Technical Appendix

Anonymous submission

Data & Code

The data and code are included in the SI zip file. Refer to the **README.md** file. For an illustration of the file formats, see Figure 1.

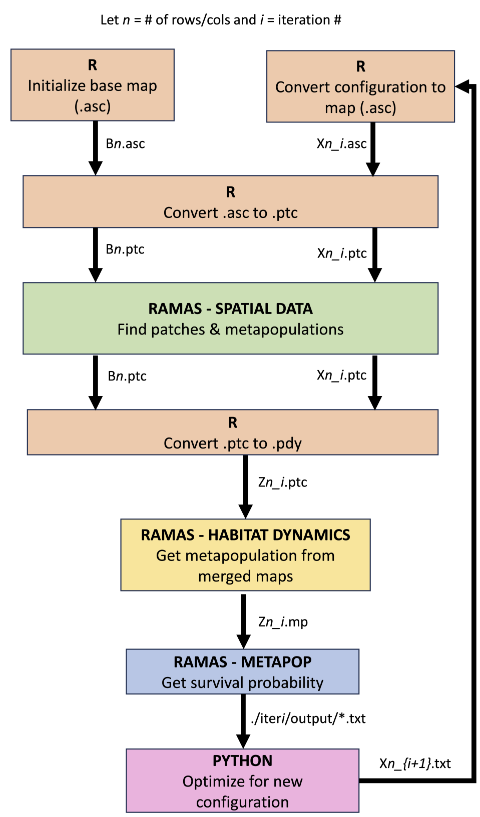

Figure 1: Our software using PVA broken down by each step in the code.

Parameters

The parameters for RAMAS GIS: Spatial Data are in Table 1 and RAMAS GIS: Habitat Dynamics in Table 2. They are separated into their respective categories by where the input appears in the RAMAS interface.

For RAMAS Metapopulation, we used 1000 replications with a duration of 100 years.

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 1: RAMAS GIS: Spatial Data parameters. *ths* is total habitat suitability.

Dispersal and Correlation Function The dispersal rate between population i and population j is calculated as

$$a * \exp\left(\frac{-D_{ij}^{c}}{b}\right). \tag{1}$$

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

Density dependency type

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

$$R(t) = R_{\text{max}} * \exp\left(\frac{\ln(R_{\text{max}}) * N_p}{K(t)}\right) \tag{2}$$

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.

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 2: 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.

In addition, the ACO parameters used in *pygmo* are in Table 3.

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

Table 3: *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.

Additional Figures

Result Solutions

In the 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 2 we display the 10×10 results and in Figure 3 has the 20×20 results.

PVA Metrics

In Figure 4, we visualize the PVA metrics used in the paper with an example of a habitat configuration that was predicted to go to extinction.

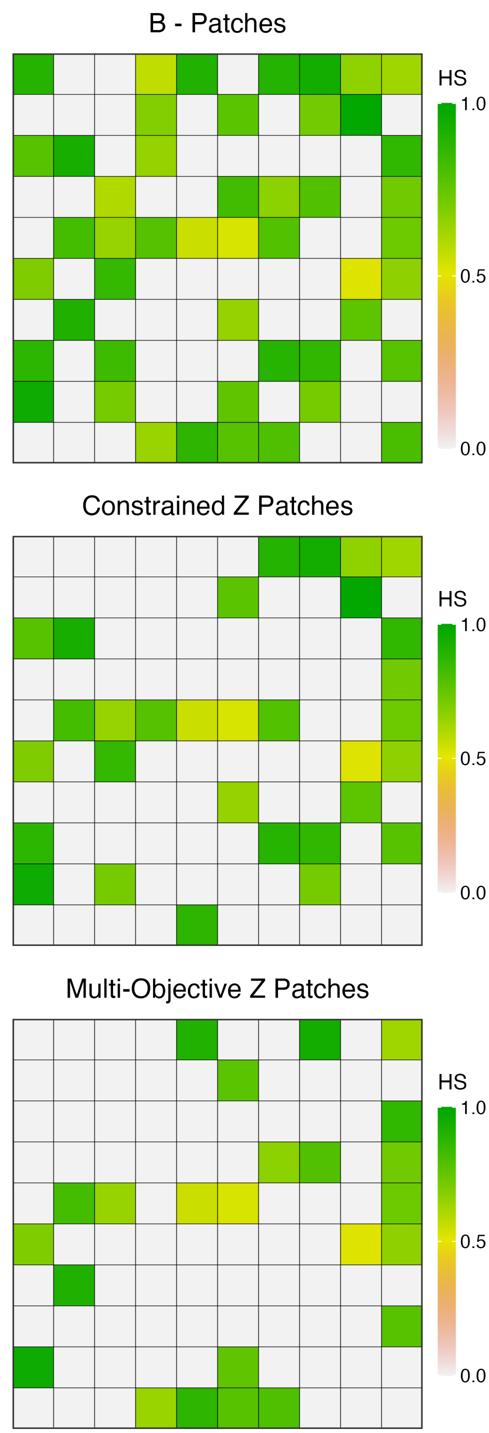

Figure 2: 10×10 solutions from paper. The baseline habitat has 16 populations. The constrained model has 12 populations and the multi-objective model has 13 populations.

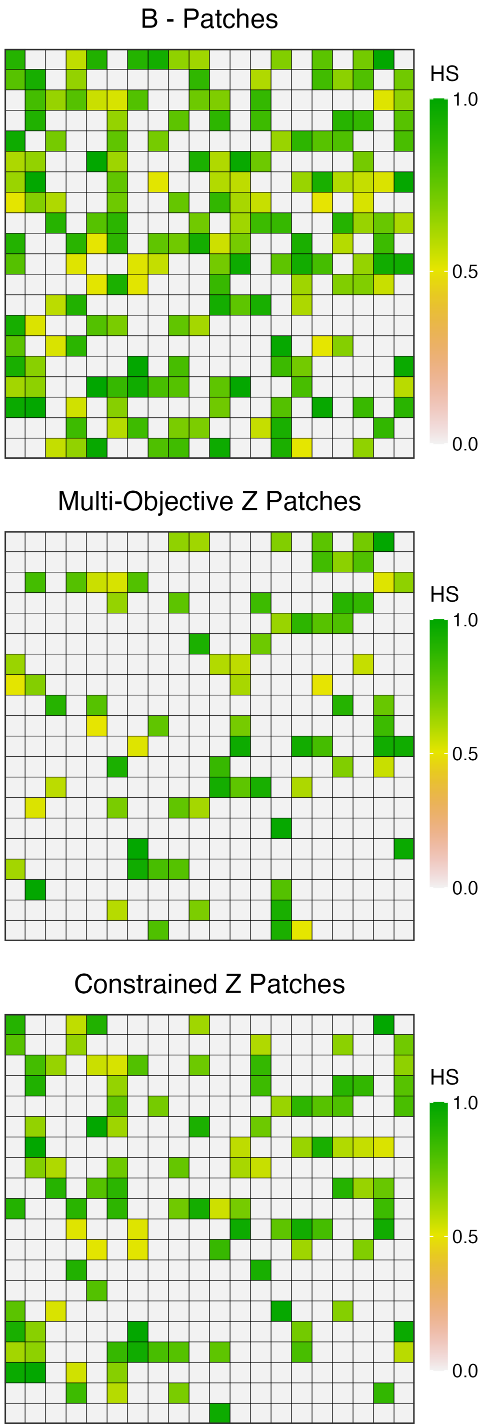

Figure 3: 10×10 solutions from paper. The baseline habitat has 35 populations. The constrained model has 43 populations and the multi-objective model has 48 populations.

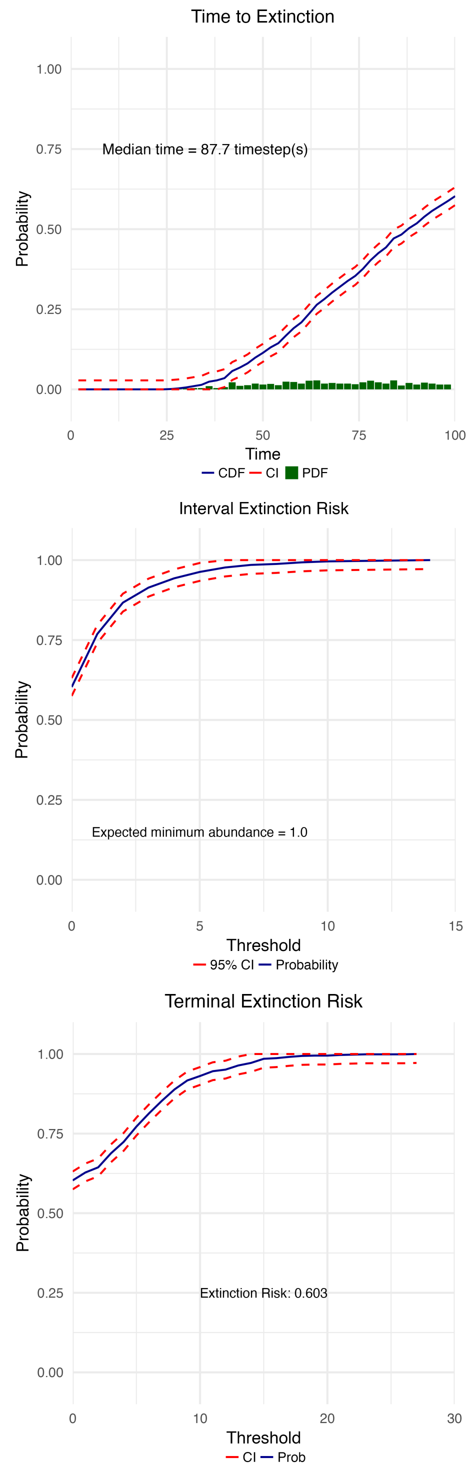

Figure 4: Median time to quasi extinction is where the probability is 0.5. Expected minimum abundance is where the probability is 0.5. Risk of extinction is the probability when the threshold is 0.