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Mathematical Modeling and Multi-Period Resource Allocation for Invasive Plant Control

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INTRODUCTION & AIM

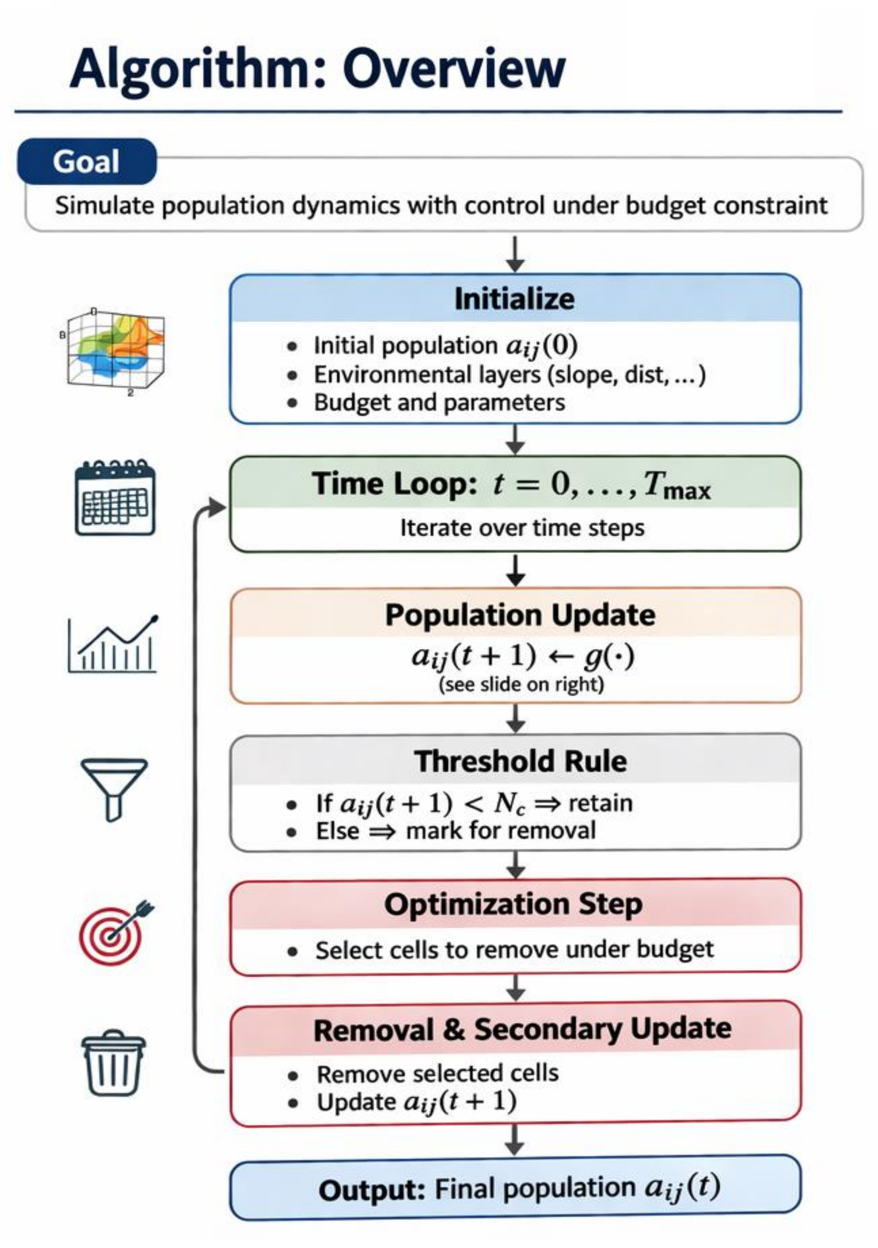
- Invasive species are non-native organisms that spread rapidly and damage natural ecosystems.
- They reduce biodiversity, alter habitats, and create significant economic and environmental impacts.
- **Chinese privet** (*Ligustrum sinense*) is a highly invasive plant that forms dense vegetation, blocks sunlight, and spreads through bird-dispersed seeds.

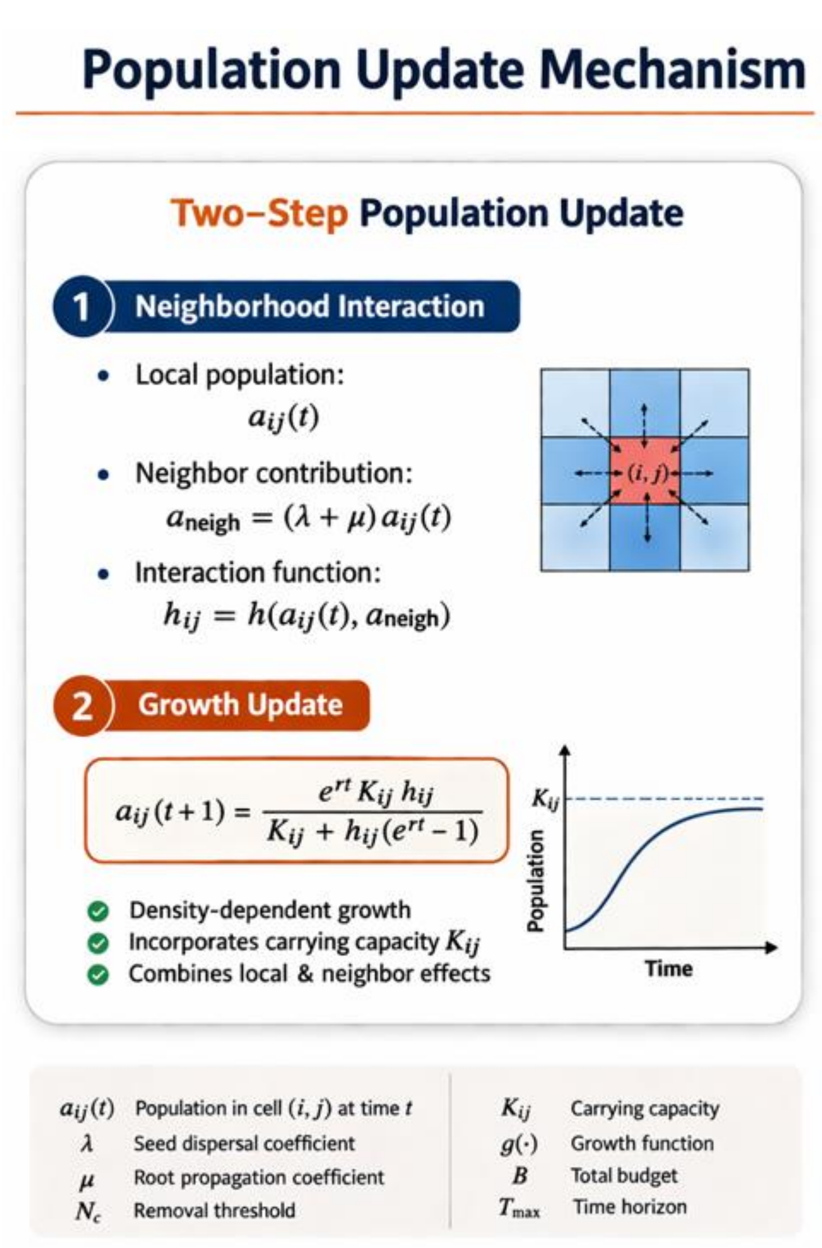
Chinese Privet

Study Aim

This study develops a multi-objective optimization framework for controlling Chinese privet spread in Reflection Riding Arboretum and Nature Center, Tennessee, USA. The model integrates invasion dynamics with operational factors to identify practical and cost-effective treatment strategies.

METHOD





Optimization Framework

The framework considers two competing objectives:

- f_1: Minimize untreated invasive population
- f_2: Minimize operational difficulty along distance and slope

The optimization is subject to budget and operational constraints, ensuring realistic implementation conditions.

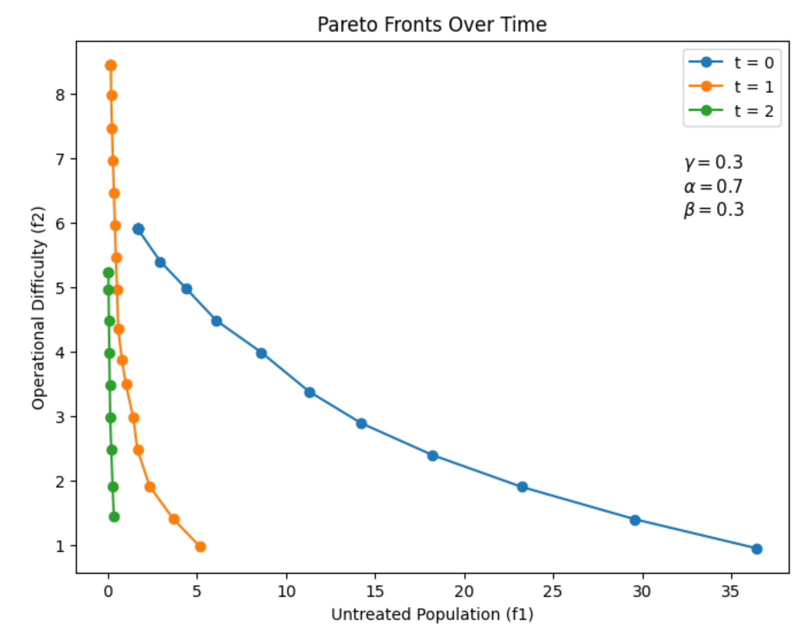
This results in a set of **Pareto-optimal solutions**, representing trade-offs between ecological benefit and management cost.

RESULTS & DISCUSSION

Analysis: Balanced Management Strategy

The Pareto framework captures trade-offs between ecological effectiveness and operational difficulty. Instead of relying on a single objective, it identifies a set of efficient solutions where no objective can be improved without worsening the other.

This allows decision-makers to select strategies that best match available resources and management priorities.



γ: minimum required control effort over the landscape.

α, β: weighting coefficients scaling the influence of slope and distance in the accessibility cost objective.

Key Findings:

- The Pareto front shifts closer to the origin over time, indicating simultaneous improvement in ecological and operational objectives.
- By $t = 2$, the system reaches a state where the invasive species can be effectively removed within three time periods under feasible operational effort levels.
- This demonstrates that sustained management actions lead to rapid ecological recovery within a short planning horizon.

Single-objective optimization alone is not sufficient in practice. Minimizing only f_1 can require too much effort under limited labor, equipment, or access. Minimizing only f_2 may leave high invasive populations and reduce ecological impact. The Pareto framework balances both goals, allowing choices that consider both ecological benefit and practical constraints.

CONCLUSION

This study developed a multi-objective optimization model for managing Chinese privet under operational constraints. Using real data from the Reflection Riding Arboretum and Nature Center, the model supports practical, cost-effective invasive species management.

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