Systematic reserve design

Introduction to Marxan
Conservation planning


- Compile biodiversity data for planning region
- Identify conservation goals for planning region
- Review existing conservation areas
- Select additional conservation areas
- Implement conservation actions
- Maintain values of conservation areas
Conservation planning


- Compile biodiversity data for planning region
- Identify conservation goals for planning region
- Review existing conservation areas
- Select additional conservation areas
- Implement conservation actions
- Maintain values of conservation areas
Gap analysis

• Identify existing levels of conservation
• Compare with conservation goals
• Calculate conservation shortfalls
Conservation planning


- Compile biodiversity data for planning region
- Identify conservation goals for planning region
  - Review existing conservation areas
  - Select additional conservation areas
- Implement conservation actions
- Maintain values of conservation areas
Reserve selection – optimization

• To address shortfalls identified in gap analysis
• Resources are finite, so “low cost” solutions are preferable
• Optimal “solution” vs. portfolio of “low cost” options
• Reserve selection is usually spatial, however tools can be used more broadly
• Marxan, Zonation, heuristics, other?
What is Marxan?

- Designed to explore trade-offs between conservation and socio-economic objectives
- Reserve System Design
- Minimum Set Problem
- University of Queensland (Ian Ball, Hugh Possingham)
- Over 100 peer-reviewed papers using Marxan over the past decade
Key Concepts

- Comprehensiveness
- Representativeness
- Efficiency
- Spatial Arrangement: Compactness and/or Connectedness
- Flexibility
- Complementarity
- Selection Frequency vs. Irreplaceability
- Adequacy
- Optimization, Decision Theory and Mathematical Programming
Comprehensiveness and Representativeness

• Comprehensiveness: Sample the full range of biodiversity (both typical and atypical)
  • Biodiversity composition
  • Structure and function
  • Evolutionary processes

• Representativeness: Reserve systems should capture biodiversity that is representative of their surroundings
Efficiency

• Marxan finds solutions to the minimum set problem where the objective is to minimize the cost of the reserve network while meeting all the biodiversity goals

• Factors limiting the efficiency of a reserve
  • The area available for reservation
  • Acquisition costs
  • The costs of ongoing management
  • Opportunity costs
Compactness and/or Connectedness

- A compact reserve system has a low edge-to-area ratio
- Structural Connectivity
- Functional Connectivity
Flexibility

- Options to achieve the conservation objectives in a number of ways

Option 1

Option 2
Complementarity

- Complementarity: the extent to which a reserve advances the goal of representing biodiversity in a network, by contributing unique elements.

Selection Frequency as Irreplaceability

• High irreplaceability = High priority

Adequacy

• The selected reserve system should be adequate to ensure the persistence of all features contained within
  • population viability
  • ecological processes
  • interaction between species, ecosystems, and landscape dynamics
• Adequacy can be addressed in Marxan by
  • Minimum patch area
  • Boundary length modifier
  • Replication and the minimum distance function
  • Planning units can be used to lock in areas that are 100% critical to species persistence and lock out highly threatened areas

Map of adequacy, measured by the proportion of each unique class (combination of environmental variables) that is represented in the reserve system. Sharafi et al. 2012.
Optimization, Decision Theory and Mathematical Programming

- Optimization: trying to find the best, or very good, solutions to a well-defined problem
- Decision theory: any mathematical, economic or social science that helps us make decisions
- Mathematical programming: Tool or algorithm used for optimization
  - Simulated annealing

\[ \sum_{P_1} \text{Cost} + \sum_{B_1} \text{BLM} + \sum_{B_2} \text{Boundary} + \sum_{C_v} \text{SPF} \times \text{Penalty} + \text{CostThresholdPenalty}(t) \]

1. The total cost of the reserve network (required)
2. The penalty for not adequately representing conservation features (required)
3. The total reserve boundary length, multiplied by a modifier (optional)
4. The penalty for exceeding a preset cost threshold (optional – see footnote 3)
Simulated Annealing

- Dr. Bob Smith’s Robot on Mars Analogy
Simulated Annealing
Simulated Annealing

September 2013
Best Practices for Systematic Conservation Planning
Simulated Annealing
Marxan – how it works

• Simulated annealing vs. heuristics (greedy, richness, rarity, etc.)
• Input text files: species, planning units, puvrsp, boundary
• Random seeds
• Sum solutions, best solution
• An absolute optimum is unlikely to be found in a typical planning situation, so the goal is to identify core sites + other opportunities
Marxan – Input files

Marxan
- Planning units
- Features
- Planning unit vs. features
- Boundary (optional)

Marxan with Zones
- Planning units
- Features
- Planning unit vs. features
- Zones
- Costs
- Zone cost
- Boundary (optional)

All input files are delimited text files, with a “.dat” extension
### Planning units

#### Marxan

<table>
<thead>
<tr>
<th>variable Name</th>
<th>default</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Critical</td>
<td>The id number for this planning unit (P.U.). It must correspond to the planning unit versus species matrix and the boundary length file.</td>
</tr>
<tr>
<td>cost</td>
<td>1</td>
<td>The individual cost of each P.U.</td>
</tr>
<tr>
<td>status</td>
<td>0</td>
<td>Whether the P.U. is locked in or out of the system</td>
</tr>
</tbody>
</table>

#### Marxan with Zones

<table>
<thead>
<tr>
<th>variable name</th>
<th>default</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>required</td>
<td>the numeric identifier for this planning unit</td>
</tr>
<tr>
<td>costname</td>
<td>optional</td>
<td>the individual cost of each P.U. Multiple cost fields with different names can be used into Marxan Z's P.U. file. The header ‘costname’ can be replaced with the actual name of the cost but must not include delimiters (spaces, tabs, etc.).</td>
</tr>
</tbody>
</table>
Planning units
Planning units – “cost”

• “Cost”: inverse of “suitability”
• Can be $, does not have to be
• Example:
  • Area
  • Road density
  • Urban density
  • Crop value
  • Urban growth
## Features

### Marxan

<table>
<thead>
<tr>
<th>variable name</th>
<th>default value</th>
<th>notes/description</th>
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<tbody>
<tr>
<td>id</td>
<td>required</td>
<td>the id number of the conservation feature; it must correspond to the planning unit versus conservation feature file</td>
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<tr>
<td>type</td>
<td>o</td>
<td>type is a user-defined type; it is used for 'block definitions'</td>
</tr>
<tr>
<td>target</td>
<td>o</td>
<td>the target amount for the conservation feature</td>
</tr>
<tr>
<td>spf</td>
<td>o</td>
<td>the penalty factor for the conservation feature</td>
</tr>
<tr>
<td>target2</td>
<td>o</td>
<td>minimum clump size; if a clump of a number of planning units with the given conservation feature is below this size then it does not count toward the target</td>
</tr>
<tr>
<td>sepdistance</td>
<td>o</td>
<td>minimum distance at which planning units holding this conservation feature are considered to be separated</td>
</tr>
<tr>
<td>targetocc</td>
<td>o</td>
<td>the number of occurrences of the conservation feature required; this can be used in conjunction with or instead of 'target'</td>
</tr>
<tr>
<td>sepnun</td>
<td>o</td>
<td>target number of mutually separated planning units in valid clumps</td>
</tr>
<tr>
<td>name</td>
<td>no_name</td>
<td>a name in words; can include spaces; all words in a name must start with a letter</td>
</tr>
<tr>
<td>fpf name</td>
<td>optional</td>
<td>the penalty factor for that feature; indicates the name of the feature; do not include any spaces or non-alphanumeric characters in the name</td>
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### Marxan with Zones

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<th>id</th>
<th>required</th>
<th>the numeric identifier for this feature; the id must be a positive integer</th>
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<tbody>
<tr>
<td>target</td>
<td>optional if prop is used</td>
<td>the target amount (in unit of puvfeat.dat file) of the feature to include across all protected zones (i.e. overall target)</td>
</tr>
<tr>
<td>prop</td>
<td>optional if target is used</td>
<td>an alternative to target; this is the proportion of the total amount of the feature which must be included in the protected zones; a value of 0.3 would indicate that 30% of that feature should be protected</td>
</tr>
<tr>
<td>targetocc</td>
<td>optional</td>
<td>the number of occurrences of the feature required; if the feature occurs in a planning unit, regardless of its amount, that is considered one occurrence; this can be used in conjunction with or instead of 'target'</td>
</tr>
<tr>
<td>propocc</td>
<td>optional</td>
<td>the percentage of occurrences of the feature required; this can be used in conjunction with or instead of 'prop'</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>id</th>
<th>prop</th>
<th>fpf</th>
<th>name</th>
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<td>110</td>
<td>0</td>
<td>1</td>
<td>Saltwater</td>
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<td>0</td>
<td>1</td>
<td>Mudflat0</td>
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<tr>
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<td>0</td>
<td>1</td>
<td>Saltmarsh</td>
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<td>210</td>
<td>0</td>
<td>1</td>
<td>Freshwater</td>
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<tr>
<td>220</td>
<td>0</td>
<td>1</td>
<td>Riparian</td>
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Planning unit vs. features

### Marxan

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<th>Default</th>
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<tbody>
<tr>
<td>species</td>
<td>critical</td>
<td>conservation feature id</td>
</tr>
<tr>
<td>pu</td>
<td>critical</td>
<td>planning unit id</td>
</tr>
<tr>
<td>amount</td>
<td>critical</td>
<td>amount of conservation feature on planning unit</td>
</tr>
</tbody>
</table>

### Marxan with Zones

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>featureid</td>
<td>required</td>
<td>feature identifier – must be indicated in the feature file</td>
</tr>
<tr>
<td>puid</td>
<td>required</td>
<td>planning unit identifier – must be indicated in the planning unit file</td>
</tr>
<tr>
<td>amount</td>
<td>required</td>
<td>amount of feature in the planning unit; the measurement unit between features can be different</td>
</tr>
</tbody>
</table>

Example data:

```
"species", "pu", "amount"
1, 1, 0.273636
2, 1, 0.259194
3, 1, 0.562101
4, 1, 0.369408
5, 1, 0.269983
6, 1, 0.157175
7, 1, 0.399254
8, 1, 0.294276
9, 1, 0.351898
10, 1, 0.283862
11, 1, 0.292283
12, 1, 0.226014
13, 1, 0.341821
```
### Boundary

Marxan and Marxan with Zones

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default</th>
<th>Notes/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>id1</td>
<td>critical</td>
<td>planning unit id</td>
</tr>
<tr>
<td>id2</td>
<td>critical</td>
<td>neighboring planning unit id or the same as id1 for the irremovable boundary</td>
</tr>
<tr>
<td>boundary</td>
<td>critical</td>
<td>the boundary length</td>
</tr>
</tbody>
</table>

JNCC ArcGIS extension from Marxan website for boundary file creation
Zones (Zones only)

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>zoneid</td>
<td>required</td>
<td>the numeric identifier number for the zone; the zoneid must be a positive integer and the file must be sorted by lowest to highest zoneid</td>
</tr>
<tr>
<td>zonename</td>
<td>required</td>
<td>indicates the name of the zone; do not include any spaces or non-alphanumeric characters in the name</td>
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</tbody>
</table>
# Costs (Zones only)

<table>
<thead>
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<th>Variable Name</th>
<th>Default</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>costid</td>
<td>required</td>
<td>the numeric identifier for the cost; the costid must be a positive integer and the file must be sorted by lowest to highest costid</td>
</tr>
<tr>
<td>costname</td>
<td>required</td>
<td>indicates the name of the cost; do not include any spaces or non-alphanumeric characters in the name</td>
</tr>
</tbody>
</table>
## Zone cost (Zones only)

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Default</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>zoneid</td>
<td>required</td>
<td>the zone identifier – must be compatible with the zones.dat file</td>
</tr>
<tr>
<td>costid</td>
<td>required</td>
<td>the cost identifier – must be compatible with the costs.dat file</td>
</tr>
<tr>
<td>multiplier</td>
<td>required</td>
<td>this number can be a fraction or an integer; in a given zone, it will be multiplied by the specified cost. All costs in a given zone will be multiplied by the specified multiplier and then added to give a total cost for each planning unit. For example, if there are 3 costs in one zone, the total cost for that zone would be calculated using the following equation: Total C = (C₁<em>M₁) + (C₂</em>M₂) + (C₃*M₃) Where C = cost, M = multiplier</td>
</tr>
</tbody>
</table>

All costs in a given zone will be multiplied by the specified cost and then added to give a total cost for each planning unit.
Input files – a few tips (learned the hard way)

• A PU or species in puvsp.dat or bound.dat that is not in pu.dat or species.dat will crash the program
• If a PU has no occurrence of a feature, exclude from puvsp.dat, do not use zeroes
• An extra return at the end of a file will crash the program
• Make sure the puvsp.dat is sorted by PU, then species
Running Marxan – Inedit

This program edits an input file for MARXAN v1.8

Created by Ian Rall 1999, Modified by Ian Rall 2001

Load  Save  Save As  Exit
Running Marxan – Inedit

![Input File Editor for Marxan]

- Simulated Annealing
  Options for Simulated Annealing appear on next tab
- Heuristic
- Iterative Improvement
  Normal Iterative Improvement
Running Marxan – Inedit

Annealing Controls

- Number of Iterations: 1000000
- Temperature Decreases: 10000
- Adaptive Annealing
- Initial Temperature: 1
- Cooling Factor: 5
- Final Temperature adaptive annealing
  - Set Cooling From Final Temperature: 7

Load  Save  Save As  Exit
Running Marxan – Inedit

![Input File Editor for Marxan](image)

- Necessary Input Files:
  - Species File Name: spec.dat
  - Planning Unit File Name: pu.dat
  - Planning Unit versus Species: puvspi2.dat

- Optional Input Files:
  - Block Definitions
  - Boundary Length: bound.dat

- Input Directory: input
Running Marxan – Inedit
‘Maximum coverage’ problem
Running Marxan – Inedit

[Image of a software interface showing options for setting starting properties, random seed, and other parameters.]
Running Marxan – input.dat
Running Marxan – input.dat
Running Marxan – input.dat
Running Marxan – input.dat
Example: Conservation Project

- The planning area contains several conservation features - fish, butterflies, and rodents.
- Each planning unit has a cost of 1.
- The boundary length modifier (BLM) has been set at 1.5.
- The species penalty factor (SPF) for all three conservation features is 10.
- The target is to have at least one occurrence of each conservation feature in the solution.

PU cost = 1  
BLM = 1.5  
SPF = 10 (all features)

Target: represent each feature at least once.
Example: Conservation Project

Score = Cost of the reserve system + Boundary length of the reserve system + Penalty incurred for unmet targets
Example: Conservation Project

Solution 1

- 4
- 12*1.5
- 10

Total = 4 + (12*1.5) + 10 = 32

Solution 2

- 4
- 8*1.5
- 0

Total = 4 + (8*1.5) + 0 = 16
## Outputs – summary (output_sum.txt)

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Score</th>
<th>Cost</th>
<th>Planning Units</th>
<th>Boundary Length</th>
<th>Penalty</th>
<th>Shortfall</th>
<th>Missing Values</th>
<th>Values</th>
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</table>
### Outputs – summary (output_sum.txt)

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Score</th>
<th>Cost Planning Units</th>
<th>Boundary Length</th>
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<tbody>
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<td>372742.00</td>
<td>45155622.37</td>
</tr>
</tbody>
</table>
Outputs – best solution (output_best.txt)
Outputs – summed solution (output_ssoln.txt)

Selection frequency as irreplaceability
Marxan uses – select new reserves

- BRBNA Conservation Partnership
- Consortium of land trusts, agencies, other organizations
- 5 counties
- Establish a CAPP
- Address multiple conservation objectives
Marxan uses – current reserve assessment
Marxan uses – compensatory mitigation

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Ratio</th>
<th>San Juan</th>
<th>Hwy. 156</th>
<th>Scenic Trail</th>
<th>Artichoke Ave.</th>
<th>G12</th>
<th>Total (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater</td>
<td>3:1</td>
<td>1.139</td>
<td>0.406</td>
<td>2.084 (mit)</td>
<td></td>
<td>0.21</td>
<td>7.349</td>
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<tr>
<td>Wetlands</td>
<td>3:1</td>
<td>0.164</td>
<td>1.824</td>
<td></td>
<td>4.0 (mit)</td>
<td>0.83</td>
<td>12.454</td>
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<tr>
<td>Riparian</td>
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<td>0.905</td>
<td>3.23</td>
<td></td>
<td></td>
<td>1.97</td>
<td>18.315</td>
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<tr>
<td>Maritime Chaparral</td>
<td>5:1</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td>0.77</td>
<td>4.65</td>
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<tr>
<td>Oak Woodland</td>
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<td>0.204</td>
<td>17.348</td>
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<tr>
<td>Grasslands</td>
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<td>18.824</td>
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<td>20.08</td>
<td>53.432</td>
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<td>Agriculture</td>
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<td>9.0</td>
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<td>Eucalyptus</td>
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<td>1.08</td>
<td></td>
<td></td>
<td></td>
<td>1.08</td>
</tr>
</tbody>
</table>
Marxan uses – non-spatial examples

**Sustainability indicator selection**
- Planning units = indicators
- Species = sustainability issues
- No boundary

**Plant palette selection**
- Planning units = plant species
- Species = plant characteristics
- No boundary
Marxan and climate change – examples

**Approach #1**
- Time as additional dimension
- Multiple planning units in each location
- Adjacency through time and space

**Approach #2**
- Land facets
- Physical characteristics (topography, etc.)
- “Preserving the stage”
- Ensure representation of physical types

**Approach #3**
- Attribute PU with both current and future species distributions
- Optimize for both simultaneously

*Figure 2. Illustration of the geographic distribution of land facets, defined on the basis of elevation, slope, insolation, and topographic position, draped over a hillshade map. For clarity, not all land facets in the landscape are shown.*

(Beier & Brost 2010)