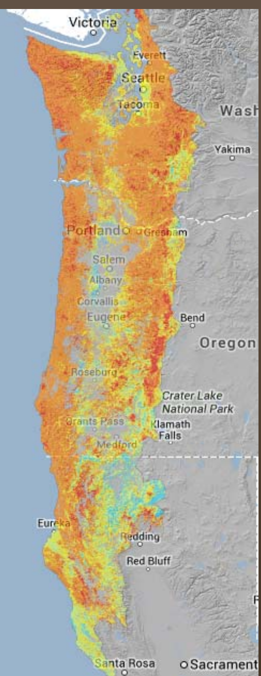
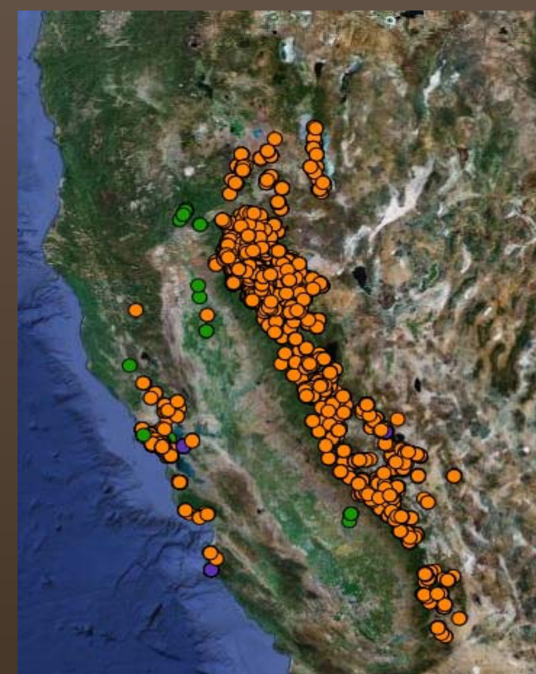


Systematic reserve design

Introduction to Marxan



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Point Blue Conservation Science for a healthy planet

CA LCC

Conservation planning

Stages in systematic conservation planning (Margules and Pressey, *Nature*, 2000):

- 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

Stages in systematic conservation planning
(Margules and Pressey, *Nature*, 2000):

- 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

Stages in systematic conservation planning (Margules and Pressey, *Nature*, 2000):

- 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?

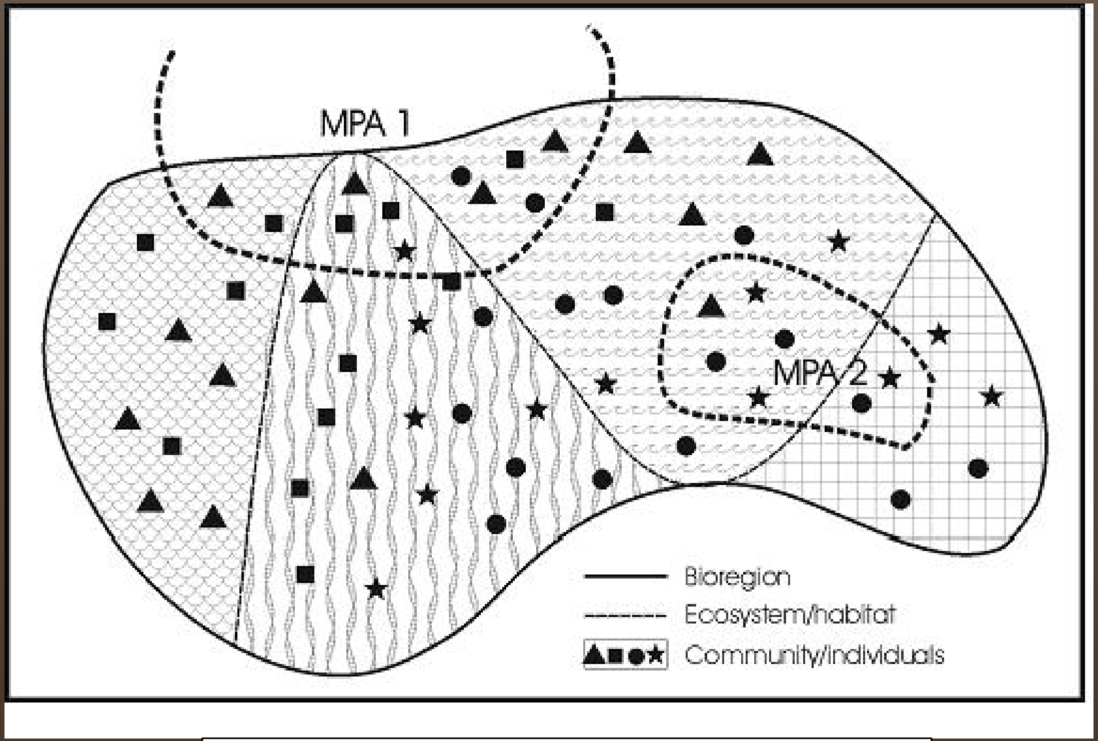
- Designed to explore trade-offs between conservation and socio-economic objectives
- Reserve System Design
- Minimum Set Problem
- University of Queensland (Ian Ball, Hugh Possingham)
- http://www.uq.edu.au/marxan/index.html
- Over 100 peer-reviewed papers using Marxan over the past decade

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



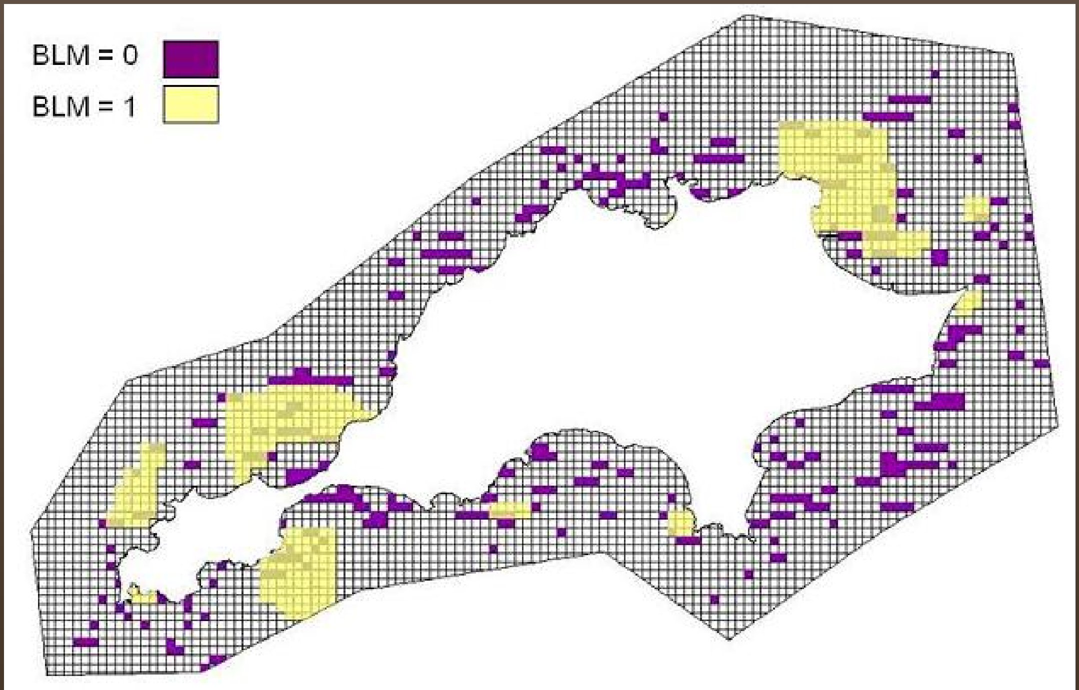
TFMPA (1999) *Understanding and applying the principles of comprehensiveness, adequacy and representativeness for the NRSMPA, Version 3.1*

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

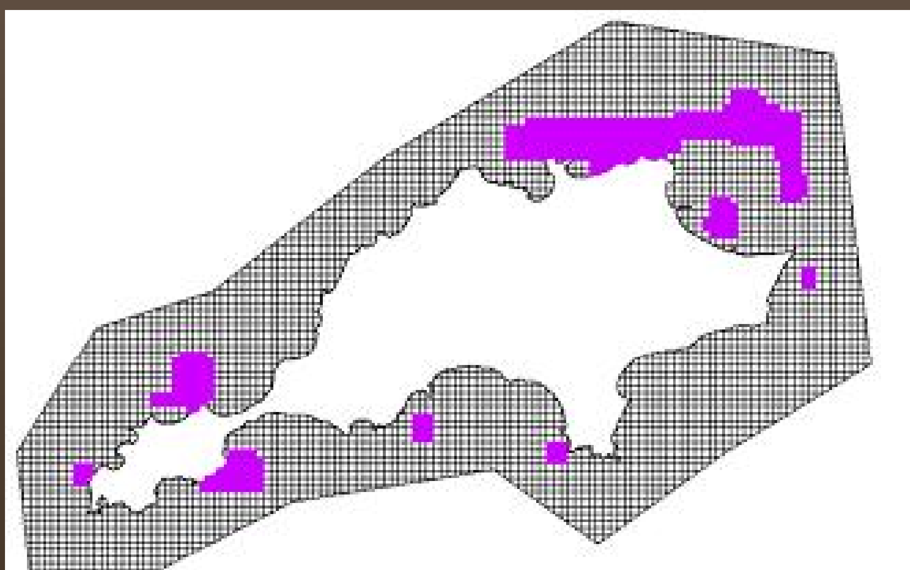
Compactness and/or Connectedness

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



Flexibility

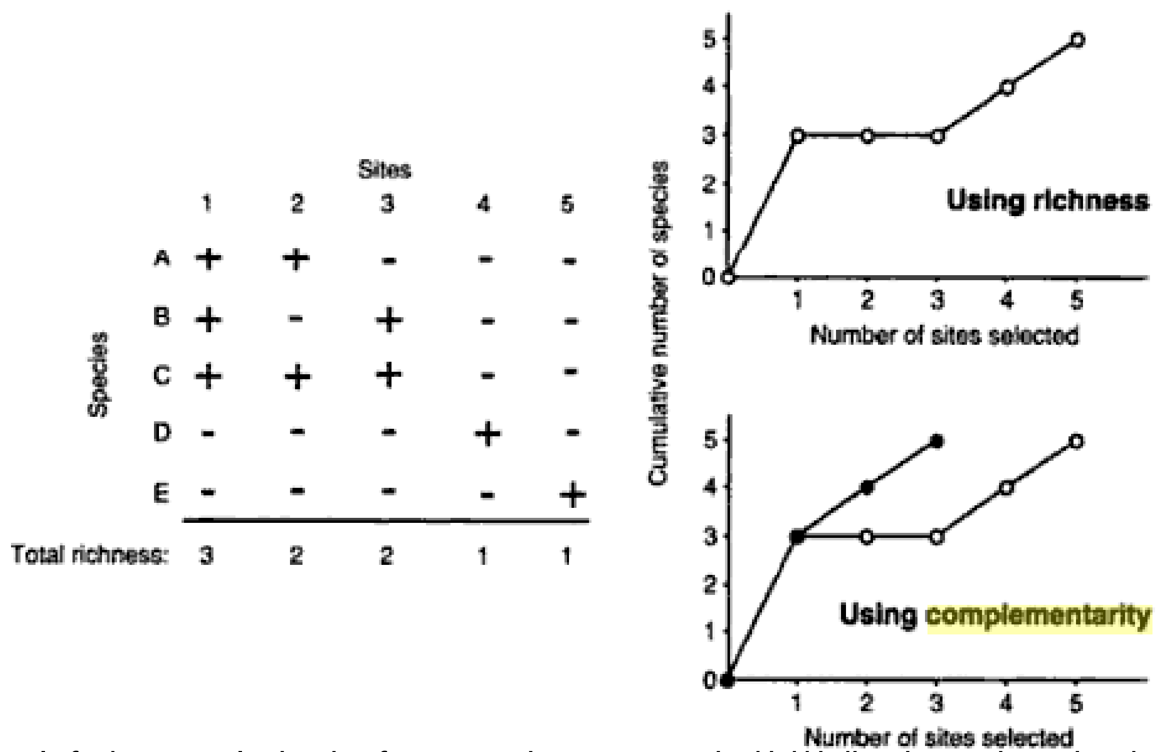
- **Options to achieve the conservation objectives in a number of ways**



Option 1

Option 2

Complementarity

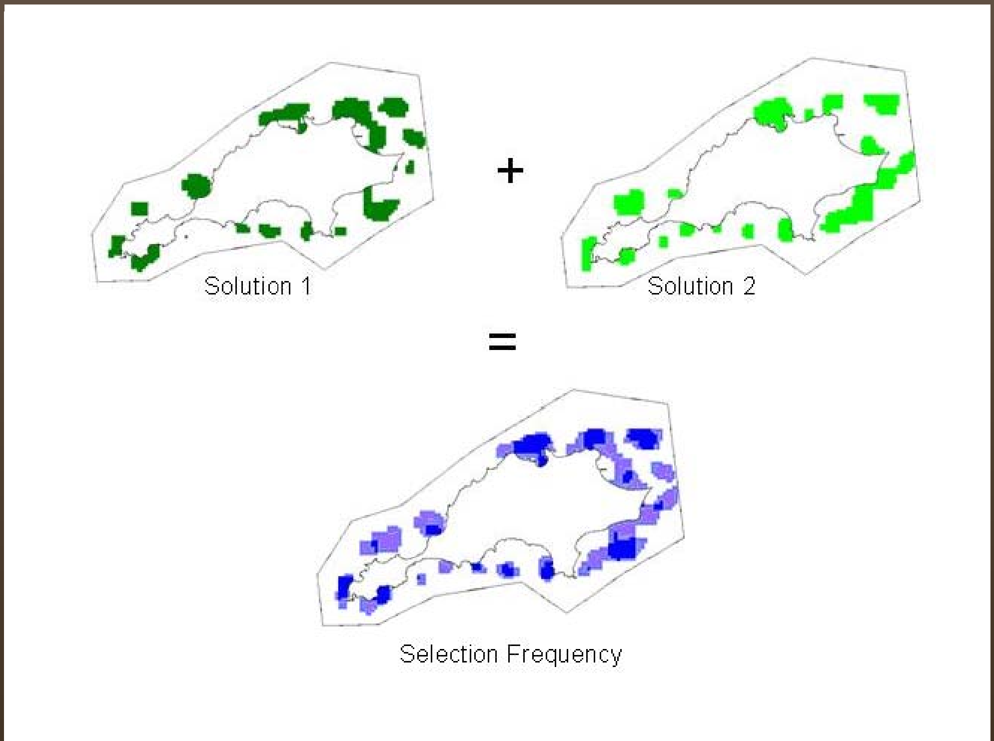


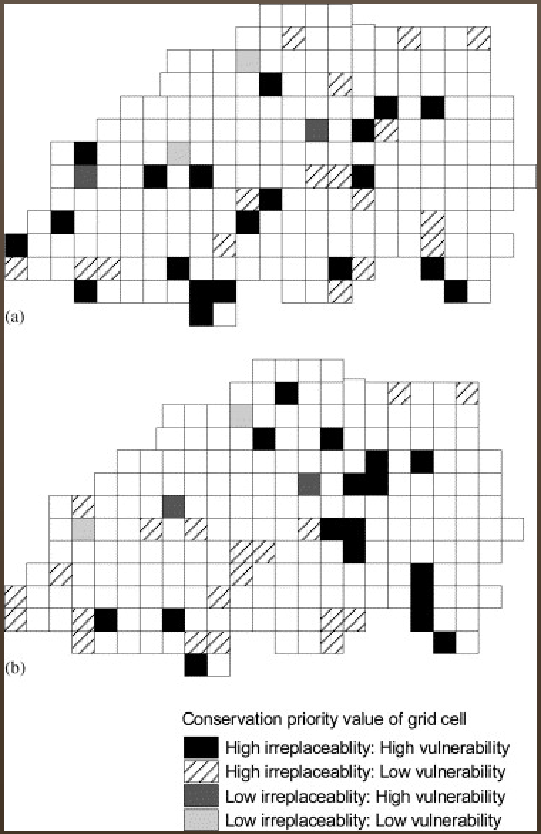
Balmford, 2002, "Selecting sites for conservation", In: *Conserving bird biodiversity*, Norris & Pain, eds.

- 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**

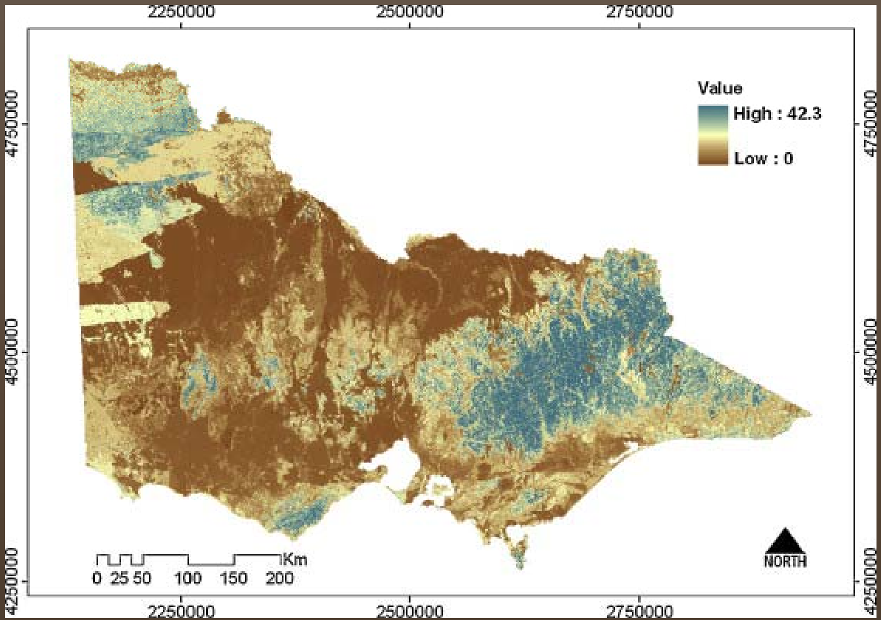




Reyers, 2004.

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

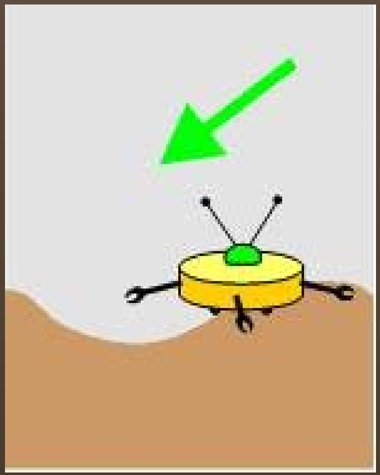
- Optimization: trying to find the best, or very good, solutions to a well-defined problem
- Decision theory: any mathematical, economic or social science that helps us make decisions
- Mathematical programming: Tool or algorithm used for optimization
  - Simulated annealing

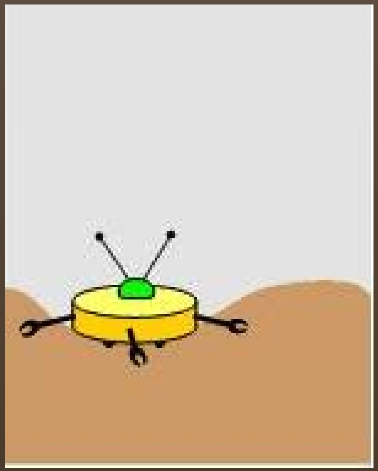
$$\overbrace{\sum_{PUs} Cost}^{1} + \underbrace{BLM \sum_{PUs} Boundary}_{3} + \overbrace{\sum_{ConValue} SPF \times Penalty}^{2} + \underbrace{CostThresholdPenalty(t)}_{4}$$

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)

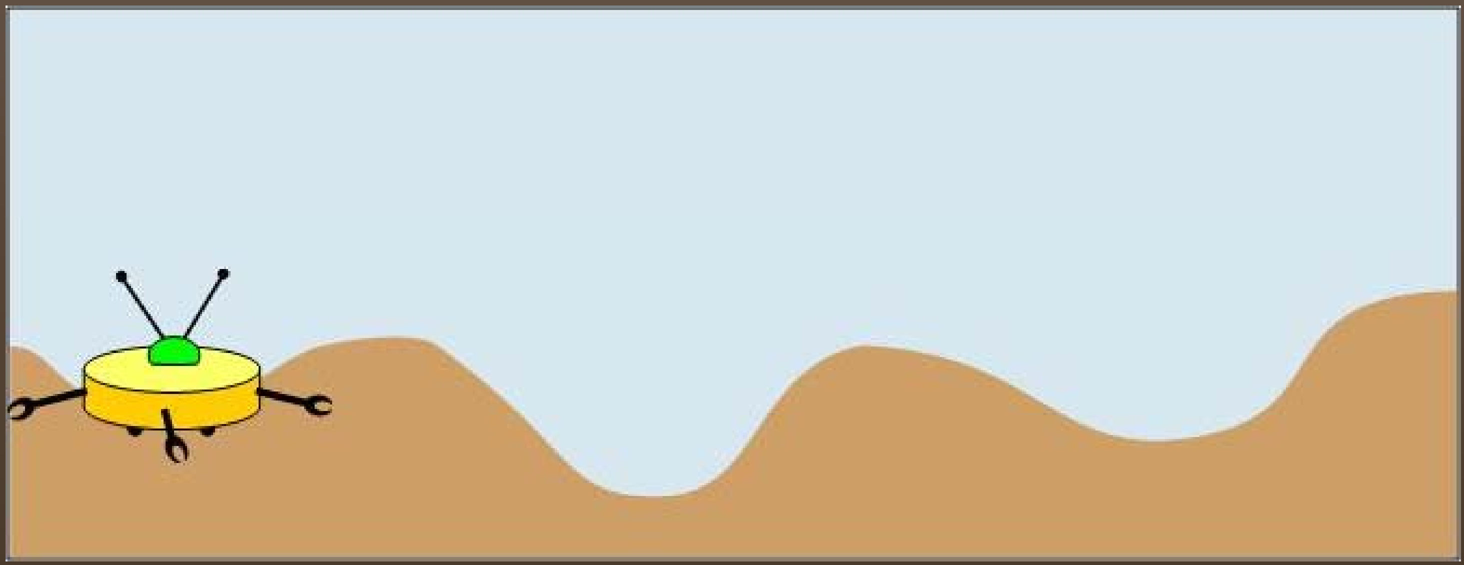
Simulated Annealing

- Dr. Bob Smith's Robot on Mars Analogy

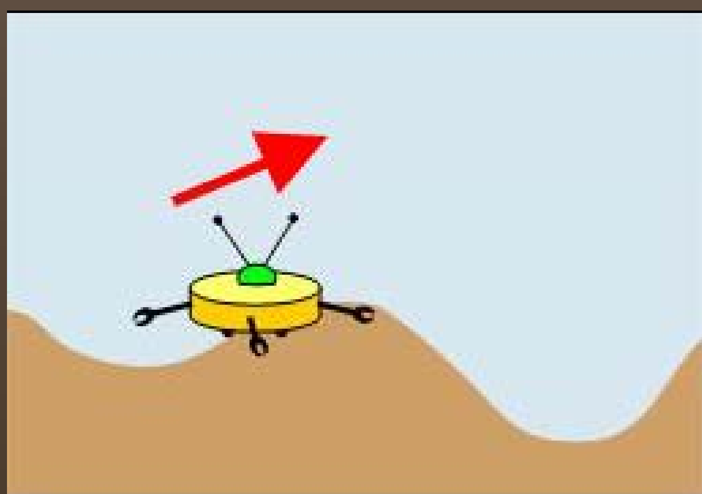


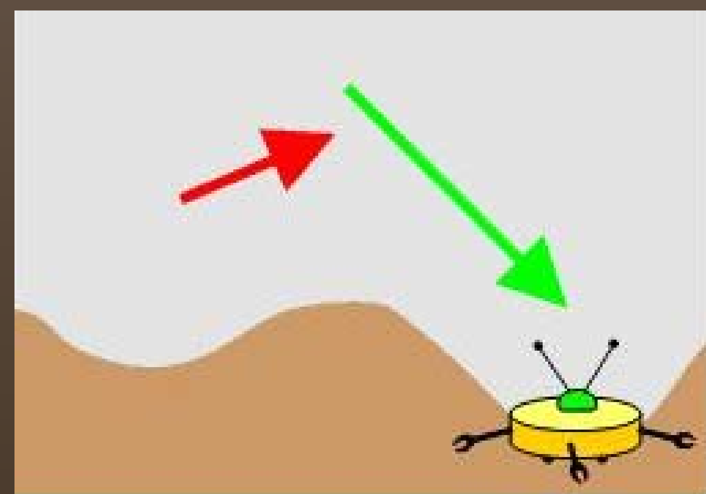


Simulated Annealing

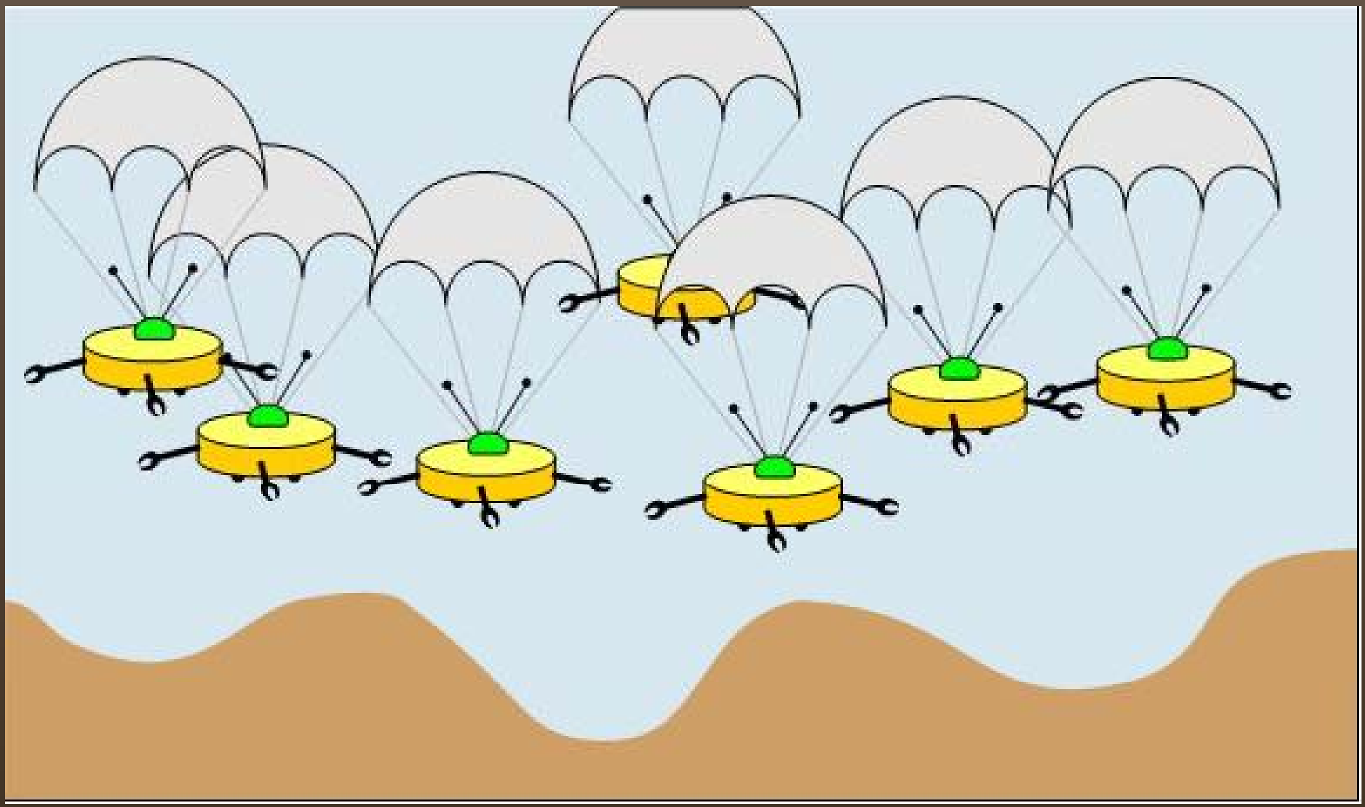


Simulated Annealing





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

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

hex_pu.dat - Notepad

File Edit Format View Help

```
id,cost,status
1,1,0
2,1,0
3,1,0
4,1,0
5,1,0
6,1,0
7,1,0
8,1,0
9,1,0
10,1,0
11,1,0
```

Marxan with Zones

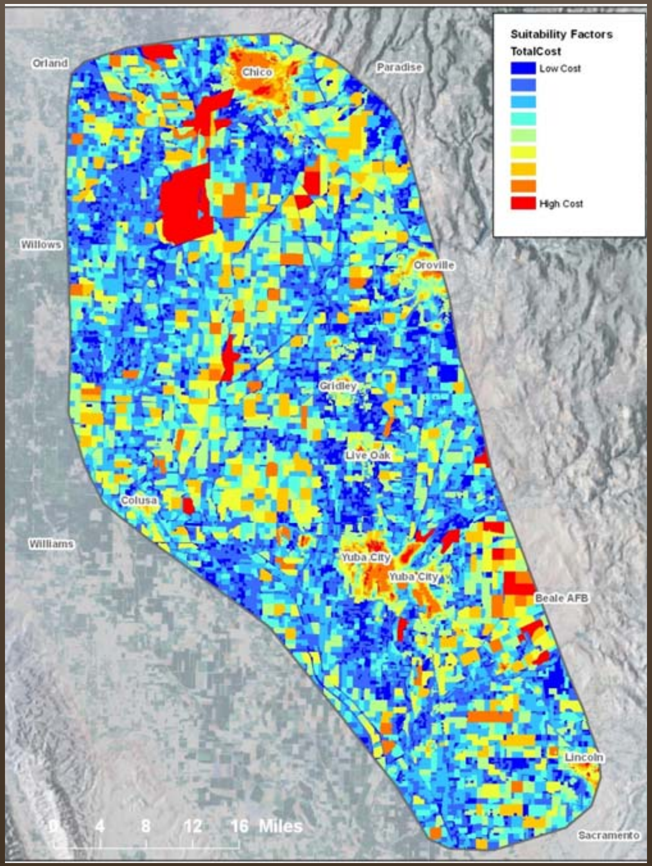
variable name	default	notes
id	required	the numeric identifier for this planning unit
costname	optional, will use a default value of 1 if not specified	the individual cost of each P.U. Multiple cost fields with different names can be used into Marxan Z's P.U. file. The header 'costname' can be replaced with the actual name of the cost but must not include delimiters (spaces, tabs, etc.).

```
id, salmonfishing, squidfishing
1, 34, 22
2, 4, 0
3, 40, 12
```

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

variable name	default value	notes/description
id	critical	the id number of the conservation feature; it must correspond to the planning unit versus conservation feature file
type	0	type is a user-defined type; it is used for ‘block definitions’
target	0	the target amount for the conservation feature
spf	0	the penalty factor for the conservation feature
target2	0	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
sepdistance	0	minimum distance at which planning units holding this conservation feature are considered to be separated
sepnum	0	target number of mutually separated planning units in valid clumps
name	no_name	a name in words; can include spaces; all words in a name must start with a letter
targetocc	0	the number of occurrences of the conservation feature required; this can be used in conjunction with or instead of ‘target’

spec-esf.dat - Notepad

File Edit Format View Help

```
id      type    target      spf     target2 sepdistance     sepnum  name    targetocc
110     0       2293073.774         1       0       0       0       Saltwater       0
120     0       4609324.004         1       0       0       0       Mudflat 0
130     0       4369162.863         1       0       0       0       Saltmarsh       0
210     0       588148.5387         1       0       0       0       Freshwater      0
220     0       1842347.477         1       0       0       0       Freshwater Wetlands     0
240     0       2196362.067         1       0       0       0       Riparian        0
```

Marxan with Zones

id	required	the numeric identifier for this feature; the id must be a positive integer
target	optional if prop is used	the target amount (in unit of puvfeat.dat file) of the feature to include across all protected zones (i.e. overall target
prop	optional if target is used	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
targetocc	optional	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’
propocc	optional	the percentage of occurrences of the feature required; this can be used in conjunction with or instead of ‘prop’
fpf name	optional optional	the penalty factor for that feature; indicates the name of the feature; do not include any spaces or non-alphanumeric characters in the name

```
id, prop, fpf, name
1, 0.3, 1, RockyReef
2, 0.9, 1, KelpForest
3, 0.5, 1, FishingGrounds
```

Planning unit vs. features

Marxan

Variable Name	Default	Notes
species	critical	conservation feature id
pu	critical	planning unit id
amount	critical	amount of conservation feature on planning unit

puvsp.dat - Notepad

File Edit Format View Help

```
"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
```

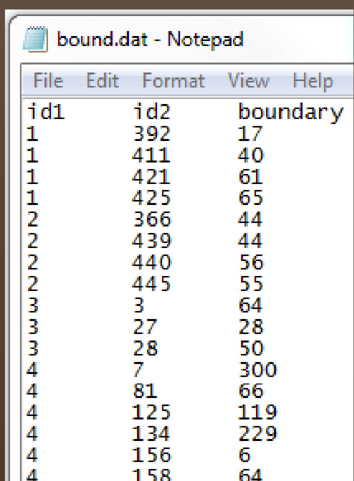
Marxan with Zones

Variable Name	Default	Notes
featureid	required	feature identifier – must be indicated in the feature file
puid	required	planning unit identifier – must be indicated in the planning unit file
amount	required	amount of feature in the planning unit; the measurement unit between features can be different

```
featureid, puid, amount
1, 1, 350
1, 2, 50
1, 3, 100
2, 3, 160
3, 1, 300
3, 2, 200
```

Boundary

Marxan and Marxan with Zones


bound.dat - Notepad

File Edit Format View Help

id1	id2	boundary
1	392	17
1	411	40
1	421	61
1	425	65
2	366	44
2	439	44
2	440	56
2	445	55
3	3	64
3	27	28
3	28	50
4	7	300
4	81	66
4	125	119
4	134	229
4	156	6
4	158	64

Variable Name	Default	Notes/Description
id1	critical	planning unit id
id2	critical	neighboring planning unit id or the same as id1 for the irremovable boundary
boundary	critical	the boundary length

JNCC ArcGIS extension from Marxan website for boundary file creation

Zones (Zones only)

```
zoneid, zonename
1, Available
2, MarineReserve
3, MarinePark
4, FishingZone
```

Variable Name	Default	Notes
zoneid	requred	the numeric identifer number for the zone; the zoneid must be a positive integer and the file must be sorted by lowest to highest zoneid
zonename	required	indicates the name of the zone; do not include any spaces or non-alphanumeric characters in the name

Costs (Zones only)

```
costid, costname
1, area
2, salmonfishing
3, squidfishing
```

Variable Name	Default	Notes
costid	requred	the numeric identifier for the cost; the costid must be a positive integer and the file must be sorted by lowest to highest costid
costname	required	indicates the name of the cost; do not include any spaces or non-alphanumeric characters in the name

Zone cost (Zones only)

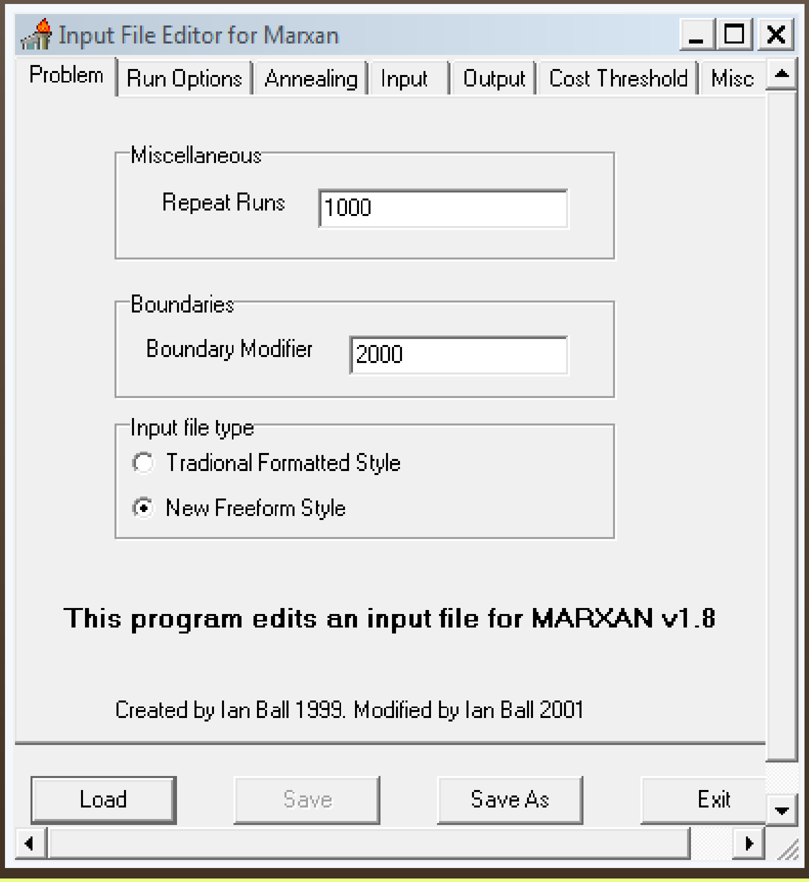
```
zoneid, costid, multiplier
2, 1, 0.2
2, 2, 0.4
```

Variable Name	Default	Notes
zoneid	requred	the zone identifier – must be compatible with the zones.dat file
costid	required	the cost identifier – must be compatible with the costs.dat file
multiplier	required	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*M1)+(C2*M2)+(C3*M3) Where C = cost, M = multiplier

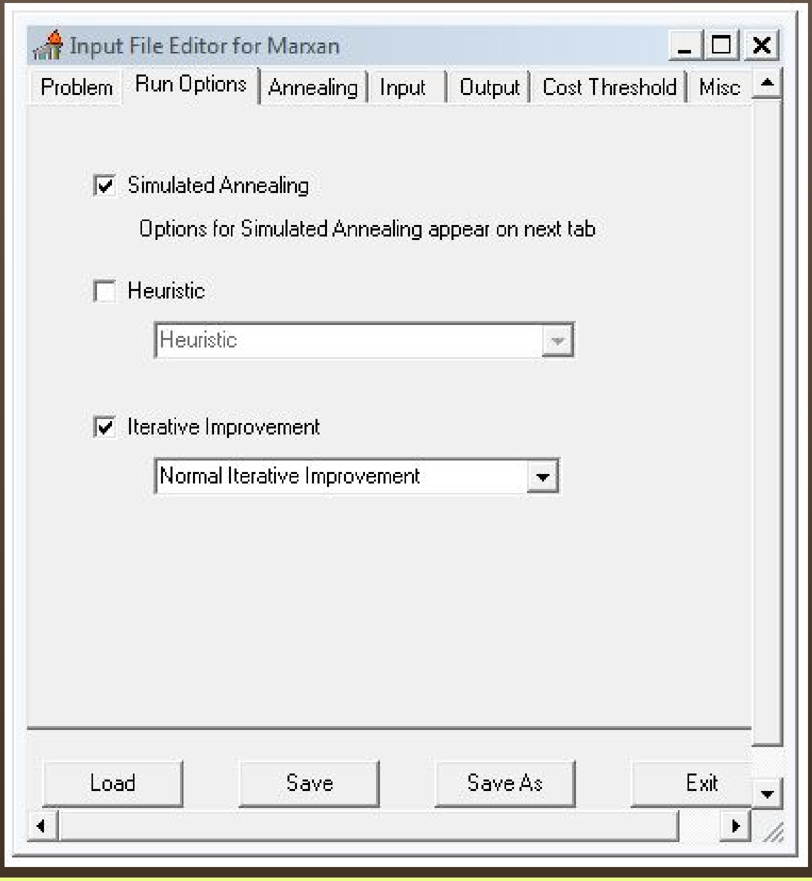
Input files – a few tips (learned the hard way)

- 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

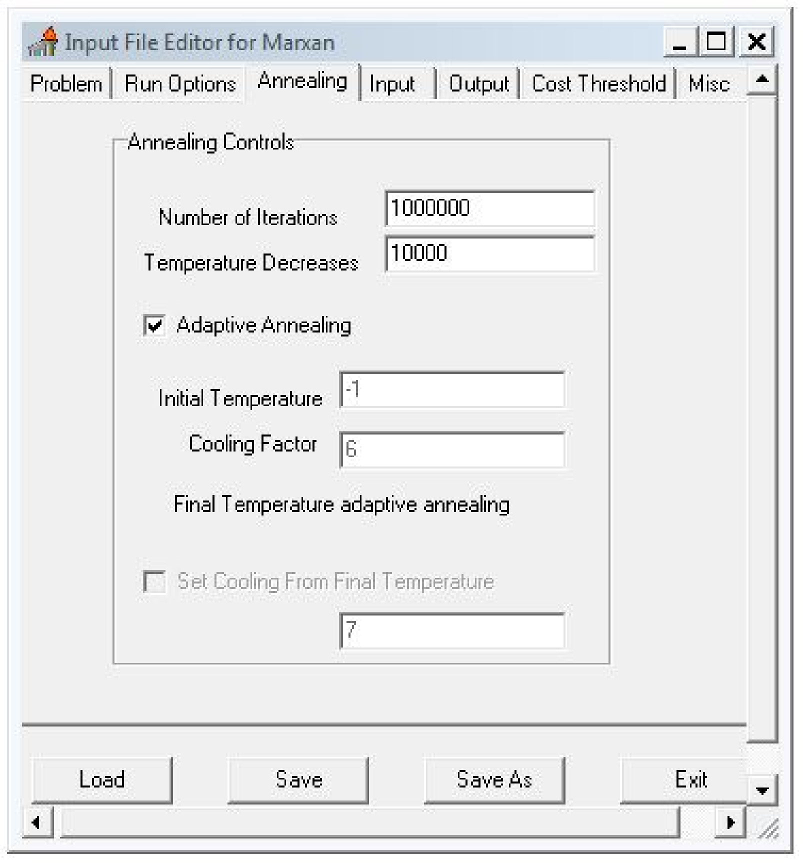
Running Marxan – Inedit



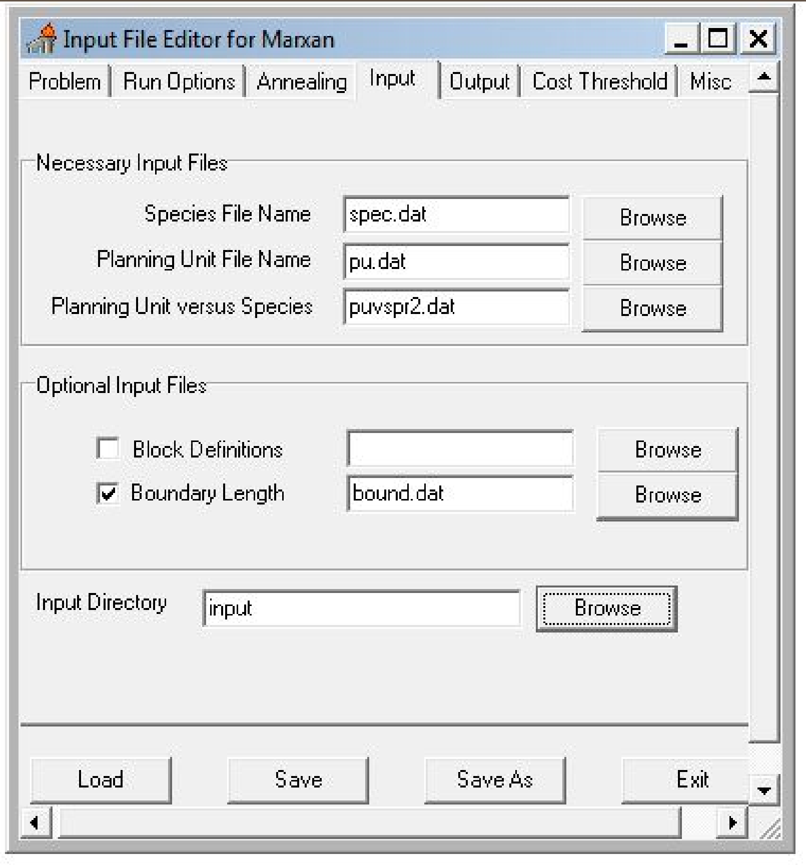
Running Marxan – Inedit



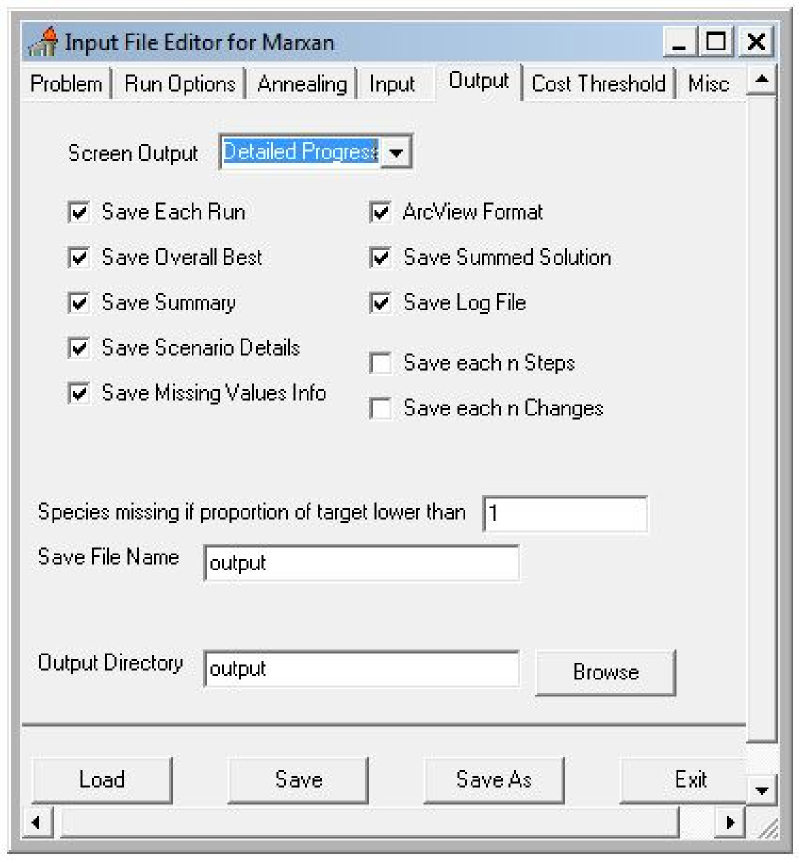
Running Marxan – Inedit



Running Marxan – Inedit

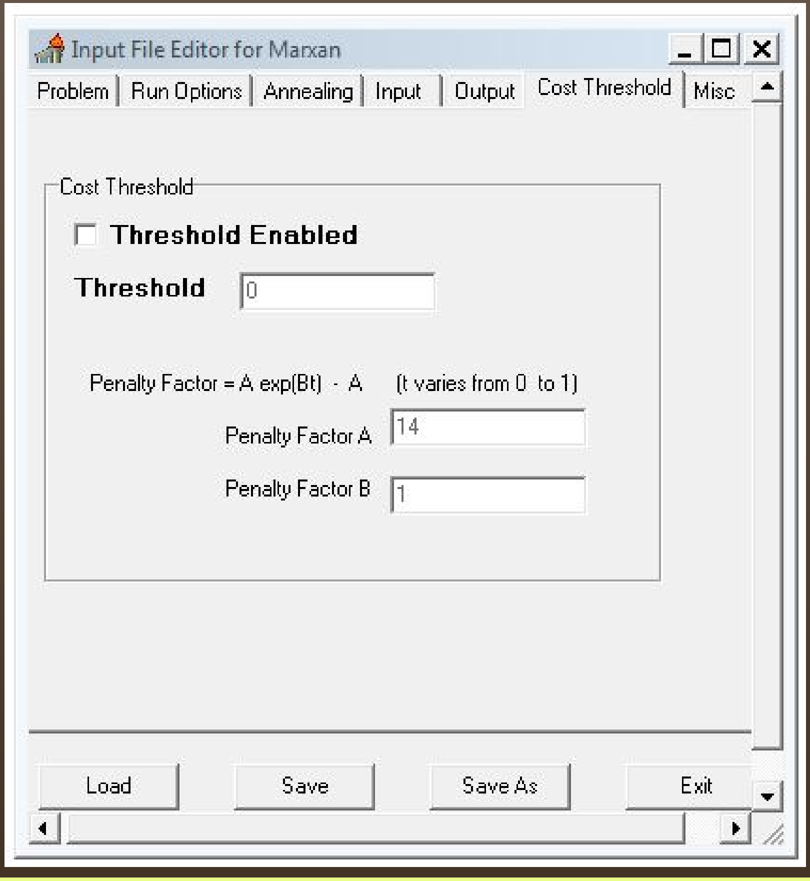


Running Marxan – Inedit

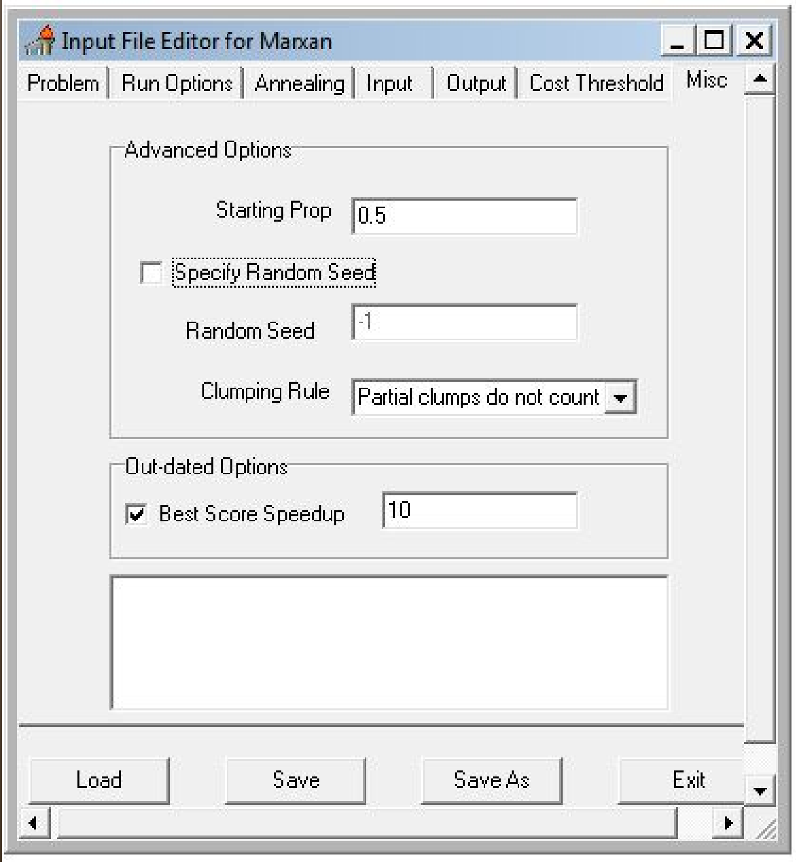


Running Marxan – Inedit

'Maximum coverage' problem



Running Marxan – Inedit



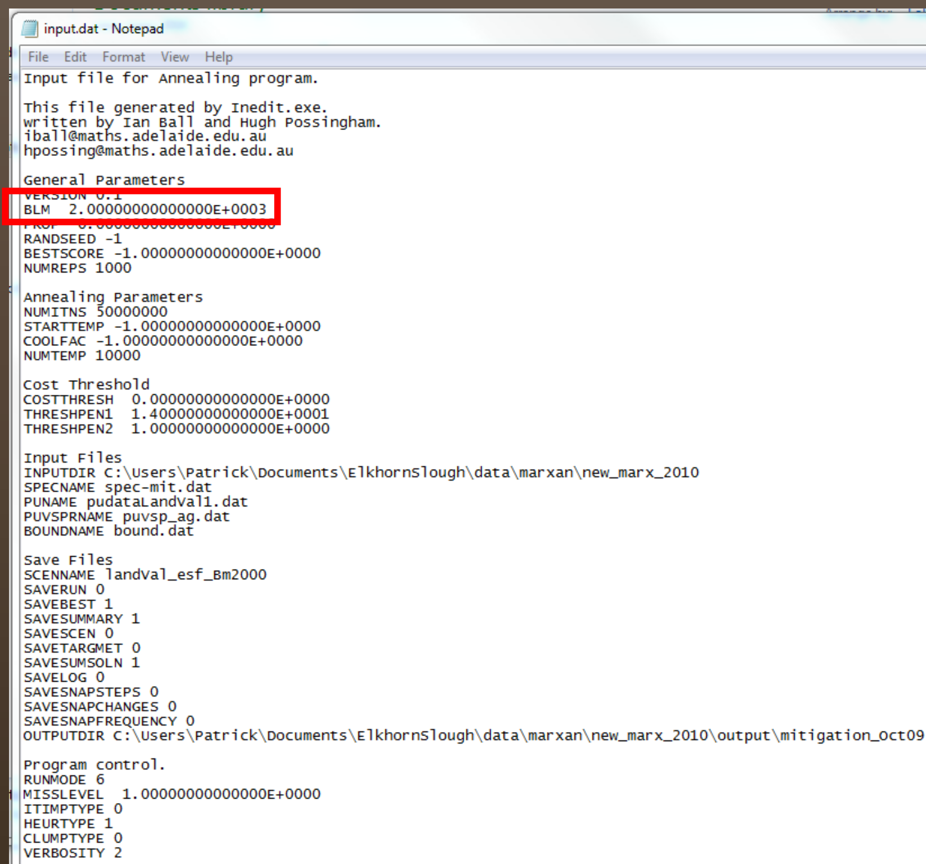
Running Marxan – input.dat

input.dat - Notepad

File Edit Format View Help

```
Input file for Annealing program.

This file generated by Inedit.exe.
written by Ian Ball and Hugh Possingham.
iball@maths.adelaide.edu.au
hpossing@maths.adelaide.edu.au

General Parameters
VERSION 0.1
BLM  2.00000000000000E+0003
PROP  0.00000000000000E+0000
RANDSEED -1
BESTSCORE -1.00000000000000E+0000
NUMREPS 1000

Annealing Parameters
NUMITNS 50000000
STARTTEMP -1.00000000000000E+0000
COOLFAC -1.00000000000000E+0000
NUMTEMP 10000

Cost Threshold
COSTTHRESH  0.00000000000000E+0000
THRESHPEN1  1.40000000000000E+0001
THRESHPEN2  1.00000000000000E+0000

Input Files
INPUTDIR C:\Users\Patrick\Documents\ElkhornSlough\data\marxan\new_marx_2010
SPECNAME spec-mit.dat
PUNAME pudataLandval1.dat
PUVSPRNAME puvsp_ag.dat
BOUNDNAME bound.dat

Save Files
SCENNAME landval_esf_Bm2000
SAVERUN 0
SAVEBEST 1
SAVESUMMARY 1
SAVESCEN 0
SAVETARGMET 0
SAVESUMSOLN 1
SAVELOG 0
SAVESNAPSTEPS 0
SAVESNAPCHANGES 0
SAVESNAPFREQUENCY 0
OUTPUTDIR C:\Users\Patrick\Documents\ElkhornSlough\data\marxan\new_marx_2010\output\mitigation_Oct09

Program control.
RUNMODE 6
MISSLEVEL  1.00000000000000E+0000
ITIMPTYPE 0
HEURTYPE 1
CLUMPTYPE 0
VERBOSITY 2
```

Running Marxan – input.dat



input.dat - Notepad

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SAVETARGMET 0
SAVESUMSOLN 1
SAVELOG 0
SAVESNAPSTEPS 0
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CLUMPTYPE 0
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Running Marxan – input.dat

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input.dat - Notepad
File  Edit  Format  View  Help
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Annealing Parameters
NUMITNS 50000000
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COOLFAC -1.00000000000000E+0000
NUMTEMP 10000

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COSTTHRESH  0.00000000000000E+0000
THRESHPEN1  1.40000000000000E+0001
THRESHPEN2  1.00000000000000E+0000

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Annealing Parameters
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STARTTEMP -1.00000000000000E+0000
COOLFAC -1.00000000000000E+0000
NUMTEMP 10000

Cost Threshold
COSTTHRESH  0.00000000000000E+0000
THRESHPEN1  1.40000000000000E+0001
THRESHPEN2  1.00000000000000E+0000

Input Files
INPUTDIR C:\Users\Patrick\Documents\ElkhornSlough\data\marxan\new_marx_2010
SPECNAME spec-mit.dat
PUNAME pudataLandval1.dat
PUVSPRNAME puvsp_ag.dat
BOUNDNAME bound.dat

Save Files
SCENNAME landval_esf_Bm2000
SAVERUN 0
SAVEBEST 1
SAVESUMMARY 1
SAVESCEN 0
SAVETARGMET 0
SAVESUMSOLN 1
SAVELOG 0
SAVESNAPSTEPS 0
SAVESNAPCHANGES 0
SAVESNAPFREQUENCY 0
OUTPUTDIR C:\Users\Patrick\Documents\ElkhornSlough\data\marxan\new_marx_2010\output\mitigation_Oct09

Program control.
RUNMODE 6
MISSLEVEL  1.00000000000000E+0000
ITIMPTYPE 0
HEURTYPE 1
CLUMPTYPE 0
VERBOSITY 2
```

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 =

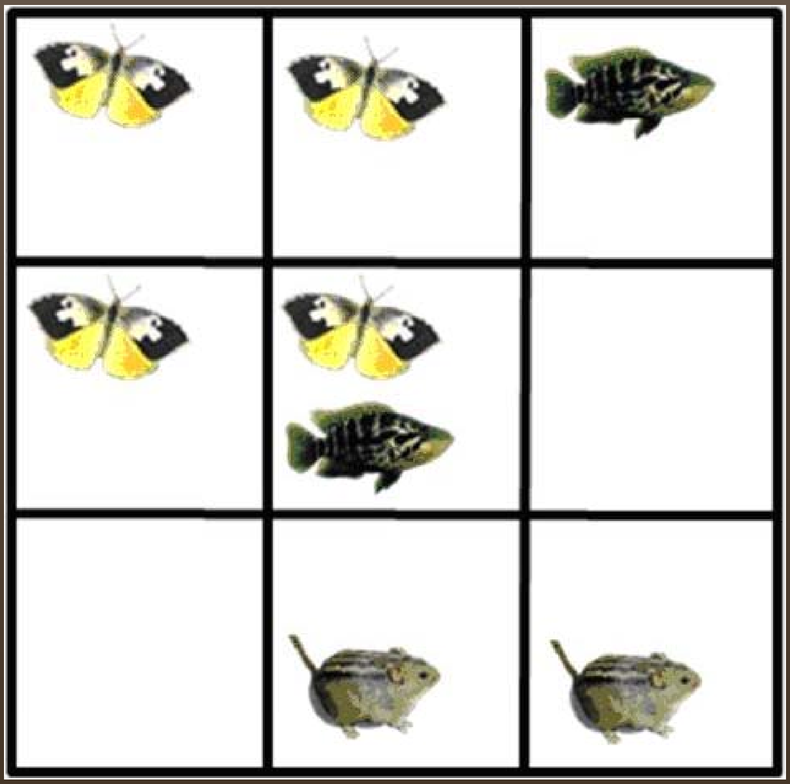
<u>**Cost**</u> of the reserve system

+

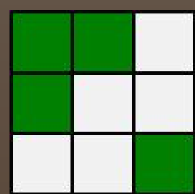
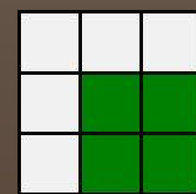
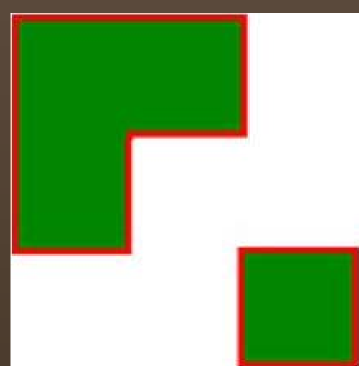
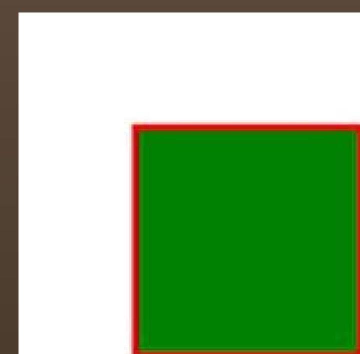
<u>**Boundary length**</u> of the reserve system

+

<u>**Penalty**</u> incurred for unmet targets



Example: Conservation Project

Solution 1				Solution 2
4		Total PU Cost		4
12*1.5		BLM		8*1.5
10		SPF		0

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

Total = 4+(8*1.5)+0 = 16

Outputs – summary (output_sum.txt)

landVal_esf_Bm100_sum.dat - Notepad

File Edit Format View Help

Run no.	Score	Cost	Planning Units	Boundary Length	Penalty	Shortfall	Missing Values
1	306526900.47	223901602.00	364	372486.00	45376698.47	3347857.62	6
2	306551033.60	223402026.00	363	371526.00	45996407.60	3402256.62	6
3	306568109.86	223876921.00	362	370947.00	45596488.86	3182558.63	7
4	306642909.71	224106148.00	364	372164.00	45320361.71	3169513.62	6
5	306642909.71	224106148.00	364	372164.00	45320361.71	3169513.62	6
6	306583991.34	224596431.00	365	371513.00	44836260.34	3171165.62	6
7	306551799.37	224121977.00	364	372742.00	45155622.37	3330979.62	6
8	306589564.92	224884008.00	366	373699.00	44335656.92	3136902.62	6
9	306646519.21	224654278.00	366	369549.00	45037341.21	3232586.16	7
10	306526900.47	223901602.00	364	372486.00	45376698.47	3347857.62	6
11	306593287.95	225027310.00	365	373011.00	44264877.95	3115002.16	7
12	306555293.15	223318793.00	363	373226.00	45913900.15	3403292.62	6
13	306551799.37	224121977.00	364	372742.00	45155622.37	3330979.62	6

Outputs – summary (output_sum.txt)

landVal_esf_Bm100_sum.dat - Notepad

File Edit Format View Help

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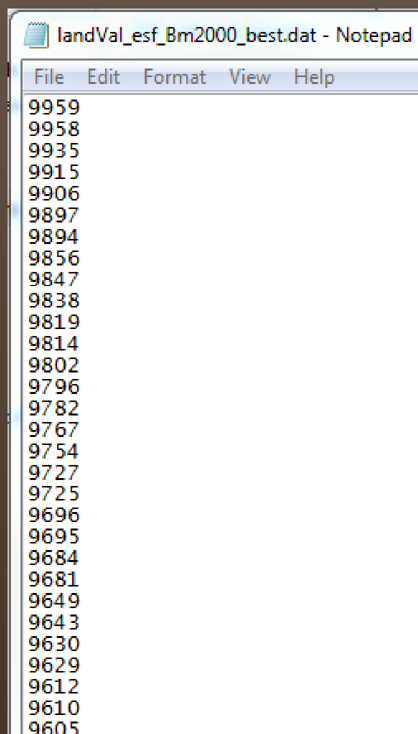
5	306642909.71	224106148.00	364	372164.00	45320361.71	3169513.62	6
6	306583991.34	224596431.00	365	371513.00	44836260.34	3171165.62	6
7	306551799.37	224121977.00	364	372742.00	45155622.37	3330979.62	6
8	306589564.92	224884008.00	366	373699.00	44335656.92	3136902.62	6
9	306646519.21	224654278.00	366	369549.00	45037341.21	3232586.16	7
10	306526900.47	223901602.00	364	372486.00	45376698.47	3347857.62	6
11	306593287.95	225027310.00	365	373011.00	44264877.95	3115002.16	7
12	306555293.15	223318793.00	363	373226.00	45913900.15	3403292.62	6
13	306551799.37	224121977.00	364	372742.00	45155622.37	3330979.62	6

Outputs – best solution (output_best.txt)


landVal_esf_Bm2000_best.dat - Notepad

File Edit Format View Help

9959
9958
9935
9915
9906
9897
9894
9856
9847
9838
9819
9814
9802
9796
9782
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9629
9612
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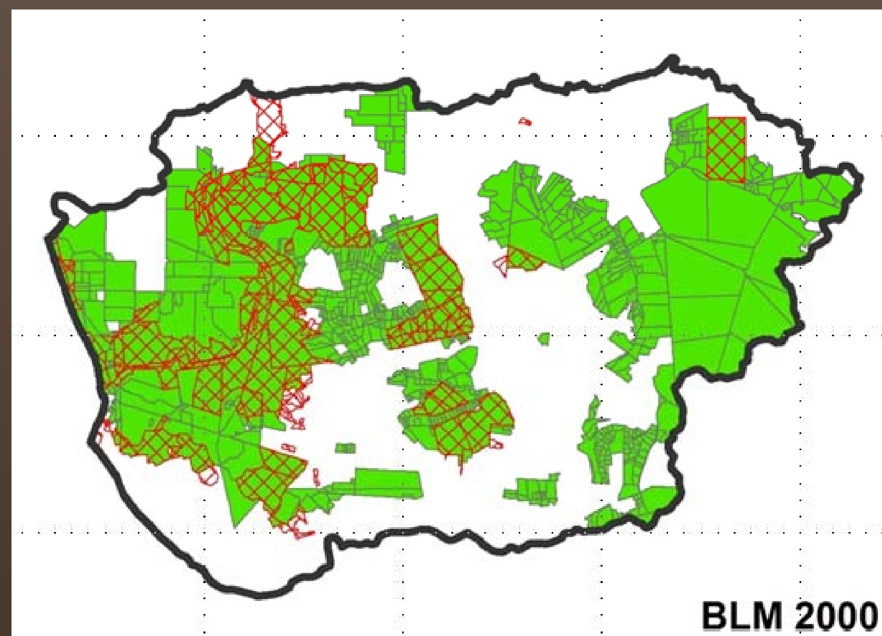
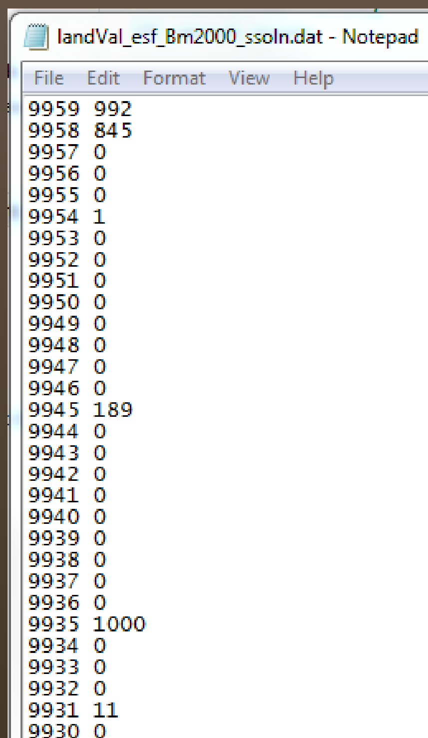
9605

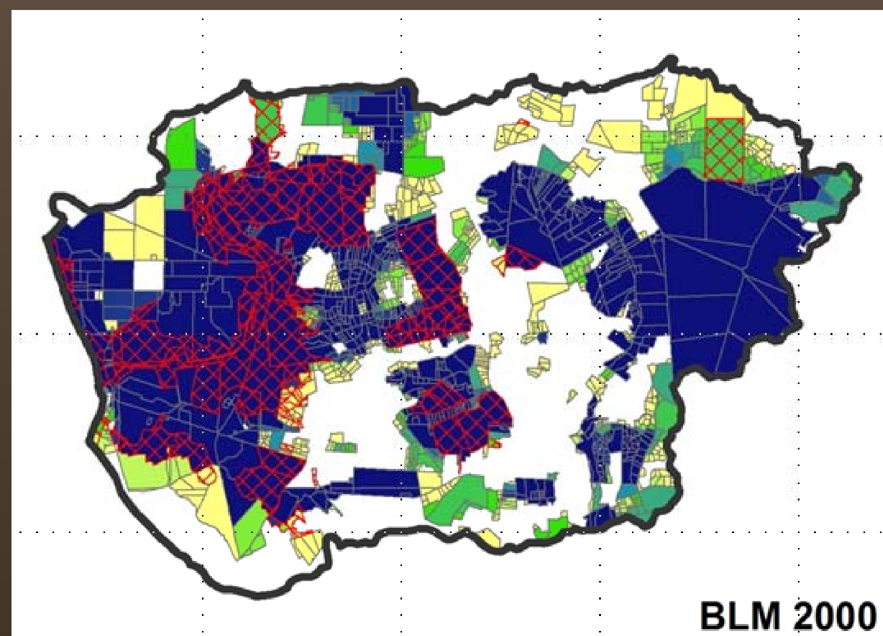


Outputs – summed solution (output_ssoln.txt)

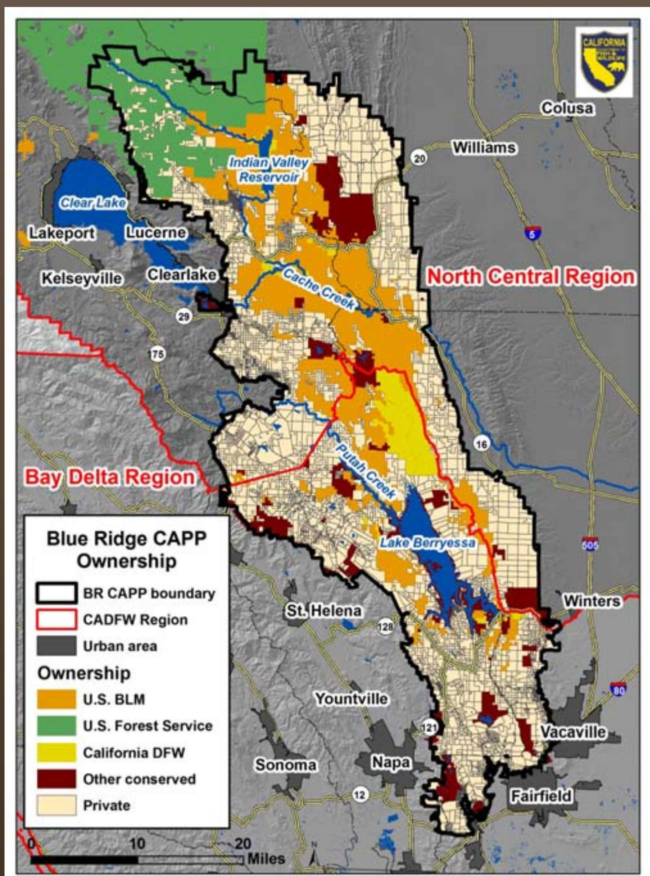

landVal_esf_Bm2000_ssoln.dat - Notepad
File Edit Format View Help

```
9959 992
9958 845
9957 0
9956 0
9955 0
9954 1
9953 0
9952 0
9951 0
9950 0
9949 0
9948 0
9947 0
9946 0
9945 189
9944 0
9943 0
9942 0
9941 0
9940 0
9939 0
9938 0
9937 0
9936 0
9935 1000
9934 0
9933 0
9932 0
9931 11
9930 0
```

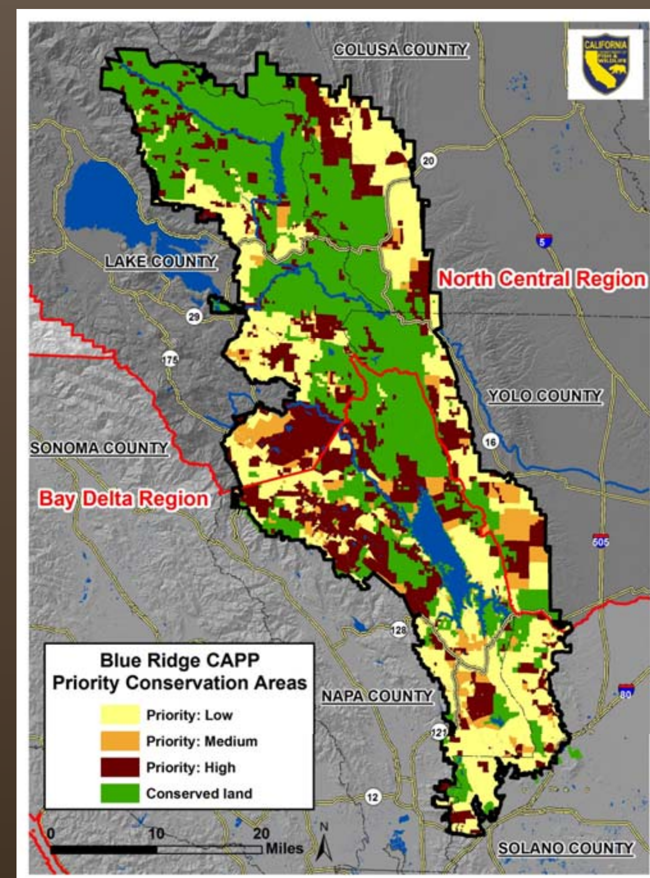
Selection frequency as irreplaceability



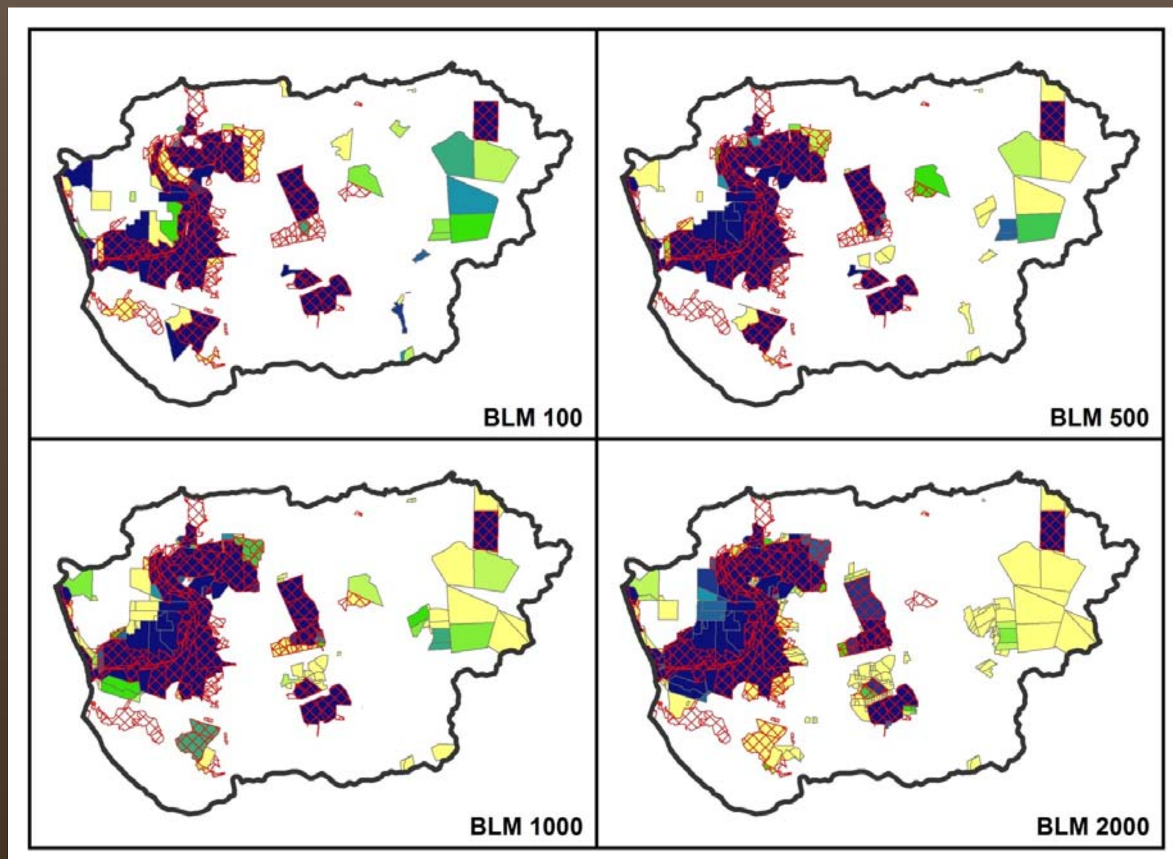
Marxan uses – select new reserves



- •BRBNA Conservation Partnership
- • Consortium of land trusts, agencies, other organizations
- • 5 counties
- • Establish a CAPP
- • Address multiple conservation objectives



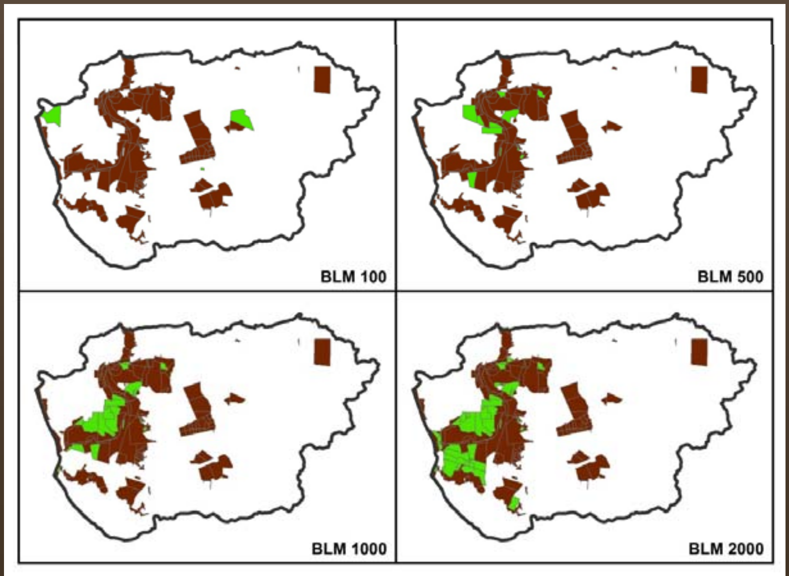
Marxan uses – current reserve assessment



Marxan uses – compensatory mitigation

Projects

Habitat	Ratio	San Juan	Hwy. 156	Scenic Trail	Artichoke Ave.	G12	Total (acres)
Freshwater	3:1	1.139	0.406	*2.084 (mit)*		0.21	7.349
Wetlands	3:1	0.164	1.824		*4.0 (mit)*	0.83	12.454
Riparian	3:1	0.905	3.23			1.97	18.315
Maritime Chaparral	5:1		0.16			0.77	4.65
Oak Woodland	5:1	0.204	17.348			6.52	120.36
Grasslands	1:1	14.528	18.824			20.08	53.432
Agriculture	1:1	0.205	165.0		9.0	6.12	180.325
Eucalyptus	1:1			1.08			1.08



Marxan uses – non-spatial examples

Sustainability indicator selection

- Planning units = indicators
- Species = sustainability issues
- No boundary

```
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1,0,1,1,0,0,"Land &amp; Soil",0,0
2,0,1,1,0,0,"Agricultural Productivity",0,0
3,0,1,1,0,0,"Agrobiodiversity",0,0
4,0,1,1,0,0,"Carbon Sequestration",0,0
5,0,1,1,0,0,"Cropping Systems",0,0
6,0,1,1,0,0,"Crop Yield",0,0
7,0,1,1,0,0,"Desertification",0,0
8,0,1,1,0,0,"Disasters - Environmental Impact",0,0
9,0,1,1,0,0,"Ecosystem Health",0,0
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Plant palette selection

- Planning units = plant species
- Species = plant characteristics
- No boundary

```
id,type,target,spf,target2,sepdistance
260,0,13,1,0,0,0,"natbeepoll",0
270,0,3,1,0,0,0,"natbeenest",0
280,0,6,1,0,0,0,"bumble",0
290,0,4,1,0,0,0,"honey",0
300,0,5,1,0,0,0,"predatory",0
310,0,15,1,0,0,0,"butterfly",0
320,0,1,1,0,0,0,"AdeBre_host",0
325,0,1,1,0,0,0,"AtaCam_host",0
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340,0,1,1,0,0,0,"BatPhi_host",0
345,0,1,1,0,0,0,"BatPhi_nectar",0
```

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

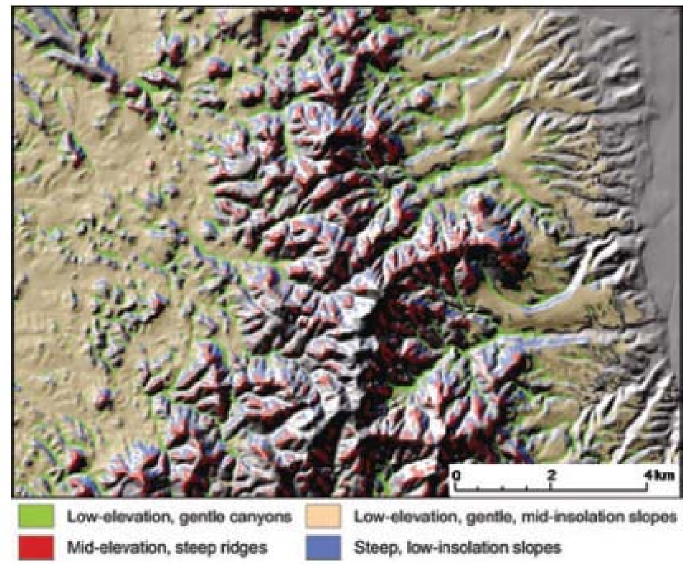

Figure 2. Illustration of the geographic distribution of land facets, defined on the basis of elevation, slope, insolation, and topographic position, draped over a hillshade map. For clarity, not all land facets in the landscape are shown.

(Beier & Brost 2010)