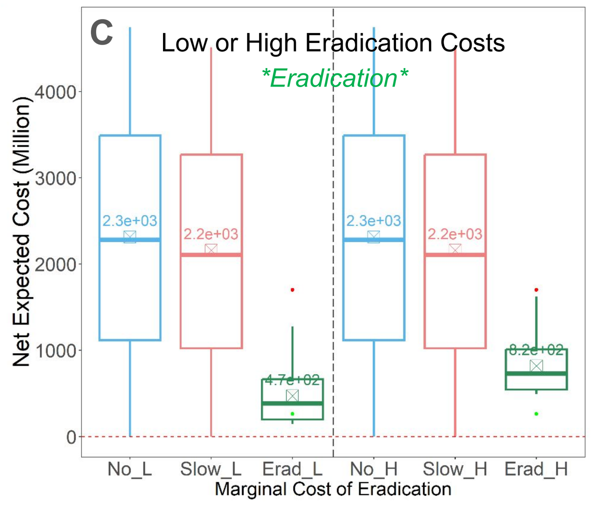
B. Resolving damage uncertainty, while other uncertainties remain:

⟶ Slow-the-Spread becomes optimal if damages are low; Eradication remains optimal if damages are low.

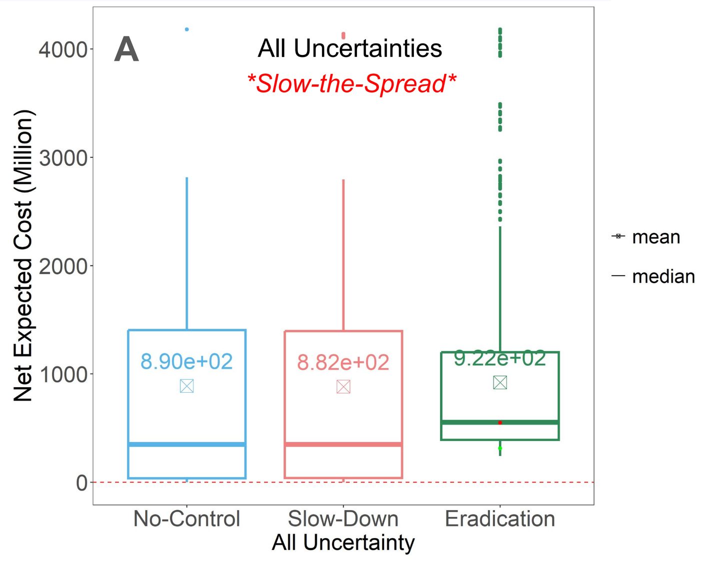
C. Resolving eradication cost uncertainty while other uncertainties remain:

⟶ Eradication remains optimal for high and low eradication





The optimal management strategy is sensitive to economic damages, with different damages level leading to different preferred responses.

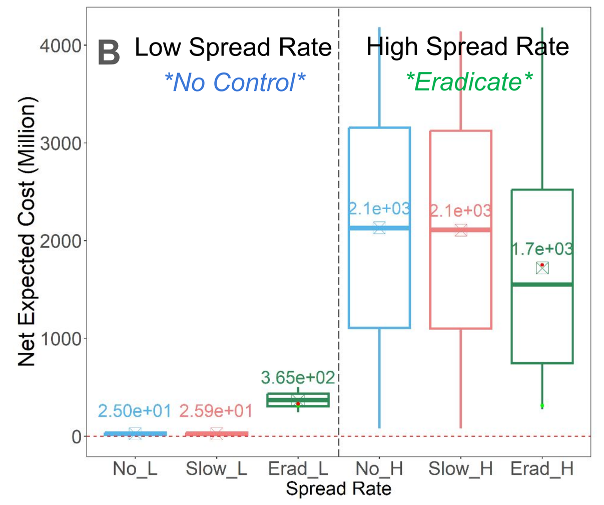


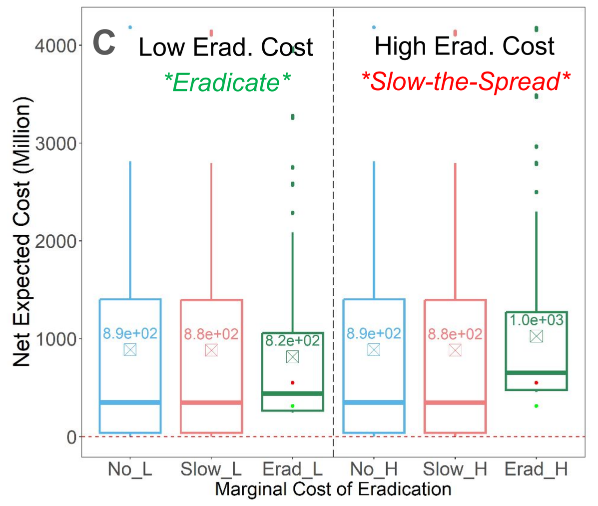
Box plots show the distribution of expected total costs under three strategies: No Control, Slow-Down-Spread, and Eradication.

A. Under full uncertainty, the mean expected costs and damages of all three strategies are similar, with Slow-the-Spread having lowest mean costs.

B. Eradication becomes dominant strategy when spread rate is high and other uncertainties remain.

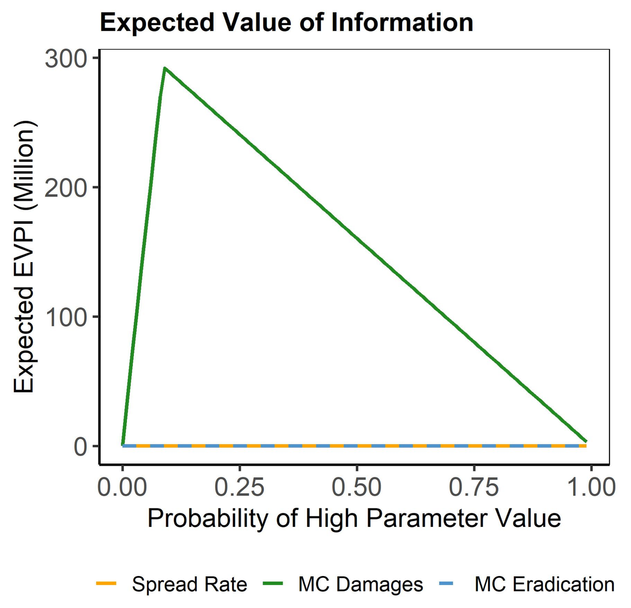
C. Eradication also becomes dominant strategy when eradication cost is low and other uncertainties remain.



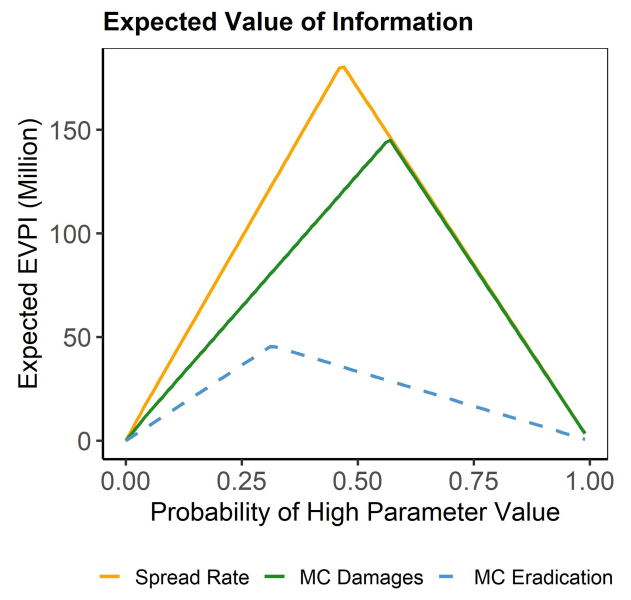


The optimal management strategy is sensitive to uncertainty in each of the variables.

Value of Information



- **Resolving uncertainty in marginal damages can lower total expected costs** by enabling better management decisions.
- When the probability of high damages is low to moderate, damage *uncertainty is costly.* In this range, **improved information can meaningfully change decisions, and VOI is high. (~$300 million)**
- There is **no value in resolving uncertainty about spread rate or eradication cost**, as these uncertainties do not affect the choice of strategy.



- **Resolving uncertainty in spread rate, marginal damages, and eradication cost can reduce total expected management costs**.
- For each parameter, the **value of information is highest if uncertainty is high** (i.e. probabilities of being high or low values ~50/50).
- **VOI is highest for eradication costs. Resolving this uncertainty provides an expected value of >$150 millio**n, by enabling a better decision about whether or not to attempt eradication.
- **VOI is lowest for damage costs, and therefore less critical to resolve,** all else equal.

Parameters Values

Model parameter	EGVM	Spotted Lanternfly
Asymptotic Population growth rate	0.5 - 5 km/yr	2.2 - 4.5 km/yr
Max population extent	3,519 km2	3,134,050 km2
Marginal damage costs	0 - 61,775 $/km2	193 - 10,000 $/km2
Marginal eradication costs	85,124 - 285,124 $/km2	19,768,400 - 37,065,750 $/km2
Marginal slow the spread cost	3,381- 5,637 $/km2	197,684 - 370,657 $/km2
Quarantine efficacy	0.5	0.05-0.5
Probability that eradication is successful	0.75-0.95	0.1-0.6
Discount rate	0.03	0.05

Discussion

Overview:

- We developed a **decision support tool**, based on a bioeconomic model, that compares the expected costs and damages across several potential post-detection management responses (no control, slow-the-spread, and eradication). It also explores **how uncertainty affects optimal management choice** and the potential for improving outcomes through reducing uncertainties.
- The choice of optimal management strategy can be highly sensitive to key parameter values, depending on pest attributes an context, including population growth rates, economic damage impacts, and the cost and efficiency of the management strategy.

Results:

- In our our illustrative **EGVM pest incursion**, eradication has the lowest total damages and costs when all parameters are uncertain. If the damage uncertainty were resolved and damages are low, the optimal strategy would change to slow the spread. The VOI figure shows the reduction in total expected costs from resolving damage uncertainty.
  - Investing to improve data on marginal economic damages of EGVM offers the greatest potential benefit to improve decision-making and lead to more cost-effective management actions.
- For the illustrative **Spotted Lanternfly incursion**, results indicate that uncertainty in spread rate, marginal damages, and eradication costs affect strategy selection. VOI analysis supports a dual focus on monitoring population spread and refining damage estimates to enhance the cost-effectiveness of invasive species responses.

Decision Support:

- Our model **requires minimal information, enabling rapid application to support decisions**.
- By allowing extensive uncertainty regarding invasion attributes, the tool enables comparison among strategies, illustrates uncertainty about expected costs, and **determines which uncertainties most hinder management**.
- The VOI analysis points managers to where additional research to reduce uncertainty would be most economically valuable by improving decisions.

Next Steps

- Apply the model to additional invasive species scenarios, particularly those with different spread mechanisms or host ranges, to test the generalizability of findings.
- Develop a flexible library of parameter distributions that can be integrated into the model and updated comprehensively and dynamically as new information becomes available.
- The tool will be transitioned to decision-makers to support post-detection invasion response.

Contact Information

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