SPATIAL-DYNAMIC MANAGEMENT OF INVASIVE SPECIES IN A RIVER NETWORK:

Stochastic Species Dispersal and Native-Invasive Species Competition

H.J. Albers
Oregon State University
with Kim Hall, Majid Taleghan, Tom Dietterich, and Mark Crowley
INVASIVE SPECIES: THE ISSUE

- What makes a species invasive?
- Why do we care?
  - Economically Costly
    - Interrupt productive processes
    - Costly removal
    - Costly prevention and control policies
  - Ecologically Costly
    - Reduces biodiversity
    - Disrupts provision of ecosystem services
ECONOMICS OF INVASIVE SPECIES

- Until recently:
  - Dispersal via trade
  - SDP approaches - purely dynamic
  - Limited spatial work - often steady state

- Little on ecological process of invasion
  - Species competition
  - Non-trade dispersal pathways

- Invasion as Spatial and Dynamic Process
  - Management of the frontier
  - Deterministic or steady state analyses typical
Analytical solutions rare or not descriptive

Numerical solutions confounded by dimensionality

NSF-funded program in Computational Sustainability
  - Programming methods
  - Results analysis
Spatial-temporal bioeconomic model of invasive species

- Economic optimization decision framework
- Spatial representation (river network)
- Ecological model of species dispersal and competition
- Dynamic Programming Computational Solution Method
Metapopulation Model

Reaches in network (here, 5)

Habitat sites per reach
- Native, invasive, empty

In each time period:
- Natural death*
- Propagule production (can vary rate - one competition method)
- Dispersal*
- Site-competition*, colonization, establishment

(*represents stochastic component)
Minimize expected discounted costs (sum of cost of invasive and cost of management)

Choose timing and location of management options \((m)\):
- do nothing
- eradicate
- eradicate and restore

Subject to annual budget constraint

Subject to ecological growth/dispersal
ECONOMIC OPTIMIZATION MODEL

\[ \min_{m_{it}, t, i} \left( c_{it}(n_{it}, m_{it}) \right) \]

s.t. \[ c_{it}(n_{it}, m_{it}) \leq b_t \quad t \]

s.t. ecological growth and dispersal model
ECOLOGICAL MODEL: DISPERSAL

\[ K_{ij} = C u^{NU_{ij}} d^{ND_{ij}} \]

Where:

- \( C \) is a normalization constant
- \( u \) is the upstream propagule survival rate
- \( d \) is the downstream propagule survival rate
- \( NU_{ij} \) is the # of upstream reaches between reach i and j
- \( ND_{ij} \) is the # of downstream reaches between reach i and j
ECOLOGICAL MODEL: COMPETITION AND COLONIZATION OF EMPTY SITES

\[ p_k = \frac{g_k}{(g_k + g_k)} \]

Where

\[ P_k = \text{probability that species } k \text{ wins competition} \]

\[ B = \text{competitiveness parameter} \]

\[ g_i = \text{number of propagules of species } i \]
**Solution Method**

- **Markov Decision Process**
- **Near-optimal policy for each possible state**
  - Dimensionality issues - 14 billion combinations
  - Estimate transition probabilities matrix by drawing samples from stochastic ecological simulation model
    - Until within small confidence bounds
  - Use value iteration on approx. transition matrix
- **Pathways program defines possible evolutions from a starting state**
RESULTS: ROLE OF NATIVES/HABITAT CONDITIONS

- Habitat quality: natives v. empty sites
- Native species
  - Provide propagules to lower invasive’s colonization success
  - Make habitat sites unavailable for invaders
- Impact on Policy: for same invasive pattern
  - Restore (plant natives) more often when empty sites
  - Eradicate when have more natives
EMPTY VERSUS NATIVES IN HABITAT SITES
Increasing downstream flow moves eradicate and restore upstream.

Less focus on reach 3.
High downstream dispersal \((d \gg u)\)
- Propagules leave system so less invasion pressure
  - Eradicate more, less benefit to Restore
- Low impact of downstream invasion on upstream
  - Treat upstream

High propagule production case
- More even treatments across space
- But still tend towards upstream at higher \(d\)
With no long-distance dispersal, more likely to:
- eradicate than restore (especially upstream)
- treat center reach - reach 3

So, ignoring long distance, low probability invasions leads to inefficient policy types and locations.
Species Competition (1)

- Site-competition
  - An ability to out-compete once arriving at a site
  - In model: $\beta > 1$, disproportionately competitive

- Propagule Production
  - Produce many propagules/seeds
  - More seeds, more likely to establish

- Both species’ characteristics matter

- Tamarisk in Cottonwood area
  - Tamarisk swamps system with propagules
  - Cottonwood better at site-competition
COMPETITION COMPARISON

Tamarisk: propagule production

Site competition advantage
Species Competition (2)

- Site Competition
  - Policy centers on eradication
    - High value to get propagules out of system
  - Treat upstream
    - Protect all reaches by removing propagules

- Propagule Production Advantage
  - Policy centers on restoring
    - Removes invasive propagules
    - Increases number and ratio of native propagules
    - Blocks invasion in that reach
  - Treat reach 3 then upstream to downstream
    - Propagules in reach 3 can easily spread everywhere
RESULTS: RULE OF THUMB POLICIES VS. OPTIMAL

- Near-Optimal Policy Pathway from model
- Managers and Literature suggest:
  - Triage: treat most invaded reaches first
  - Chades, et al.: upstream first; extreme nodes first (one reach treated per period)
  - Treat leading edge of spread
COST COMPARISONS: RULE OF THUMB POLICIES VS. OPTIMAL

Total Costs

- Large pop, up to down
- Chades
- Leading Edge
- Optimal
ONGOING AND FUTURE WORK

**Ongoing:**
- More investigation of space-time interactions
- Stochastic arrivals
- Broader network
- Other objective functions
- Human dispersal via boating
- Application to Tamarisk

**Computational**
- Algorithm for learning to reduce sampling
- Relational learning to distill general rules

**Future:**
- Other spatial ecological dispersal patterns
- Monitoring/detection
Patterns of enforcement and livelihood project locations

Marine Protected Areas in low-income countries

Forest degradation; REDD implementation

Interdisciplinary agent-based modeling of fire prone landscapes

Reserve site selection with spatial risk
CONCLUSION

- Characteristics of habitat within and beyond invaded reaches inform policy

- Directionality: treat upstream

- Long-distance dispersal matters for both location and type of policy

- Ecological process of invasion matters

- Rules of thumb policies can be quite wrong: spatial processes inform optimal policies