Cost-Effective Recovery of an Endangered Species: The Red-Cockaded Woodpecker

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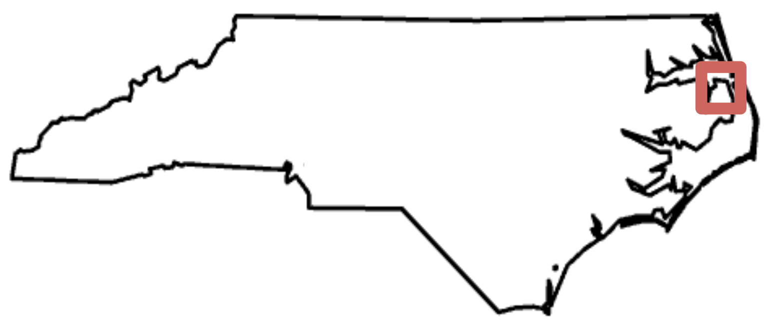
The Red-Cockaded Woodpecker

Fig (a). Adult female RCW outside nesting cavity

- Listed as an endangered species in 1970.
- A 'keystone species' – primary excavator of cavities used by at least 27 other species
- We base our analysis on population in Palmetto Peartree Preserve



The Red-Cockaded Woodpecker

- Cooperative breeders
  - Live in breeding groups consisting of a breeding pair and up to 4 adult helpers
  - Each member occupies its own cavity
- Territorial
  - Breeding groups occupy territories (100-500 acres) consisting of nesting (cavities) and foraging habitat
- Population Dynamics
  - New territory creation is rare
  - Environmental carrying capacity limited to the number of suitable cavity clusters

RCW Management

- Majority of current RCW populations are managed
- Artificial Cavity Construction
  - Replace cavities in existing territories
  - Create territories in previously unoccupied habitat
- Translocation
  - Male and Female from donor population relocated to unoccupied territory

The Red-Cockaded Woodpecker

Fig (b). Cavity tree mortality (insert) artificial RCW cavity

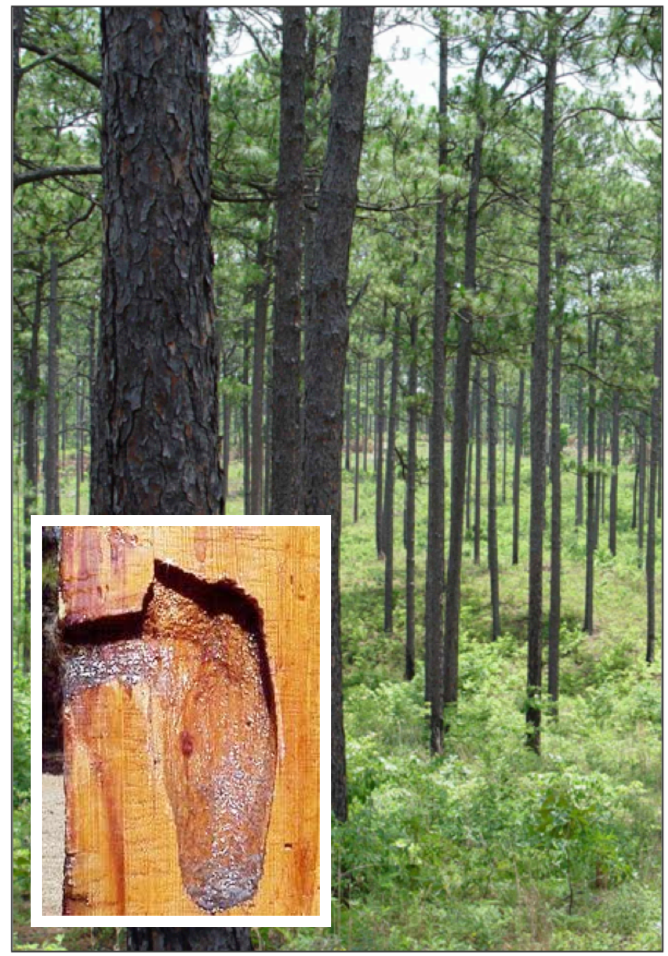


Fig (c). Suitable RCW habitat

RCW Recovery Model

- The population in *t+1* is a realization of the stochastic map $N_{t+1} = F(N_t, K_t, S_t; \varepsilon_{t+1})$.
- The carrying capacity in *t+1* is a deterministic map $K_{t+1} = Min\left[G(K_t, S_t), K_{MAX}\right]$.
- $X_{i,t} \in \{0,1,2,\ldots,X_{i,MAX}\}$ denotes the discrete choice set for the i^{th} recovery action in period *t*.
- We attempt to solve for the sequence of recovery actions that reaches a specified population target at a minimum cost.
  - deterministic and stochastic instances

RCW Problem Specification

$$\underset{\{X_{1,t},\,X_{2,t}\}}{Minimize} \quad C = \sum_{t=0}^{t=T-1} \rho^t \left(c_1 X_{1,t} + \; c_2 X_{2,t}\right) + \rho^T \psi\,(N_T^* - N_T)$$

$$Subject\ to \quad N_{t+1} = \epsilon_{t+1}\left\{sX_{1,t} + \left(1 + r - \frac{rN_t}{K_t}\right)N_t\right\}$$

$$K_{t+1} = \min\left[\{(1-a)K_t + X_{2,t}\}, K_{MAX}\right]$$

$$X_{1,t} \in \; \{0,1,2,\ldots, X_{1,MAX}\}$$

$$X_{2,t} \in \; \{0,1,2,\ldots, X_{2,MAX}\}$$

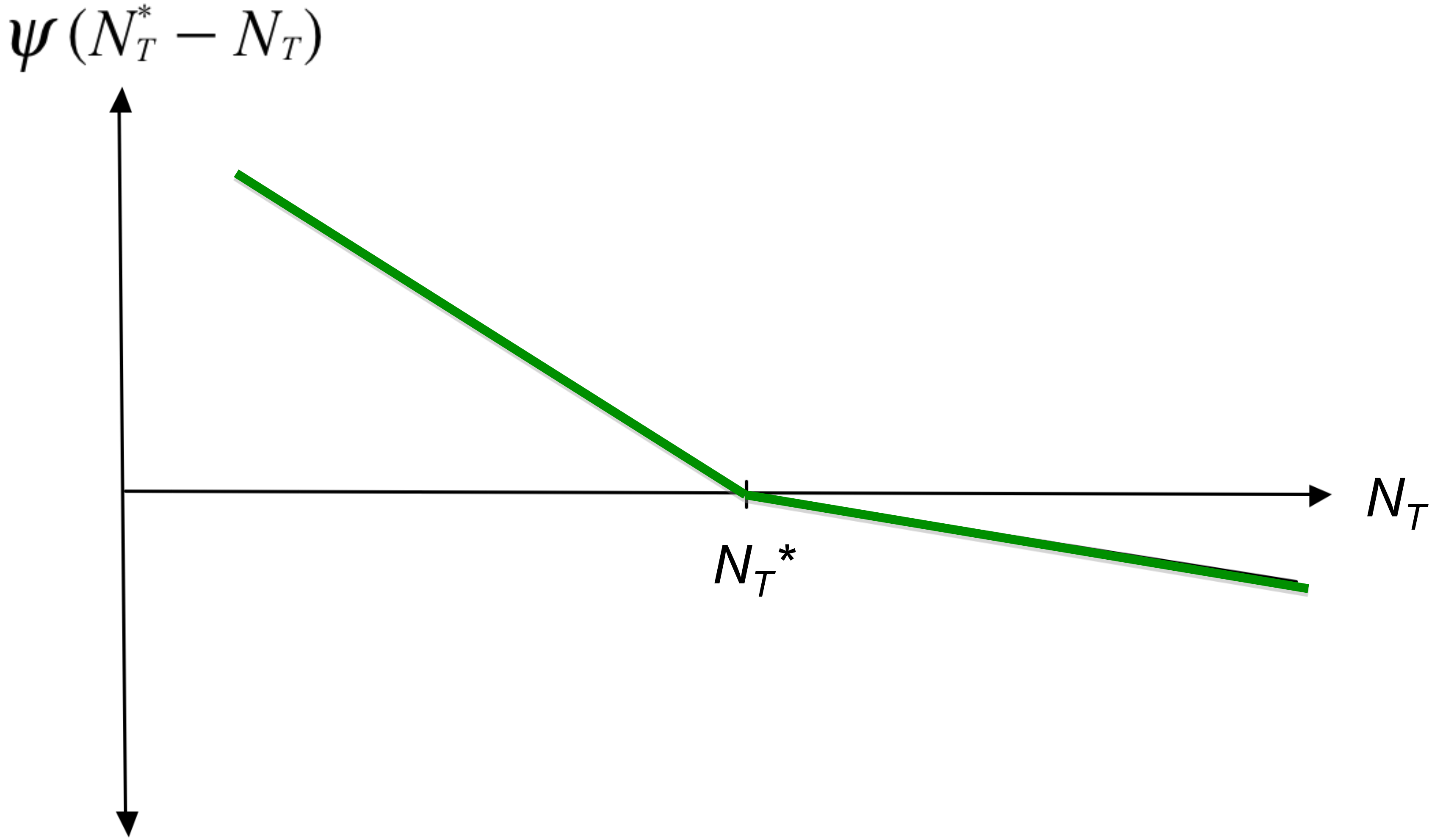
$$\psi(N_T^* - N_T) = \$Q(N_T^* - N_T) \quad \text{if} \quad N_T^* \geq N_T$$

$$\psi(N_T^* - N_T) = \$R(N_T^* - N_T) \quad \text{if} \quad N_T^* \leq N_T$$

$$K_t \geq N_t$$

$$K_0 > 0, N_0 \geq 0, given.$$

Penalty Function



Parameter Description and Estimates

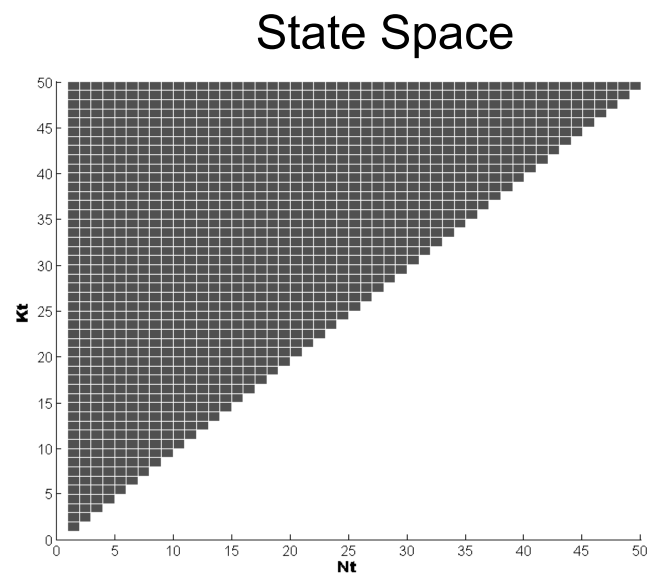
Parameter	Description	Value
r	intrinsic growth rate	0.13
s	translocation success rate	0.25
a	rate of decrease in carrying capacity due to cavity tree mortality, hardcover encroachment, kleptoparasitism, etc.	0.1
K_{MAX}	upper bound on carrying capacity	50
$X_{1,MAX}$	upper bound on the number of breeding pairs to be translocated per time period	6
$X_{2,MAX}$	upper bound on the number of recruitment clusters to be constructed per time period	10
N_0	number of breeding pairs at time $t = 0$	20
K_0	number of managed cavity clusters at time $t = 0$	30

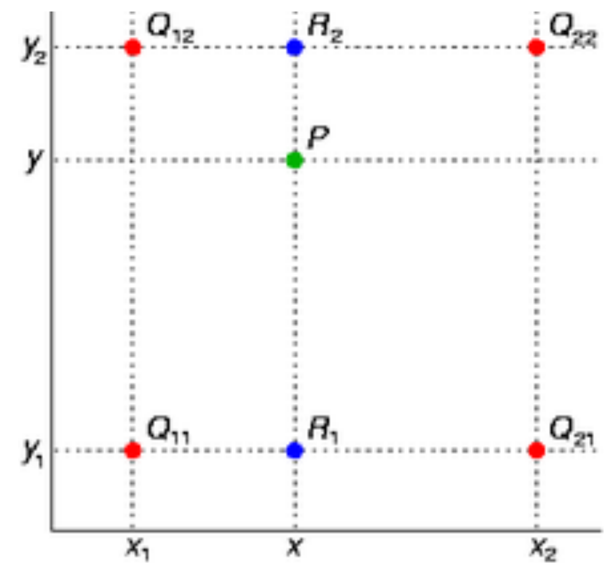
Parameter Description and Estimates

Parameter	Description	Value
c_1	cost of translocating one breeding pair	\$3,000
c_2	cost of constructing one recruitment cluster (four artificial cavities)	\$800
ε_{t+1}	random variable	$\Pr(\varepsilon = 0.75) = 0.25$
		$\Pr(\varepsilon = 1.00) = 0.50$
		$\Pr(\varepsilon = 1.25) = 0.25$
R	'Bonus' per breeding pair exceeding N_T*	\$5,000
Q	'Penalty' per breeding pair less than N_T*	\$40,000
δ	discount rate	0.05
ρ	$1/(1 + \delta)$	0.952
T	time horizon	10

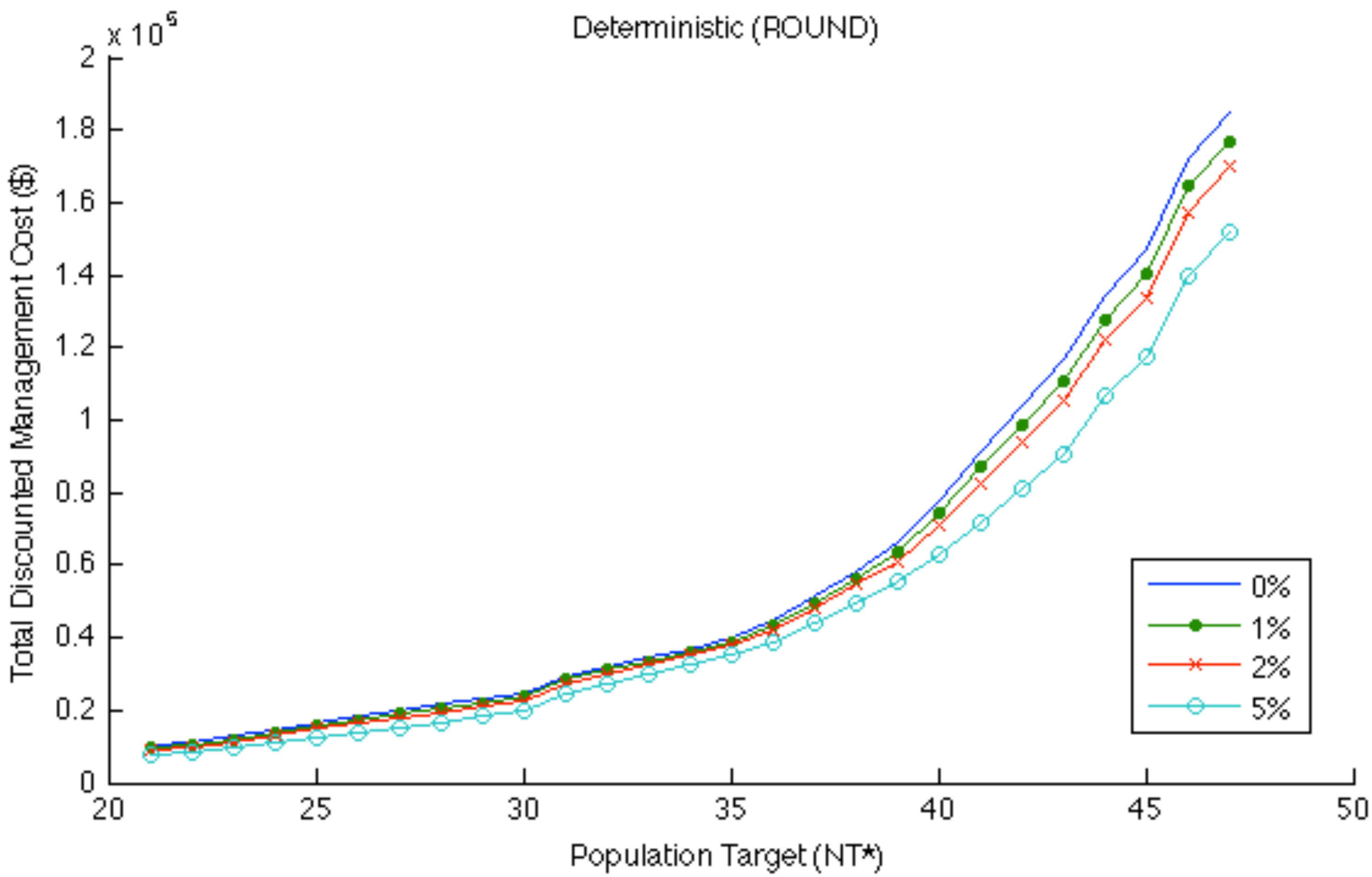
Optimization

- Dynamic Programming used to solve deterministic and stochastic models
- *round() used* to determine state transitions in deterministic model
- Bilinear interpolation used to determine state transitions in stochastic model





Total Discounted Management Cost

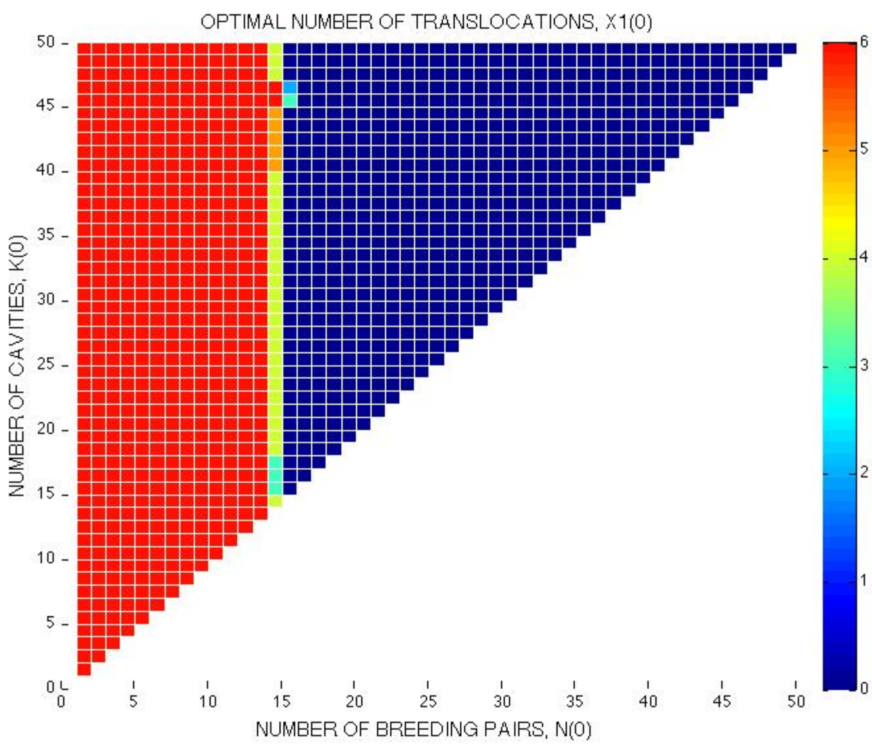


Optimal Management Actions ($N_T^* = 42$)

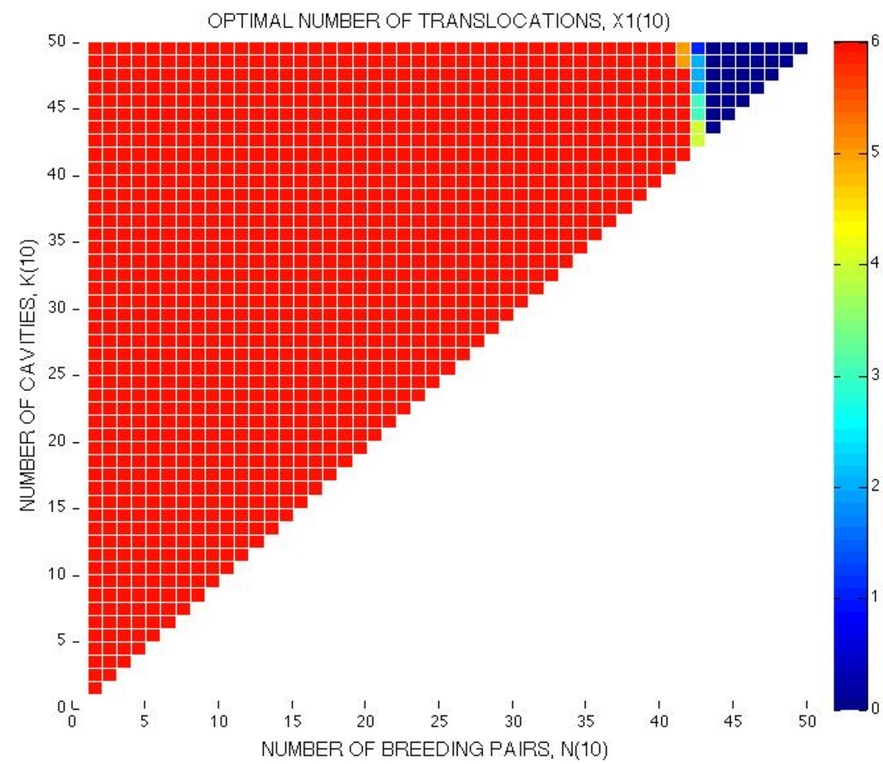
	$\delta = 0$		$\delta = 0.05$	
t	***X1(t)***	***X2(t)***	***X1(t)***	***X2(t)***
0	3	8	0	7
1	6	10	2	10
2	1	10	1	10
3	0	7	0	6
4	0	5	0	6
5	0	5	0	6
6	1	5	0	2
7	1	5	5	8
8	1	4	5	4
9	6	0	6	0
10	0	0	0	0

Optimal X_1 ($N_T^* = 42$)

t = 0

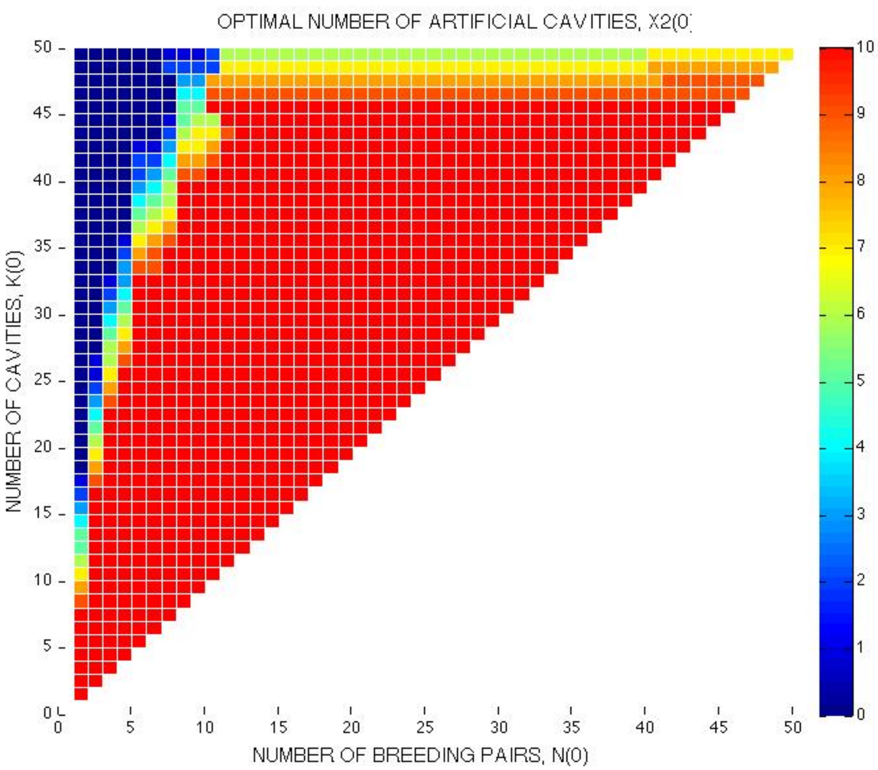


t = 9

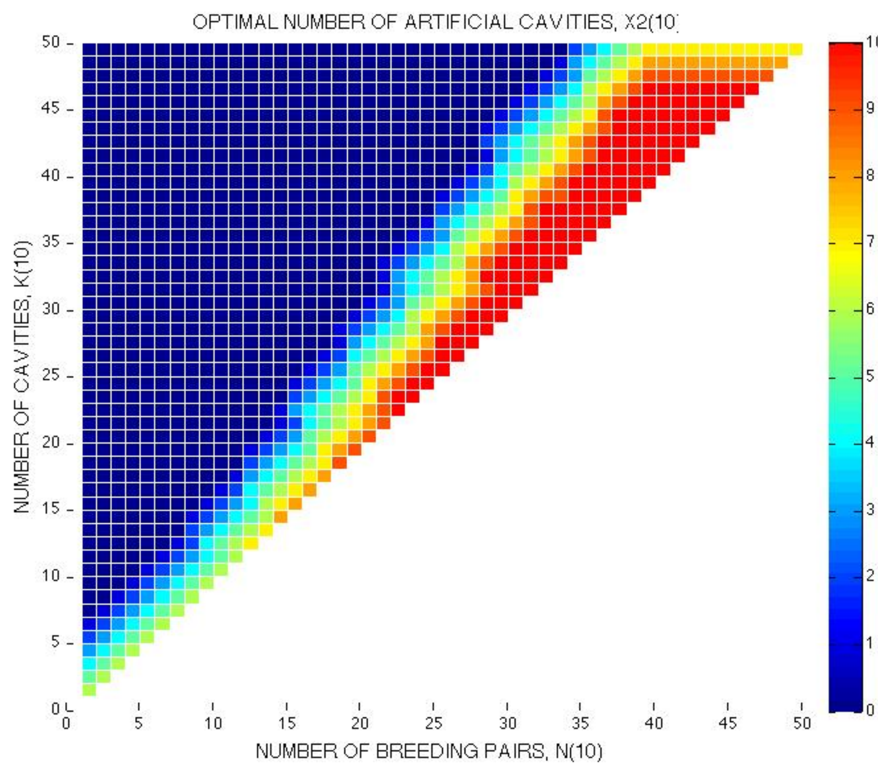


Optimal X_2 (N_T* = 42)

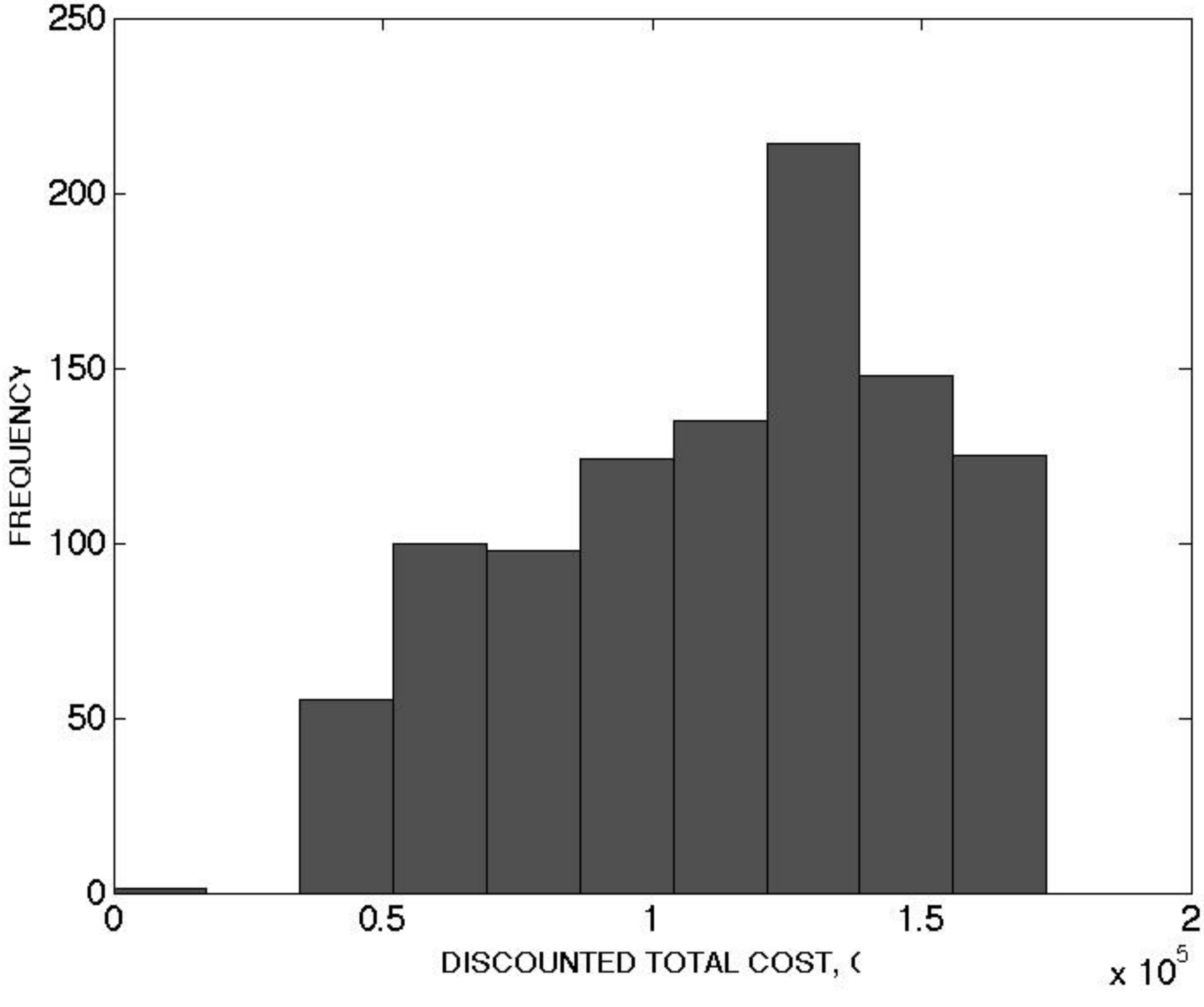
t = 0



t = 9



Frequency of Discounted Management Cost (N_T* = 42)



Conclusions

- We present an application of our general model for cost-effective recovery of an endangered or threatened species.
- Customized stochastic dynamic programming algorithm used to find optimal, adaptive management plan.
- Future work should incorporate spatial characteristics of the landscape and population.

Acknowledgements

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