Optimization Models for Red-cockaded Woodpecker Management

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Introduction

- Degradation and loss of longleaf pine ecosystem has led to decline of Red-cockaded Woodpecker (RCW)
- 'Keystone' species – primary excavators of nest cavities used by at least 27 vertebrate species
- Highly specific habitat – need mature pine trees infected with Red Heart fungus
- Cooperative breeders – territory groups consisting of one breeding pair and up to four 'helpers'
- Habitat conservation and management crucial to continued viability of Red-cockaded Woodpecker

Research Objectives

The goal of this research is to develop methods to prioritize land acquisition adjacent to current RCW populations to aid in their recovery for The Conservation Fund and its partners.

We seek to pose this as a formal optimization problem: where and when should one acquire land parcels and/or translocate birds to maximize the number of RCW breeding groups.

To solve this problem we develop a diffusion model to describe spatial patterns in RCW populations, and pose this as a stochastic network design problem.

Study Area

Palmetto Peartree Preserve (3P), owned and managed by The Conservation Fund, consists of 10,000 acres of wetland forest in Tyrrell County, North Carolina. As of September 2008, there were a total of 32 active RCW territories within the preserve.

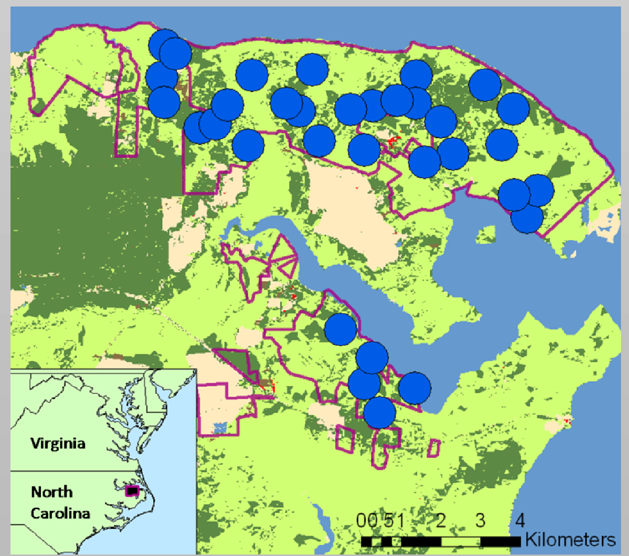

Figure 1. 3P RCW territories shown in blue

Patch-based Diffusion Model

- Based on cascade models for spread of influence in social networks; also related to metapopulation models in ecology

Model Description

- Territories i, j =1, …, n.
- Occupied or unoccupied at each time step
- May colonize other territories (probability p_{ij}), or go extinct (probability β) in each time step
- Unoccupied territories become occupied if they are colonized by one or more other territories
- All colonization and extinction events independent

Parameters

- Colonization probability decays with distance, and only succeeds if target territory has suitable habitat

$$p_{ij} = \begin{cases} q_{ij} & \text{if territory } j \text{ is suitable} \\ 0 & \text{otherwise} \end{cases}$$

Illustration

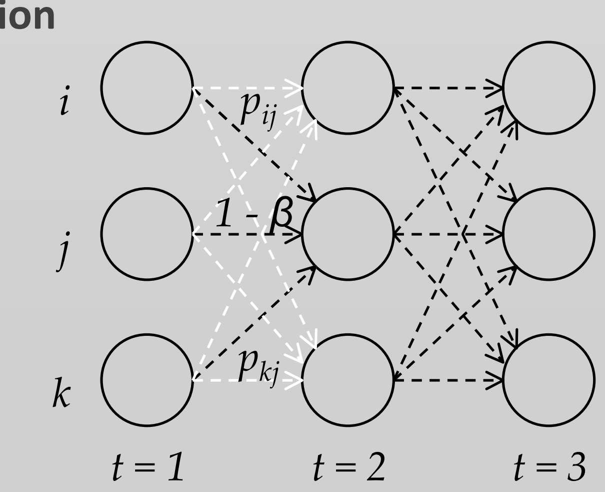

Figure 2. Time unrolled graph

Simulation Results

- Spatial configuration is very important. Dense and highly connected configurations are most stable.
- The four scenarios below show the effect of territory density on occupancy in the 3P study area.

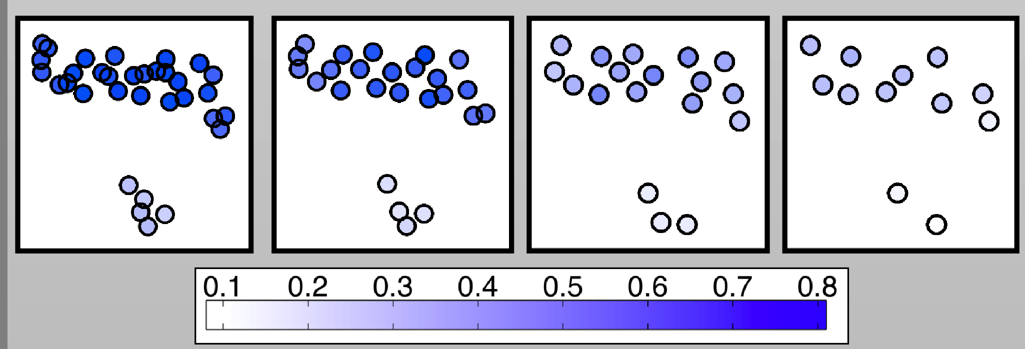

Figure 3. Shading indicated probability the territory is occupied after 100 years of simulation.

Occupancy as Network Connectivity

- We can describe the occupancy patterns of RCWs using a graphical network model

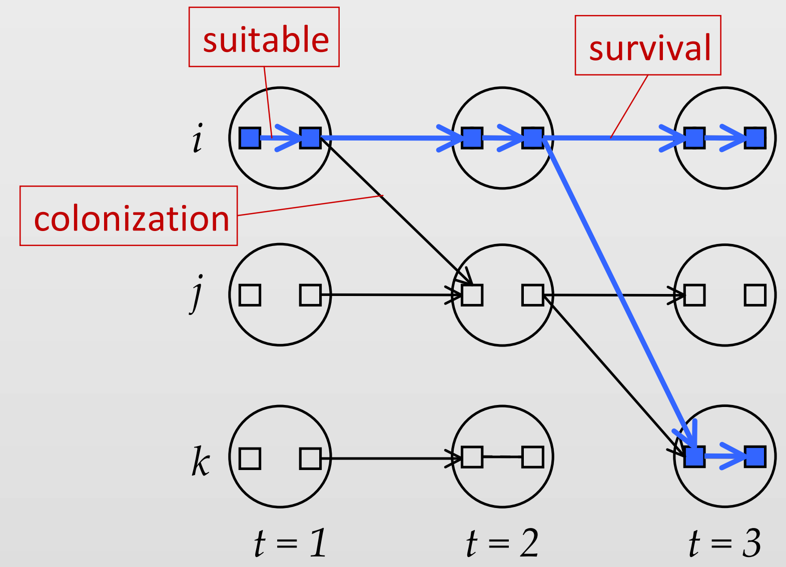

Figure 4. Time unrolled graph

- The circles represent a territory in a specific year
- Horizontal lines between squares inside the circles indicate suitability of that territory in that year
- Horizontal lines between circles indicate non-extinction from one year the next. These are present with probability 1 - β
- Diagonal lines indicate potential colonization events; colonization occurs only if the source territory is occupied. These edges are present with probability p_{ij}
- Blue lines indicate actual colonization and non-extinction (e.g. territory i colonizes territory j at t=2)
- The occupied territories at t=3 are only those that can be reached from t=1 by a sequences of edges

Optimization

- We sample many scenarios representing different outcomes of colonization and extinction events
- Goal: maximize the number of colonized territories in final year T, averaged over all scenarios
- Decision variables: which territories to purchase (i.e., make suitable) and in which time period
- Budget constraint limits the total cost of the territories we can purchase
- Purchase constraints let us buy each territory once
- Flow constraints between territories
- Capacity constraints restrict flow to suitable and colonization edges
- Integrality conditions on decision and flow variables

Network Flow Model

$$\begin{array}{lrcll}
\text{maximize} & (1/K)\sum_{k=1}^{K}\sum_{i\in\mathcal{R}} x^{ik}(i,T) & & & \\
\text{subject to} & \sum_{i\in\mathcal{R}}\sum_{t=1}^{T} b(i,t)y(i,t) & \leq & B, & \text{Budget constraint} \\
\text{Purchase constraints} & \sum_{t=1}^{T} y(i,t) & \leq & 1, \quad \forall i & \\
\text{Suitability constraints} & x^{rk}(i,t) & \leq & \sum_{s=1}^{t} y(i,s), \quad \forall\, r,k,i,t & \\
\text{Colonization constraints} & z^{rk}(i,j,t) & \leq & a^{k}(i,j,t), \quad \forall\, r,k,i,j,t & \\
 & \sum_{i\in\mathcal{R}} z^{rk}(i,j,t) & = & x^{rk}(j,t), \quad \forall\, r,k,j,t & \\
\text{Flow constraints} & x^{rk}(i,t) & = & \sum_{j\in\mathcal{R}} z^{rk}(i,j,t+1), \quad \forall\, r,k,i,t & \\
 & x^{rk}(i,t),\ y(i,t),\ z^{rk}(i,j,t) & \in & \{0,1\} \quad \forall\, r,k,i,j,t &
\end{array}$$

Solving Large-Scale Models

- Large mixed-integer programs (MIP) like ours are very difficult to solve
- We have employed the following "LP-rounding" approach rather than solving the MIP directly:
  - Solve the relaxed LP version
  - Set any integer variables < .1 to 0
  - Set the largest integer variable to 1
  - If new bounds result in infeasibility, set the previous variable to 0
  - Repeat until an integer solution is reached
- This approach is generally much faster than solving the original and obtains close to optimal results
- The table below shows the results for testing our 33 territories for 10 years, 5 simulations, random territory costs and a variable budget.

Budget	IP Solution	LP Rounding	% Optimal
300	6.6	5.8	87.9
400	8.4	6.6	78.6
500	10.2	10	98.0
600	12	11.4	95.0
700	13.6	13.2	97.1

Table 1. Average occupied territories in 10th year

Acknowledgments

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