Decision-Making for Land Conservation: A Derivative-Free Optimization Framework with Nonlinear Inputs

Technical Appendix[*]

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Data & Code Availability

The data and code can be found at the following repository https://github.com/cassiebuhler/conservation-dfo. For an illustration of the file formats, see Figure 1.

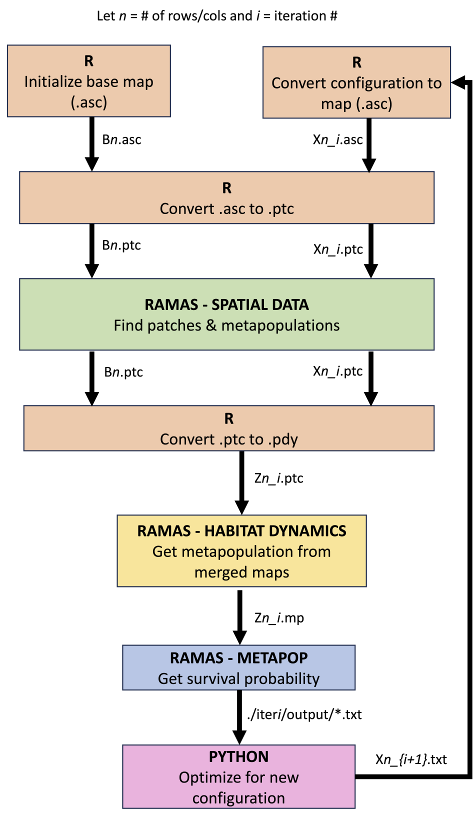

Figure 1: Our software using PVA broken down by each step in the code.

[*]This is the corresponding technical appendix for our paper accepted to AAAI'24.

Framework Parameters

Ant Colony Optimization

The parameters for our *pygmo* optimization solver, ACO (Schlüter, Egea, and Banga 2009), are in Table 1.

Ant Colony Optimization	
Generations	4
Kernel	n
Impstop	1000
Oracle	1e6

Table 1: *Generations* is the number of generations to run the algorithm, *Kernel* is the number of solutions stored in archive, *Impstop* stops the algorithm when this number of runs occurs without improvements, and *Oracle* is the penalty parameter.

PVA Software

The PVA component of our framework was implemented with *RAMAS GIS* (Akçakaya and Root 2013a) and *RAMAS Metapopulation* (Akçakaya and Root 2013b). In *RAMAS GIS*, we used *RAMAS GIS: Spatial Data* for generating our habitat and metapopulation, and *RAMAS GIS: Habitat Dynamics* to simulate the effects of parcels being protected. The parameters for *RAMAS GIS: Spatial Data* are in Table 2 and *RAMAS GIS: Habitat Dynamics* in Table 3. They are separated into their respective categories by where the input appears in the RAMAS interface.

Then, PVA was conducted in *RAMAS Metapopulation*, where each habitat configuration was evaluated for 100 years, and replicated 1000 times.

Density Dependency Scramble is defined in the RAMAS User Manual (6.0) as "Logistic or Ricker type of density dependence, characteristic of the effect of scramble competition."

The deterministic growth rate based on population size at time step t is the following

$$R(t) = R_{\max} * \exp\left(\frac{\ln(R_{\max}) * N_p}{K(t)}\right) \quad (1)$$

where N_p is the current total number of individuals in a population p, and $K(t)$ is the carrying capacity at time t. Because our data is randomly generated, this type was also randomly selected.

Dispersal and Correlation The dispersal rate (migration) between population i and population j is calculated as

$$a * \exp\left(\frac{-D_{ij}^c}{b}\right). \tag{2}$$

This function is also used as the correlation of population fluctuation between population i and population j.

RAMAS GIS: Spatial Data	
Habitat Relationships	
HS function	[<ASC file>]
HS threshold	0.500
Neighborhood distance (cells)	1.00
Link to Metapopulation	
Carrying capacity (K)	$ths * 4$
R_{max}	1.5
Initial abundance	$ths * 2$
Relative survival	$\max(1, ths * 1.2)$
Relative fecundity	$\max(1, ths * 1.2)$
Distances	Edge to edge
Default Population	
Local threshold	0
Density dependency type	Scramble
Standard deviation of K	0
Dispersal	
a	0.5
b	0.8
c	1
D	1
Correlation	
a	0.8
b	2
c	1

Table 2: Parameters for RAMAS GIS: Spatial Data. *ths* is total habitat suitability. The formula for dispersal and correlation is (2)

RAMAS GIS: Habitat Dynamics	
Habitat Changes	
B - Time step	1
B - K change to next	same until next
B - F change to next	same until next
B - S change to next	same until next
Z - Time step	10

Table 3: Parameters for RAMAS GIS: Habitat Dynamics. We assume the habitat is B for the first 10 years, then use Z for the remaining 90 years. *K* is the carrying capacity, *S* is the relative survival rate, and *F* is relative fecundity rate. These values are dependent on *ths*, thus abundance will change from B to Z.

Additional Figures

Visualizing PVA Metrics

In Figure 2, we visualize PVA metrics with an example of a habitat configuration that was predicted to go to extinction.

Framework Solutions

In this paper, we presented the figures for the solution to the 10×10 constrained model. Here we include the Z configuration, except only where it is habitable. In Figure 3 we display the 10×10 results and in Figure 4 has the 20×20 results.

References

Akçakaya, H. R.; and Root, W. 2013a. RAMAS GIS: Linking spatial data with population viability analysis. *Applied Biomathematics, Setauket, NY*.

Akçakaya, H. R.; and Root, W. 2013b. RAMAS Metapop: Viability analysis for stage-structured metapopulations (version 6). *Applied Biomathematics, Setauket, NY*.

Schlüter, M.; Egea, J. A.; and Banga, J. R. 2009. Extended ant colony optimization for non-convex mixed integer nonlinear programming. *Computers & Operations Research*, 36(7): 2217–2229.

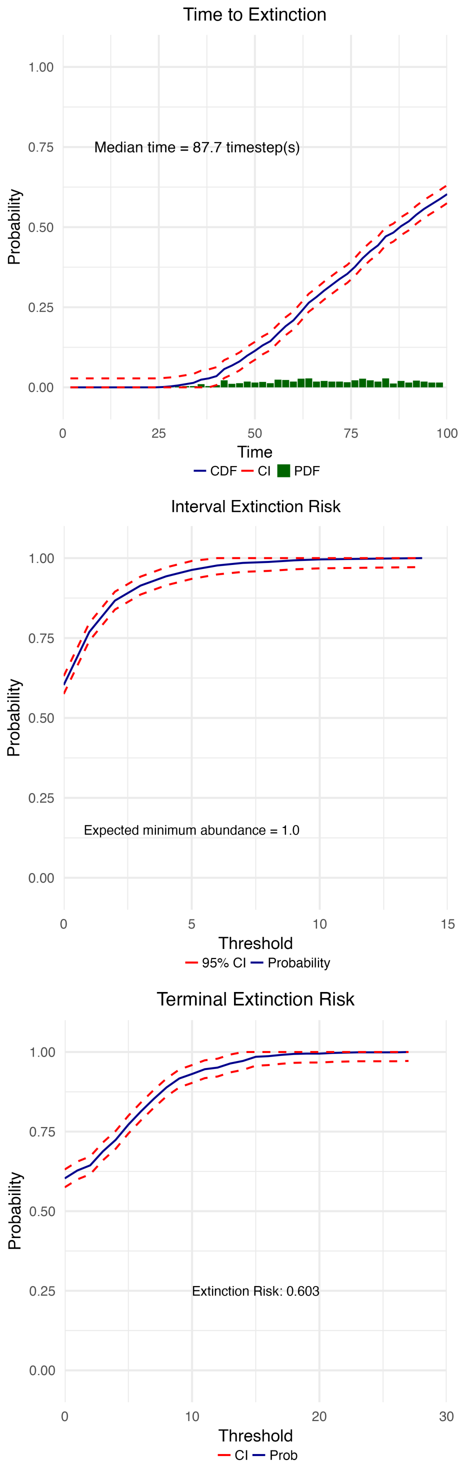

Figure 2: Median time to quasi extinction is where the probability is 0.5. Expected minimum abundance is where the probability is 0.5. Risk of extinction is the probability when the threshold is 0.

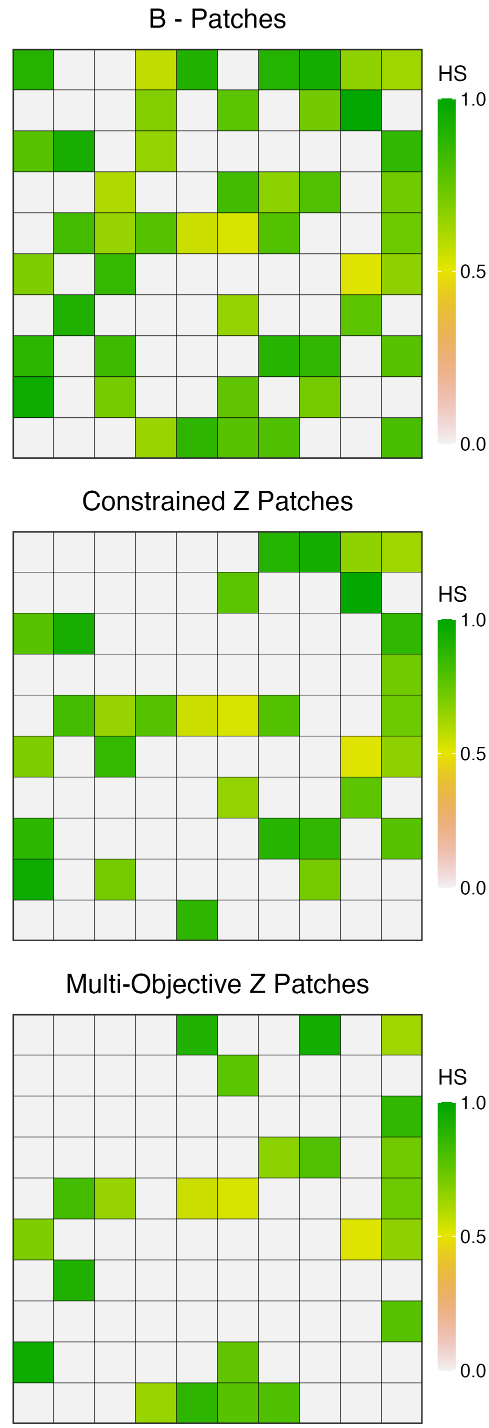

Figure 3: 10×10 solutions from paper. The baseline habitat has 16 populations. The constrained model has 12 populations and the multi-objective model has 13 populations.

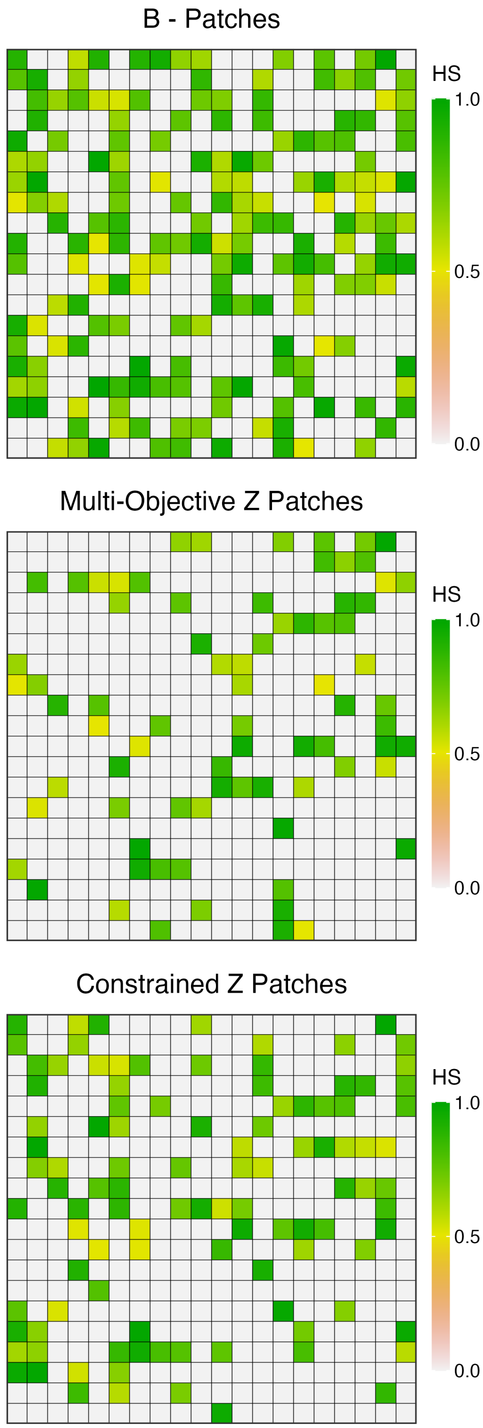

Figure 4: 20×20 solutions from paper. The baseline habitat has 35 populations. The constrained model has 43 populations and the multi-objective model has 48 populations.