Landscape Dynamics and Conservation Decisions

Hugh Possingham **plus group**

20% in maths, 50% in biology, 30% geog

Australian Research Council Centre of Excellence for Environmental Decisions (+ NERP centre = $30M over 7 yr)   (U Queensland, Melbourne, WA, ANU)

Read http://decision-point.com.au/

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The salt mines where the slaves work

Possingham lab 2005-2013

260 refereed publications

25 postdocs, 30 PhD students, 40 visitors and now two $15M research centres

Australian Research Council

The Australian Academy of Science

Australian Academy of Science

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

CONSERVATION INTERNATIONAL

αεδα
Applied Environmental Decision Analysis
Commonwealth Environmental Research Facility

ARC ceed
Centre of Excellence for Environmental Decisions

Australian Government
Department of the Environment and Heritage

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Take home messages

Conservation research is a huge and growing discipline of applied ecology (Many journals with IF > 4) – about saving planet's biodiversity.

Rational decision-making is critical, but for conservation biologists this can be a problem.

How do we get conservation managers and researchers to realise that *ad hoc* approaches to decision-making are not good enough,

Landscape planning is still in its infancy

The talk is about the process and the tools

NOT THE RESULTS!

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Overview

1. Building networks of protected areas – *Marxan* and integer linear programming
2. Dynamic optimal control problems – how to manage fire
3. Dynamic optimisation for global conservation problems
4. Given time – carbon trade-offs, assisted colonisation and equity

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1 Why biodiversity?

1. Money
2. Culture
3. The 200 trillion people who have not been born

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Why decision theory?

- While other areas of applied ecology – fisheries, pest control, epidemiology etc. used decision-making tools – the only area of conservation science that formally used operations research thinking was protected area design (from 1989 onwards)
- Problem formulation is everything

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What is decision theory?

- Set a clear objective
- Define decision variables - what do you control?
- Define system dynamics (models) including state variables and constraints
- Specify the problem
- Use an algorithm to solve the problem

1 Building the world's marine and terrestrial reserve systems

- Who decides where they go?
- Initially ad hoc
- Systematic conservation planning develops in 1980s (why? – again additive scoring methods prevailed)
- First problem formulation 1989

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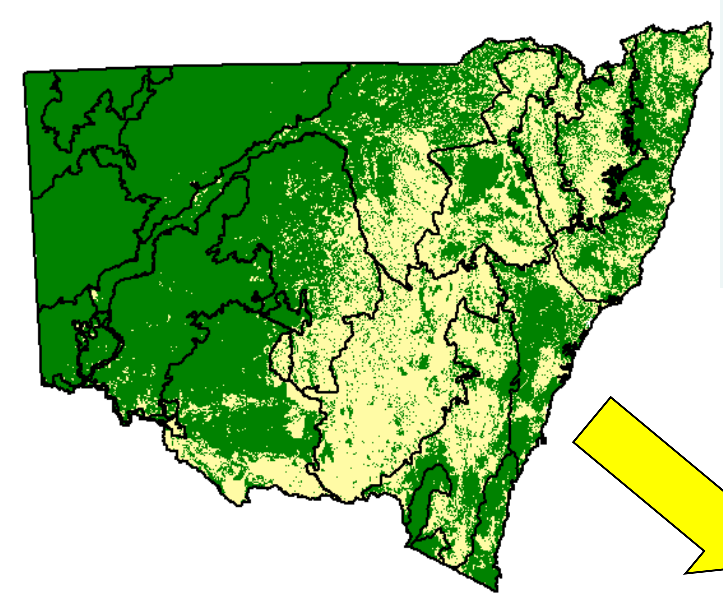
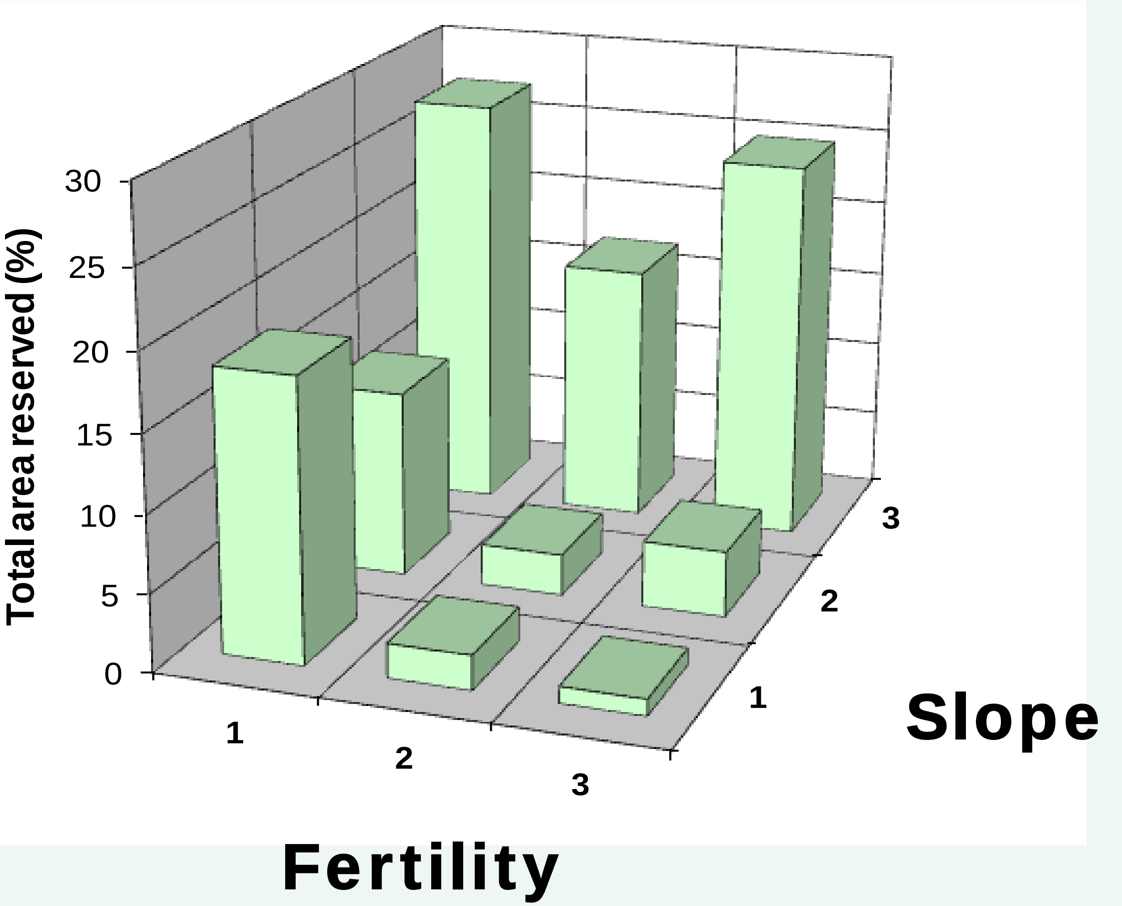
Where should we put reserves?



Reserve systems are typically highly biased away from gentle sloping fertile land

New South Wales, a state of Australia



The "minimum set" problem How do we get an efficient comprehensive reserve system

- Minimise the "cost" of the reserve system
- Subject to the "constraints" that all biodiversity targets are met
- The key is problem formulation
- (New age problems - add in spatial considerations, like total boundary length)

Example Problem

Find the smallest number of sites that represents all species

		SITE							
SPECIES	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Range**
Powerful Owl	1	1	1	1	1	1	0	1	**7**
Red Goshawk	1	1	1	1	0	0	0	1	**5**
Olive Whistler	1	1	0	1	1	1	0	0	**5**
Albert's Lyrebird	1	1	1	0	0	0	1	1	**5**
Coxen's Fig Parrot	1	1	1	1	0	0	1	0	**5**
Diamond Firetail	1	0	0	0	1	1	1	0	**4**
Black-b Button-quail	1	0	1	1	0	0	0	0	**3**
Eastern Bristlebird	1	1	1	0	0	0	0	0	**3**
Rufous Scrub-bird	0	1	0	0	1	0	0	0	**2**
Ground Parrot	0	0	1	0	0	0	0	0	**1**
Site Richness	**8**	**7**	**7**	**5**	**4**	**3**	**3**	**3**	**40**

The data matrix - **A**

ILP formulation

Minimise $\sum_{j=1}^{m} x_j$

Subject to $\sum_{j=1}^{n} a_{ij} x_j \geq 1 \qquad i = 1, \ldots, m$

$$a_{ij}, x_j \in \{0,1\}$$

$x_j = 1$ if the site is in the reserve system

Objectives and constraints

- More realistic constraints are to meet a variety of conservation targets – eg 30% of each habitat type or enough area for 2000 elephants
- More realistic objectives are to satisfy the constraints while minimising the total “cost” (which may be area, actual cost, management cost, cost of rehabilitation)
- Objectives and constraints are somewhat interchangeable
- We need compact reserve system so …

The non-linear problem

The mathematical problem to which Marxan finds good solutions is:

$$\text{minimize} \sum_{i}^{N_s} \mathrm{x}_{\mathrm{i}} c_i + b \sum_{i}^{N_s} \sum_{h}^{N_s} x_i (1 - x_h) cv_{ih}$$

subject to the constraint that all the representation targets are met

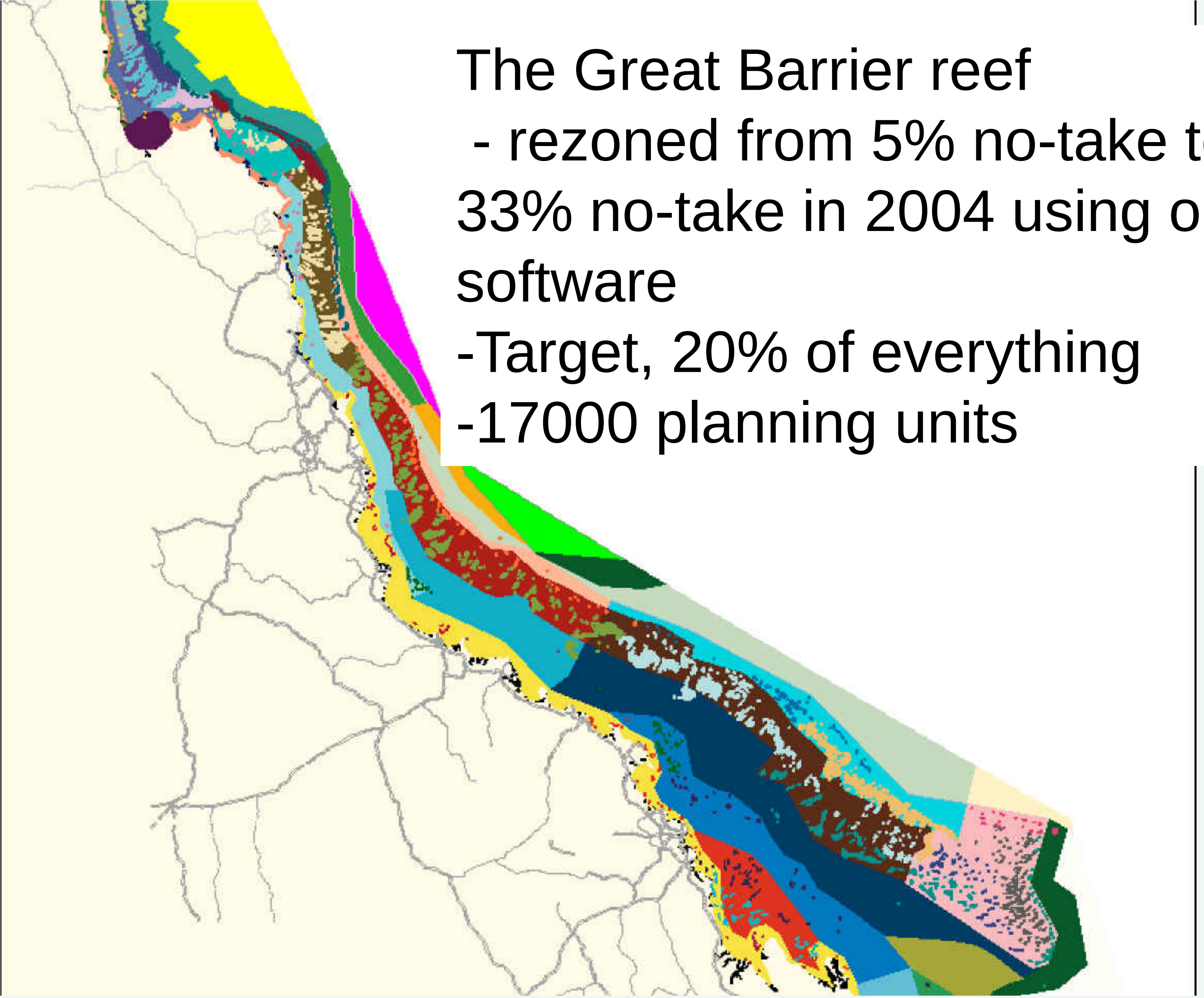
$$\sum_{i}^{N_f} \mathrm{x}_{\mathrm{i}} r_{ij} \geq T_j \quad \forall\, j$$

and x_i , the control variables which tell you if a site is in or out,
is either zero or 1

$$\mathrm{x}_i \in \{0,1\} \quad \forall\, i$$

How do we solve this?

- Why can’t we look at every possible reserve system – there are only 2^{17000}
- The number of possible solutions is a lot much bigger than the number of atoms in the universe
- We use simulated annealing, but have tried more classical optimal control methods and genetic algoithms



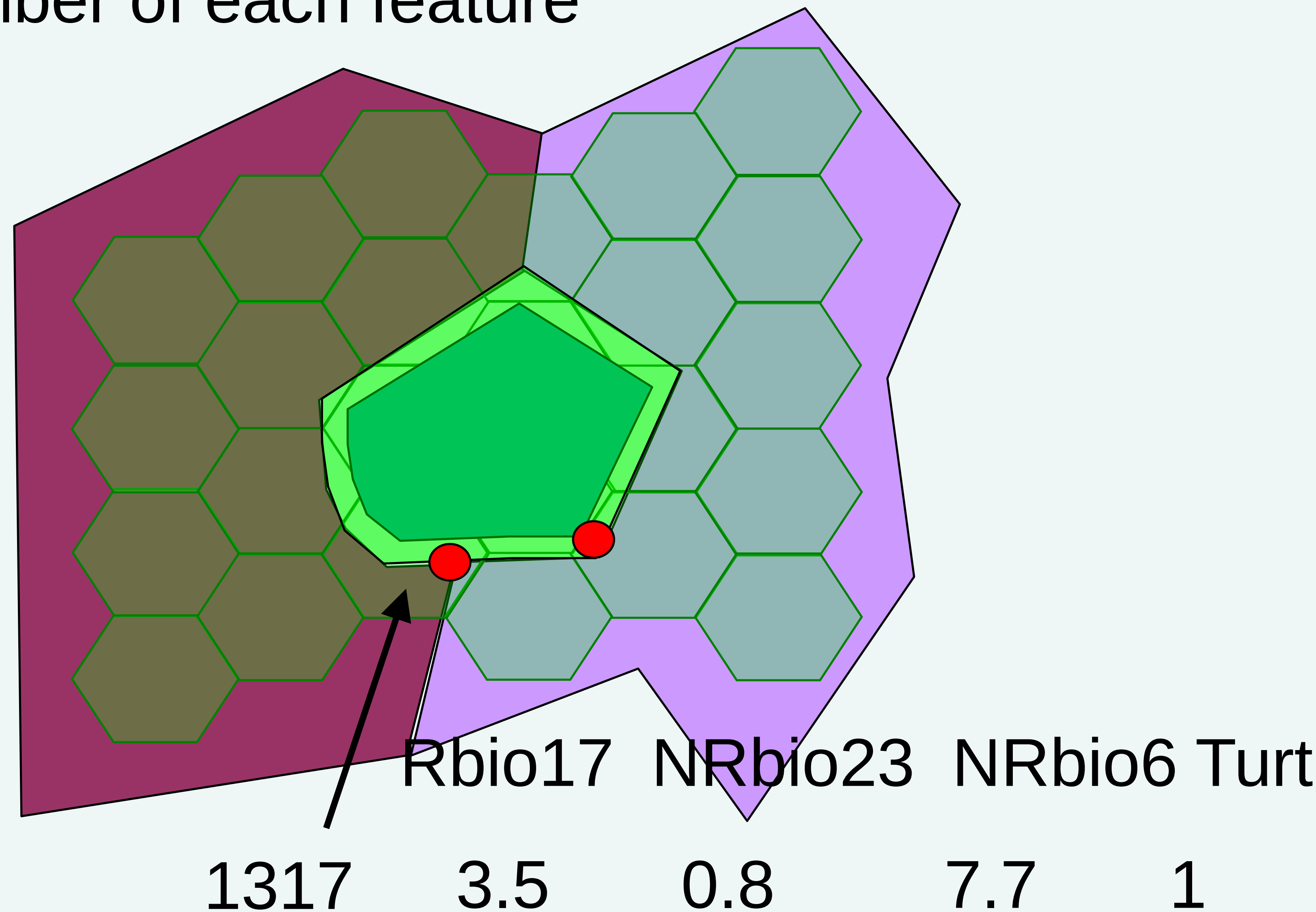
The Great Barrier reef

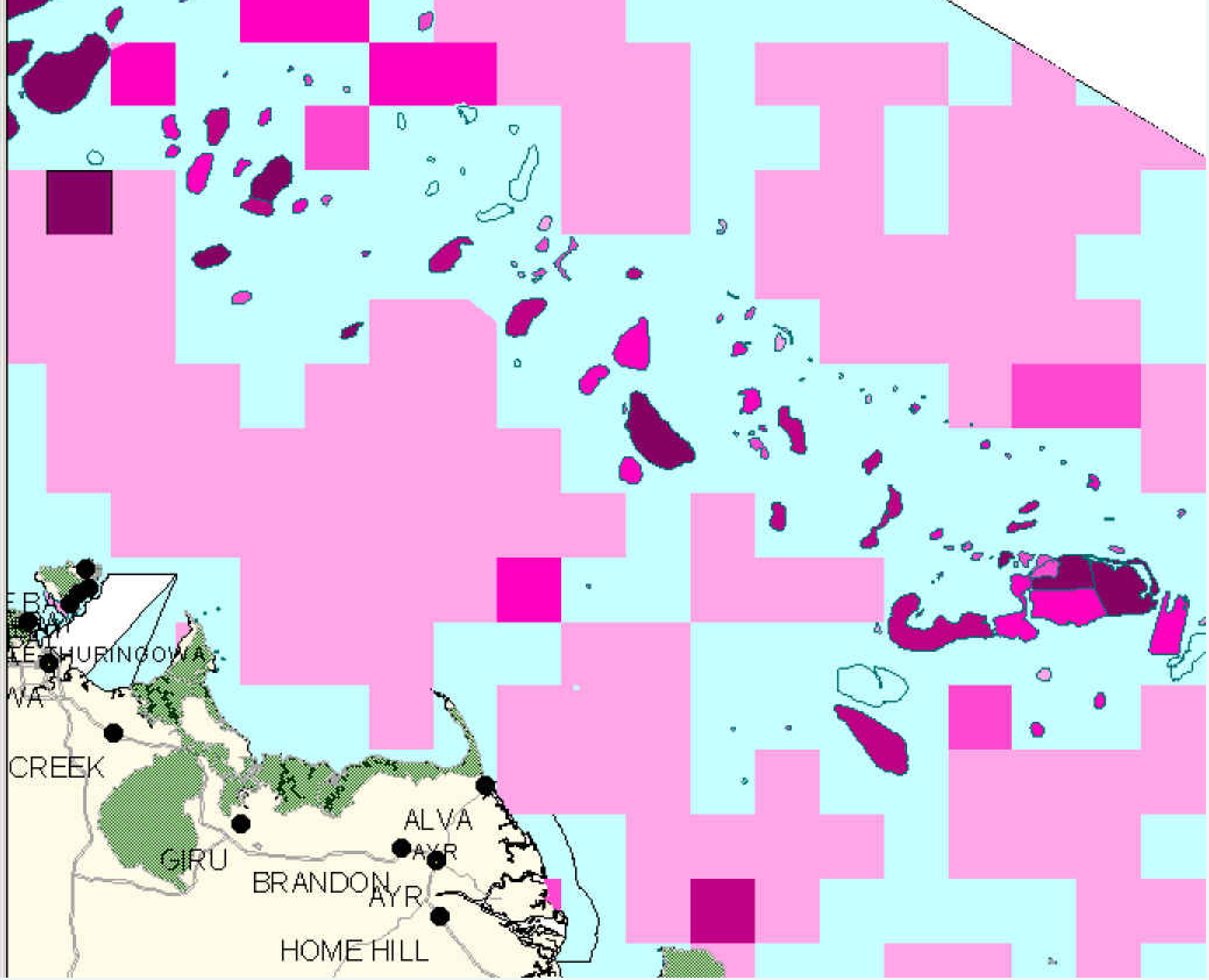
- rezoned from 5% no-take to 33% no-take in 2004 using our software
- Target, 20% of everything
- 17000 planning units

c1000km

…40 non-reef bioregions…

Each planning unit has an area or number of each feature





…Commercial fishing values…

Changing 10% of face of planet

- We developed and distribute it for free – Marxan – http://www.uq.edu.au/marxan/
- It is free because “Intellectual property is theft” – quote Possingham 2001
- Used in 100+ countries by 2000+ people and agencies – e.g. Malaysia

- ***Book: Spatial Conservation Prioritization***
  Dr Atte Moilanen, Dr Kerrie A Wilson and Professor Hugh Possinghamhttp://www.oup.com/uk/catalogue/?ci=9780199547777

ILP formulation

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$x_j = 1$ if the site is in the reserve system

What is the control variable and what is the state variable?

We have a string of papers on dynamic reserve system design

Models vs problems vs algorithms

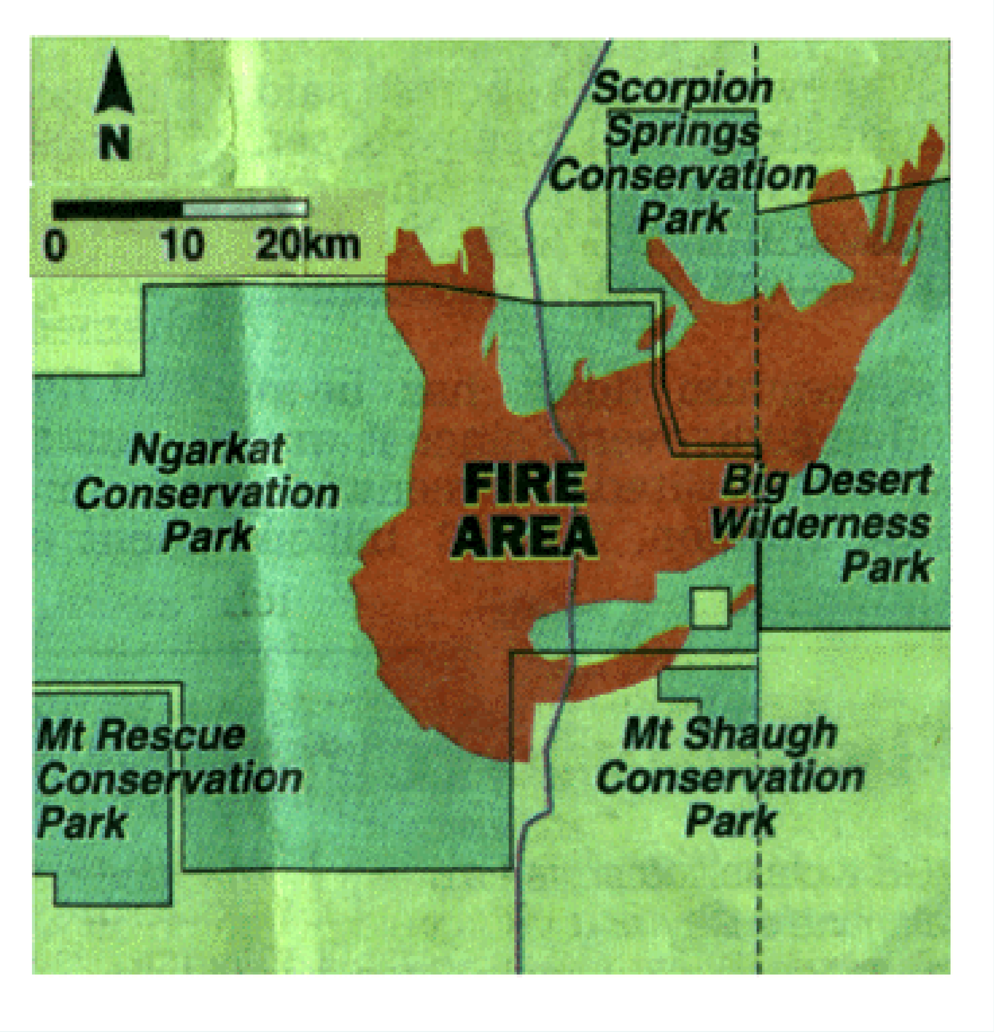
2 Optimal Fire Management for biodiversity conservation

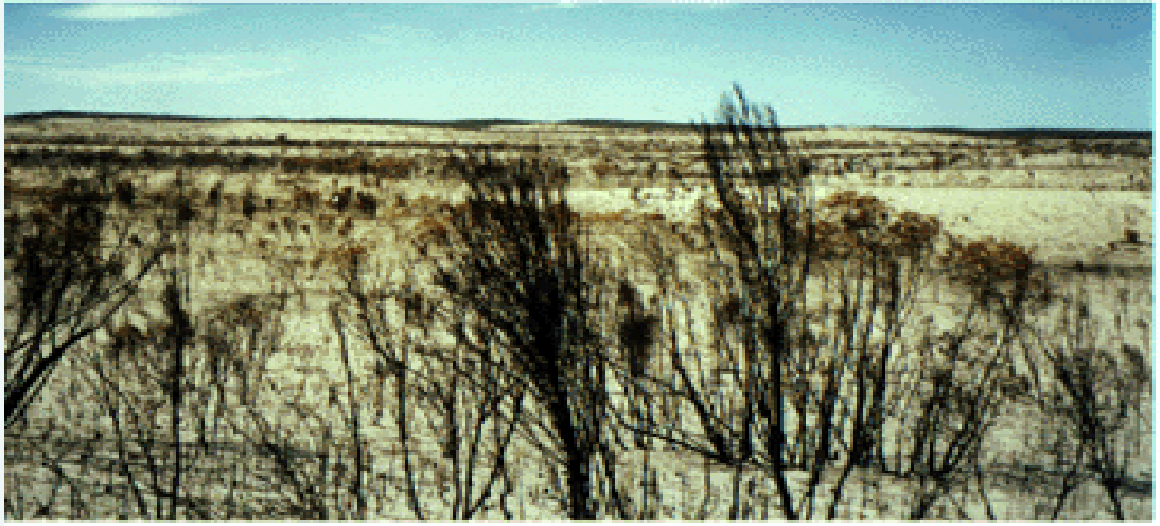
Hugh Possingham, Shane Richards, James Tizard and Jemery Day – Ecol Apps 1999

The problem

- How should I manage fire in Ngarkat Conservation Park - South Australia?
- What scale?
- What biodiversity?
- How is it managed now?
- What is the objective?

Ngarkat Conservation Park
250,000 ha

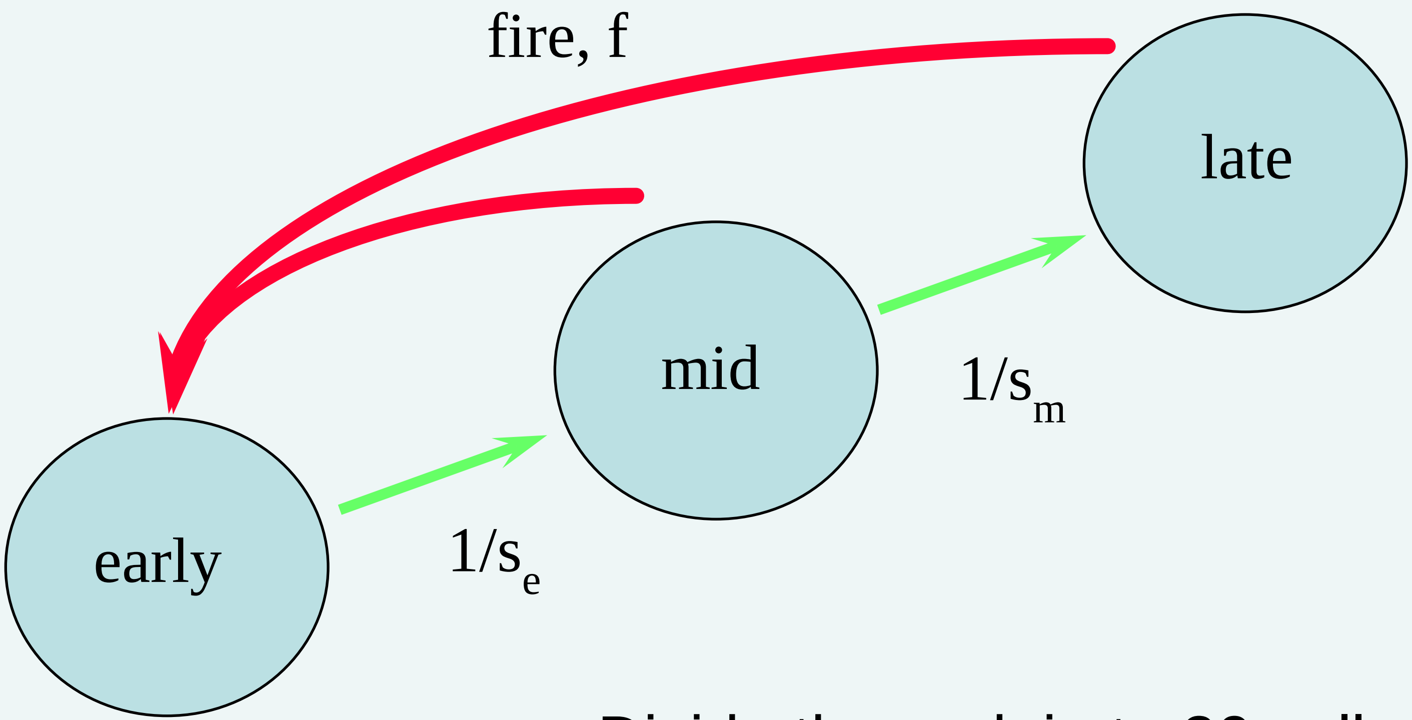




Vegetation

- Dry sandplain heath (like chapparal) - 300mm, winter rainfall
- Little heterogeneity in soil type or topography - poor soils
- Diverse shrub layer with some mallee
- Key species - Banksia, Callitris, Melaleuca, Leptospermum, Hibbertia, Eucalyptus

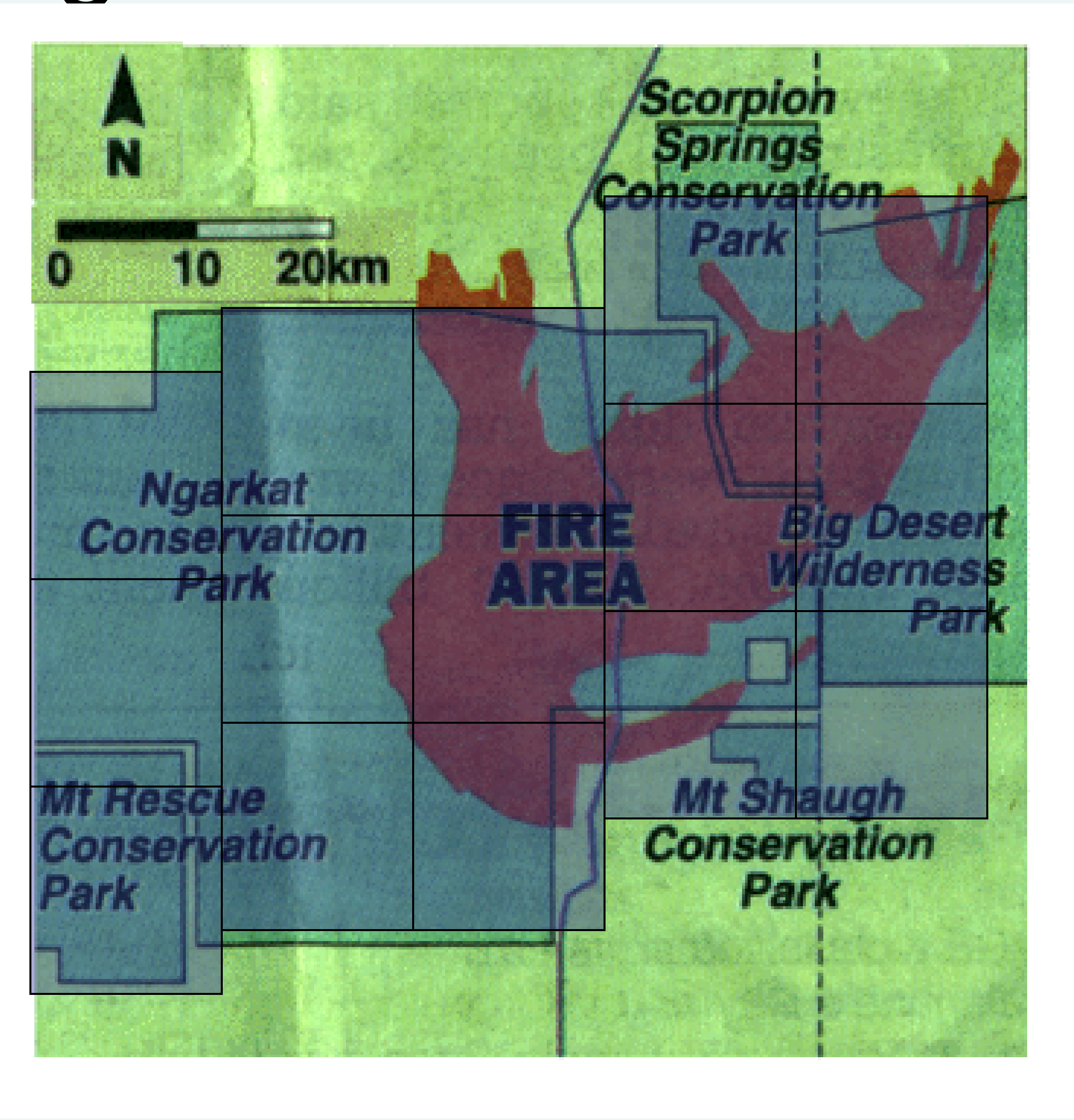
Assume three successional states



Divide the park in to 20 cells,

Each has a successional state

Ngarkat Conservation Park

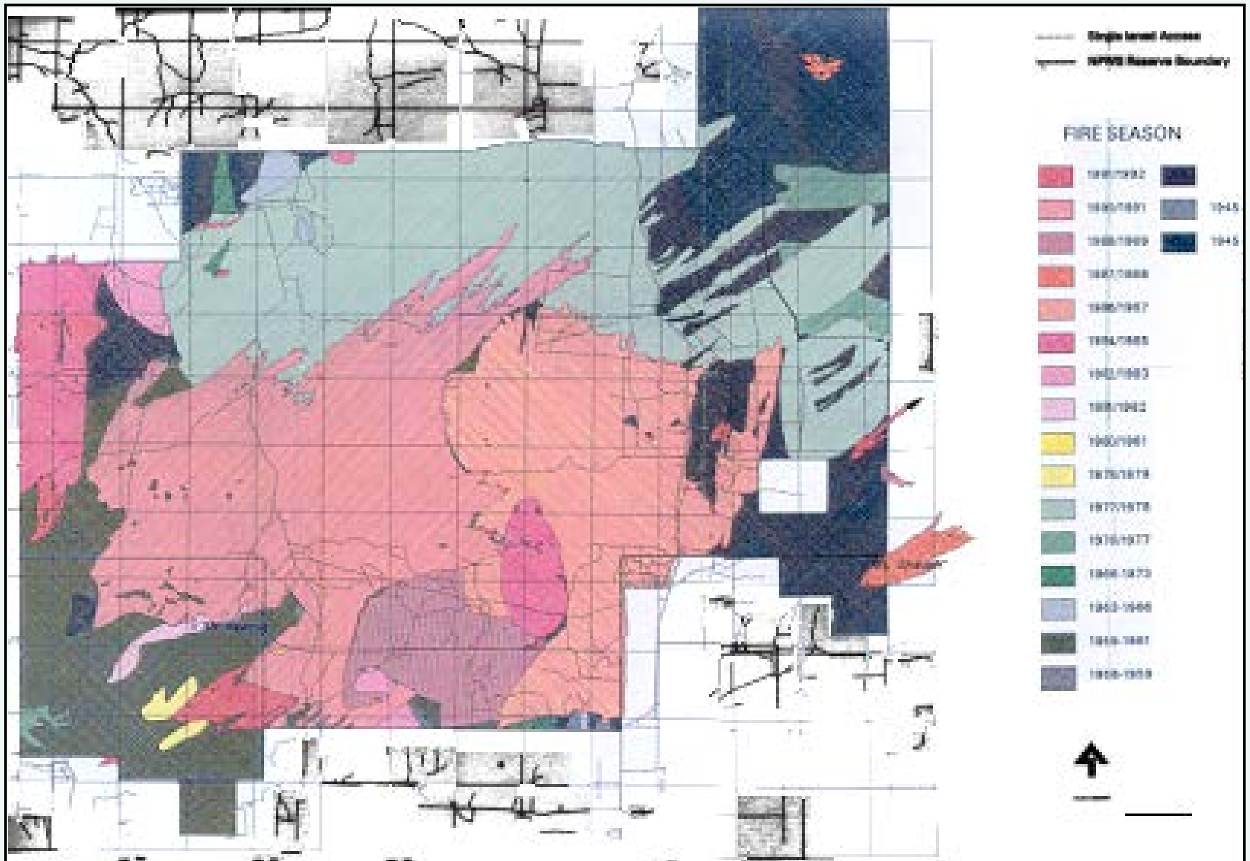


Nationally threatened bird species

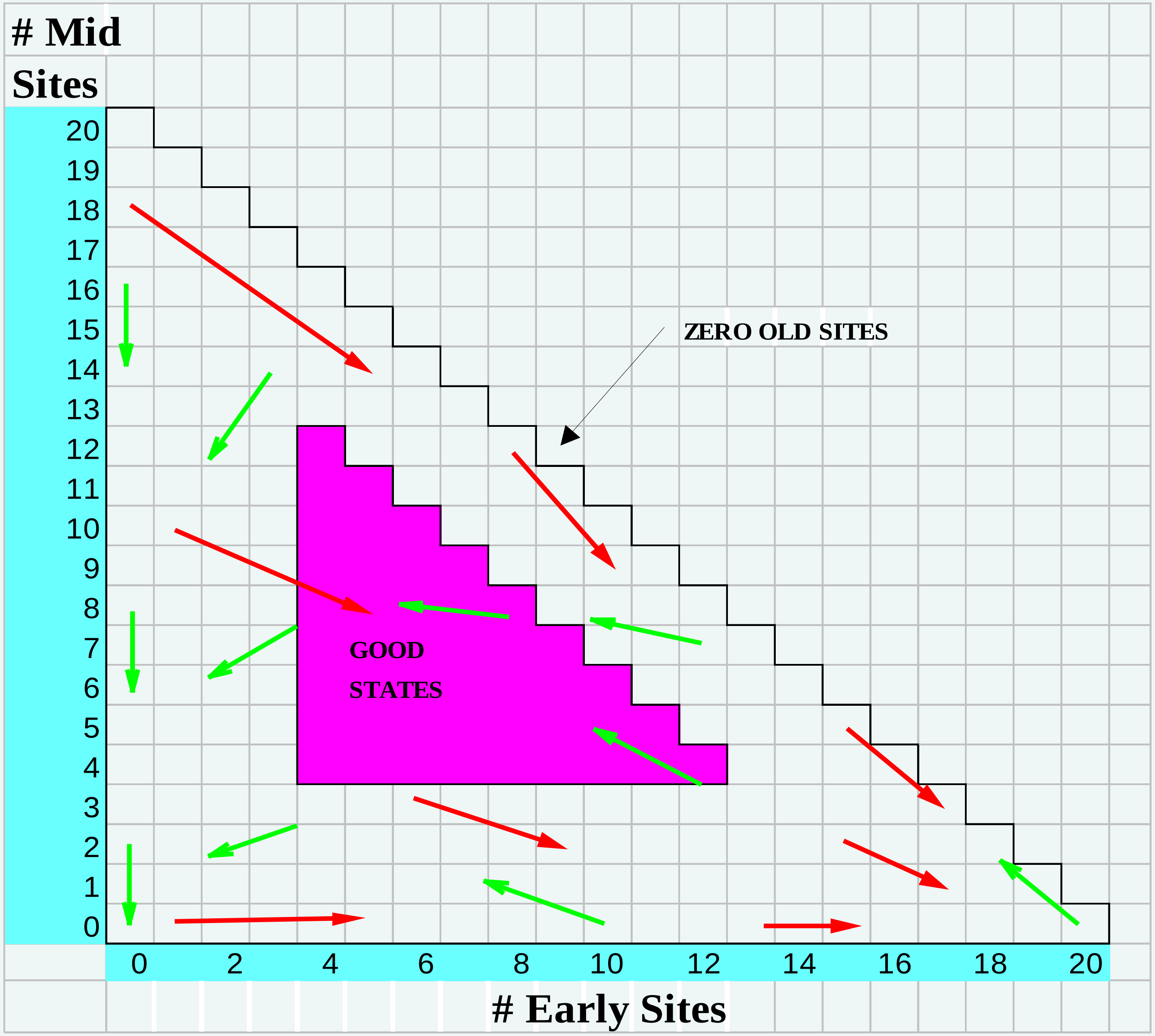
- Slender-billed Thornbill - early
- Rufous Fieldwren - early
- Red-lored Whistler - mid
- Mallee Emu-wren - mid/late
- Malleefowl - late
- Western Whipbird – late

What is the objective?

Ngarkat fire history (SA planning) – gives us an initial state



State space and dynamics



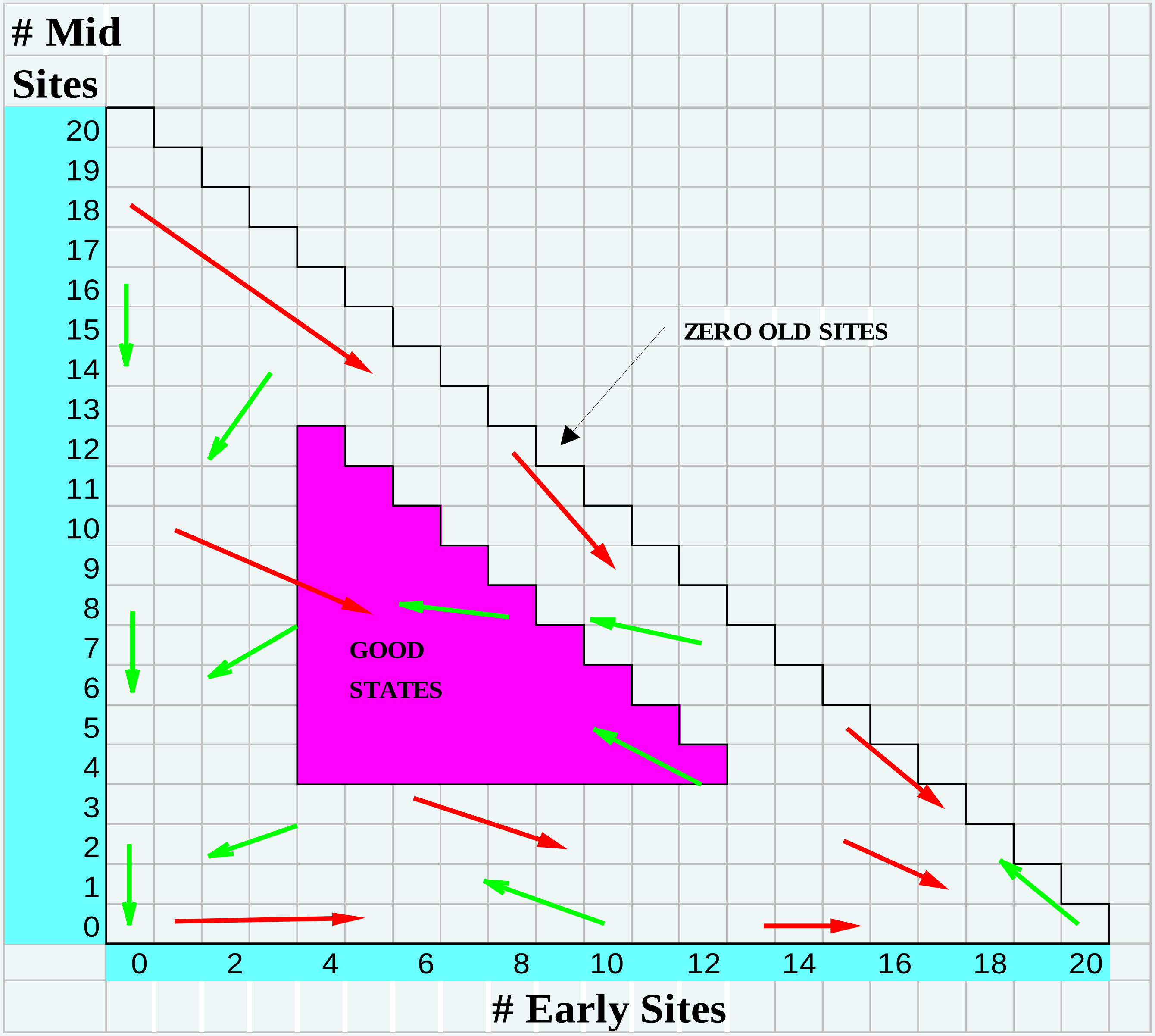
Vegetation dynamics: Transition probability from j early to i early with no fire

$$E(i|j)=\begin{cases}\binom{j}{j-i}s_e^{\,j-i}\left(1-s_e\right)^{i} & \text{if } i\le j\\ 0 & \text{otherwise.}\end{cases}$$

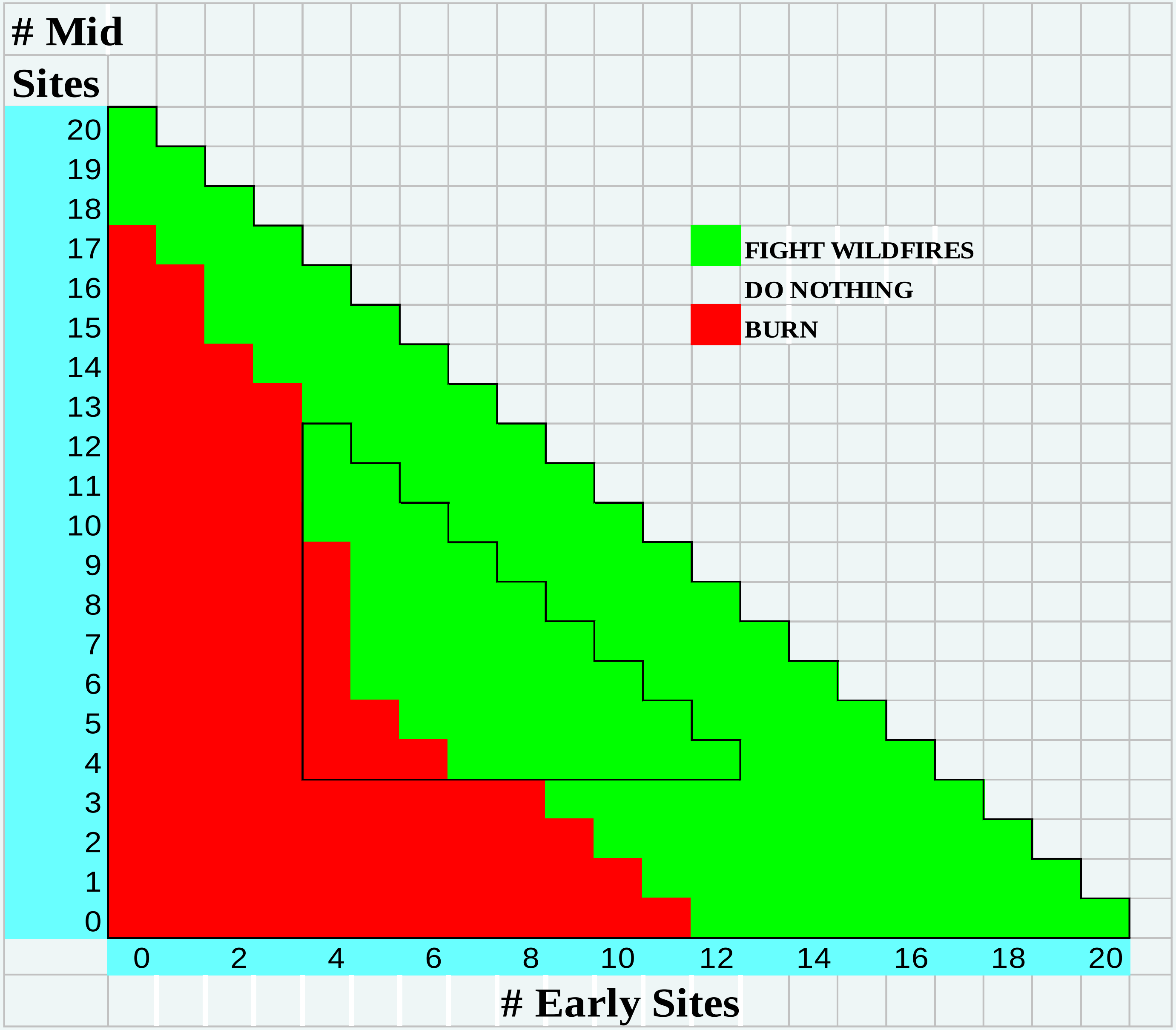
The optimization problem

- **Objective - 20% each stage**
- **State space - % of park in each successional stage**
- **Control variable - given the current state of park should you do nothing, fight fires, start fires?**
- **System dynamics determined by transition matrices**

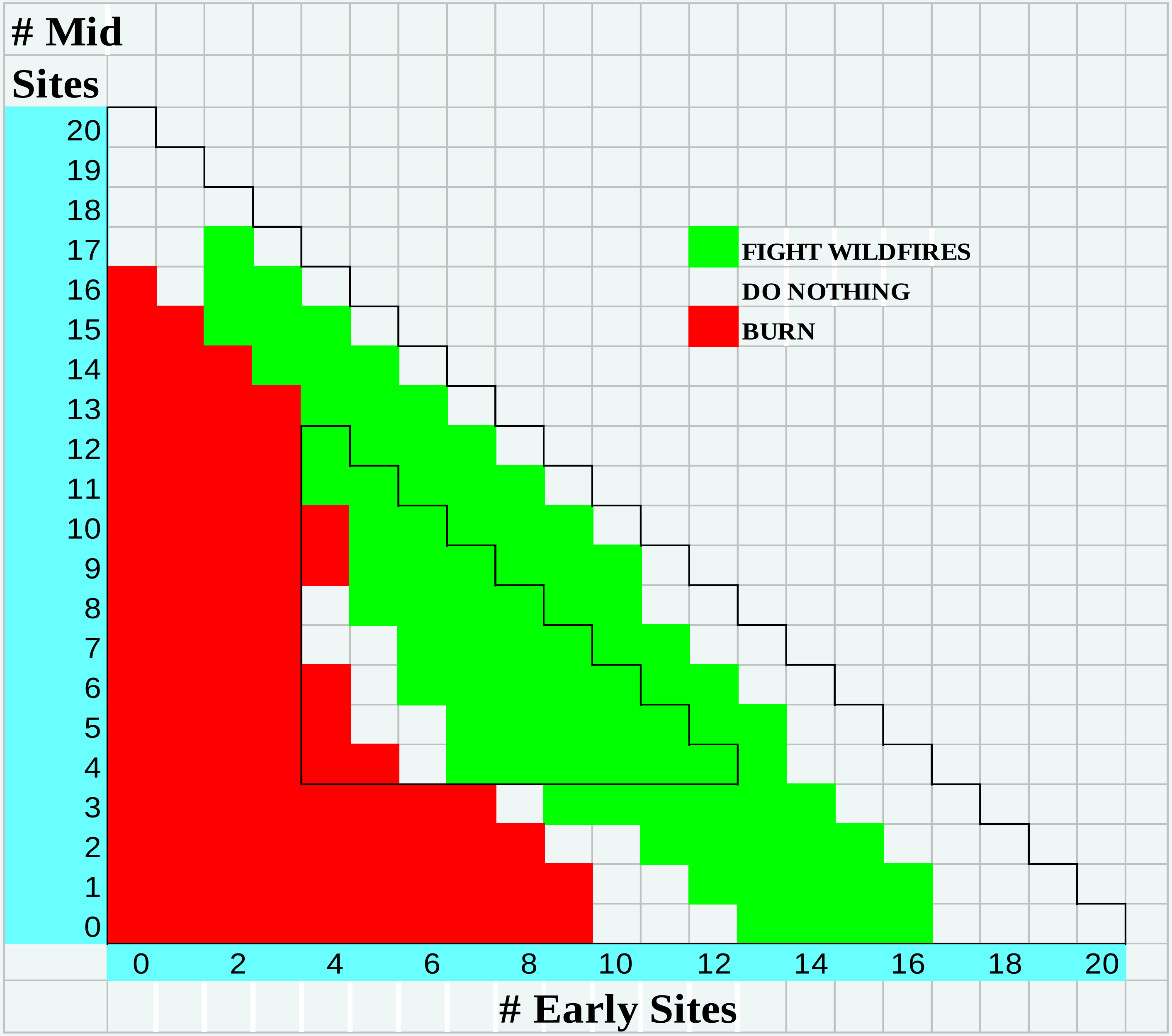
State space and dynamics



Optimal strategy with no costs



Optimal strategy with costs

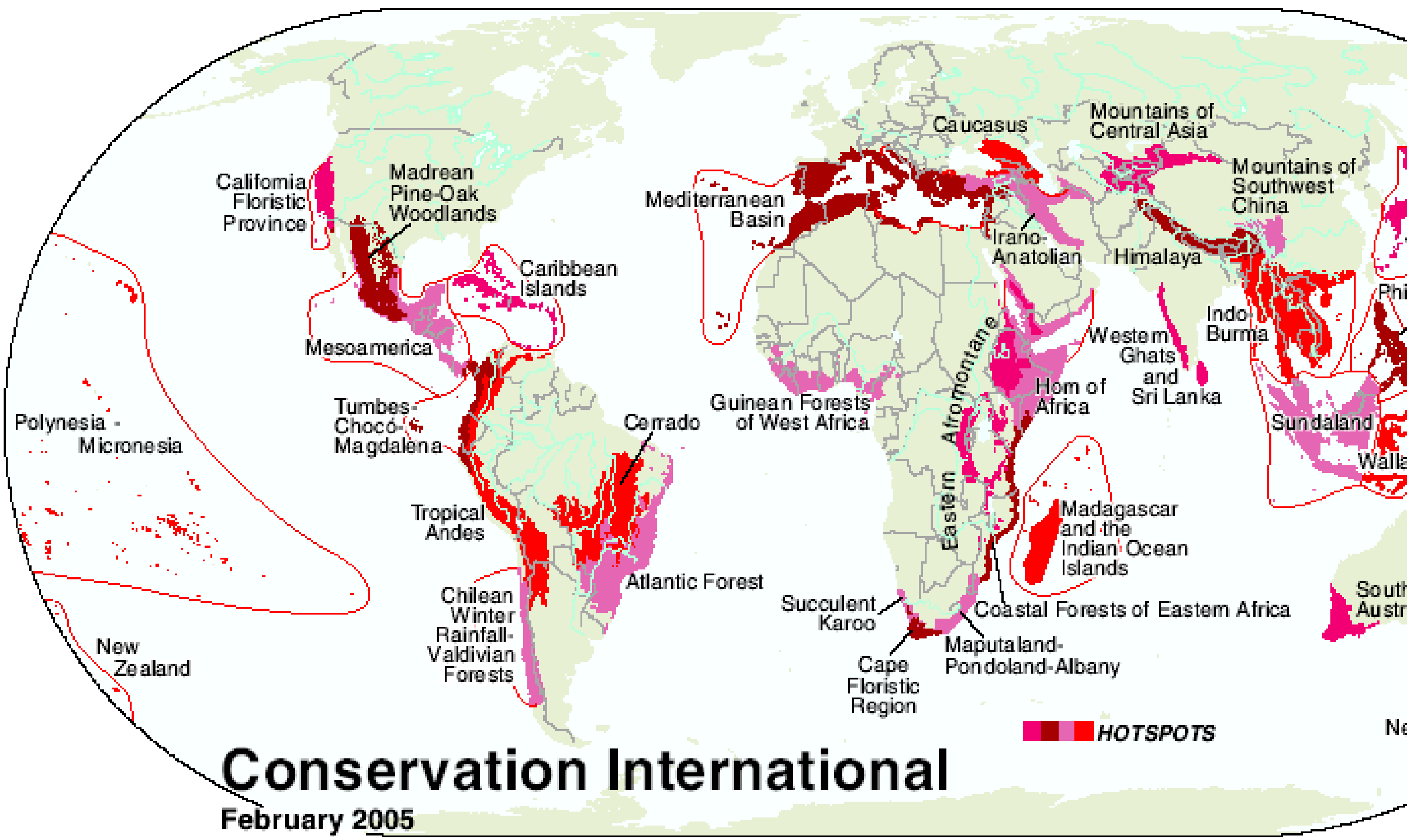


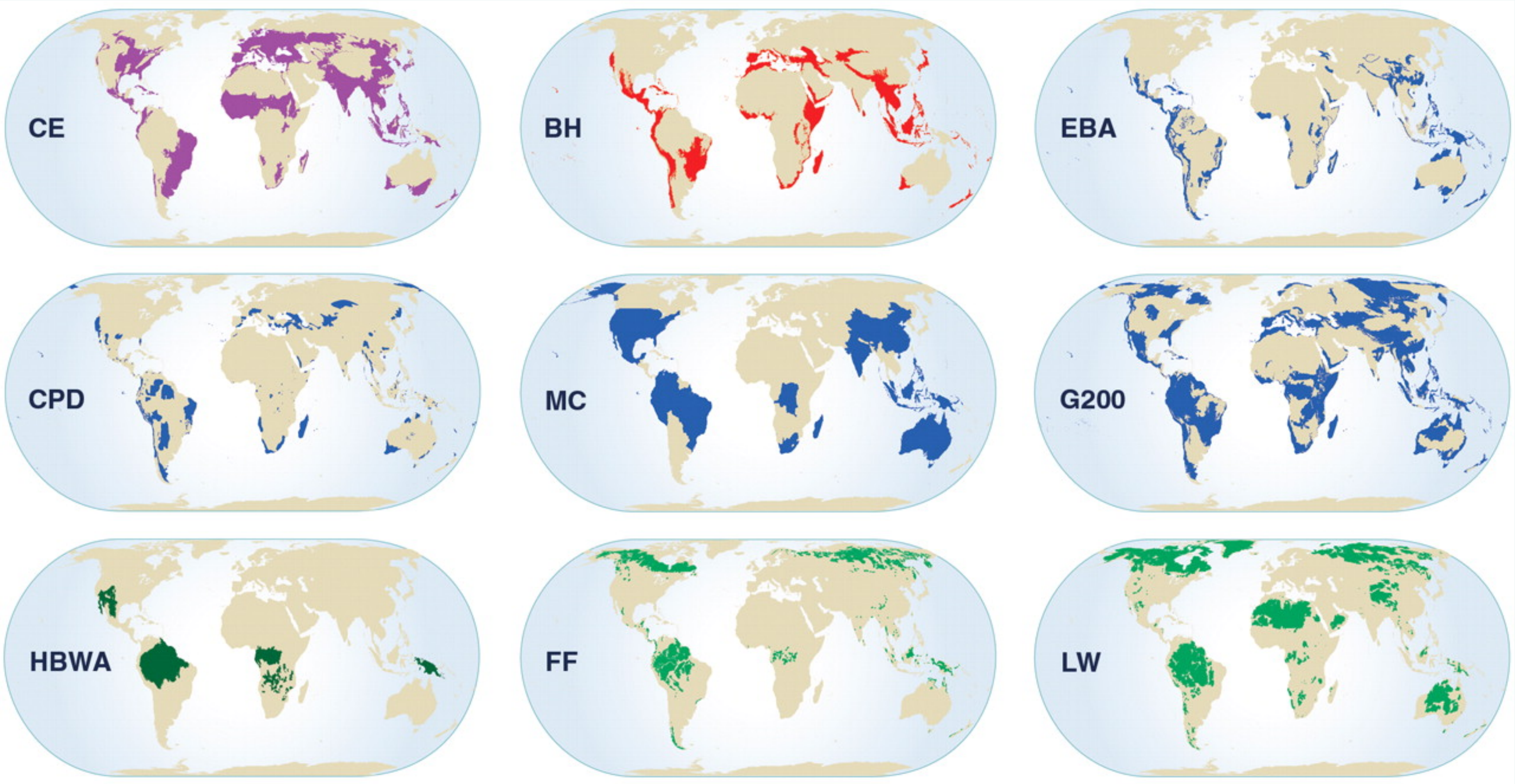
Conclusion

- Decision is state-dependent - there is no simple rule, but we should try again
- Costs may be important
- The decision theory framework allows us to address the problem and find a solution
- Details – S. Richards, Possingham and Tizard (1999) - Ecological Applications

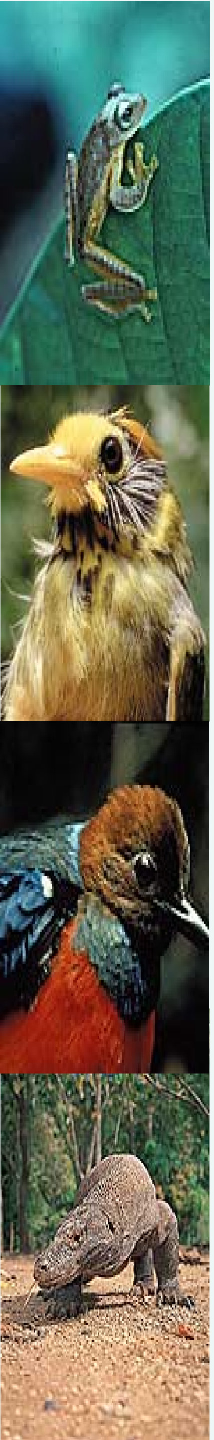
3 Where and when should we invest $ for reservation to conserve biodiversity?

Wilson, K. A., M. McBride, M. Bode, and H. P. Possingham. 2006. Prioritising global conservation efforts. ***Nature*** 440:337-340





Maps of the nine global biodiversity conservation priority templates: CE, crisis ecoregions (*21*); BH, biodiversity hot spots [(*11*), updated by (*39*)]; EBA, endemic bird areas (*15*); CPD, centers of plant diversity (*12*); MC, megadiversity countries (*13*); G200, global 200 ecoregions [(*16*), updated by (*54*)]; HBWA, high-biodiversity wilderness areas (*14*); FF, frontier forests (*19*); LW, last of the wild (*20*).



The problem (in words)

- How should we allocate scarce resources within or between different parts of the globe to conserve biodiversity?
- There are many priority setting schemes based on scores and rules and a lot of biodiversity data
- The problem is – nobody bothered to state the problem – what are these priority regions for? Nine answers and no clear question

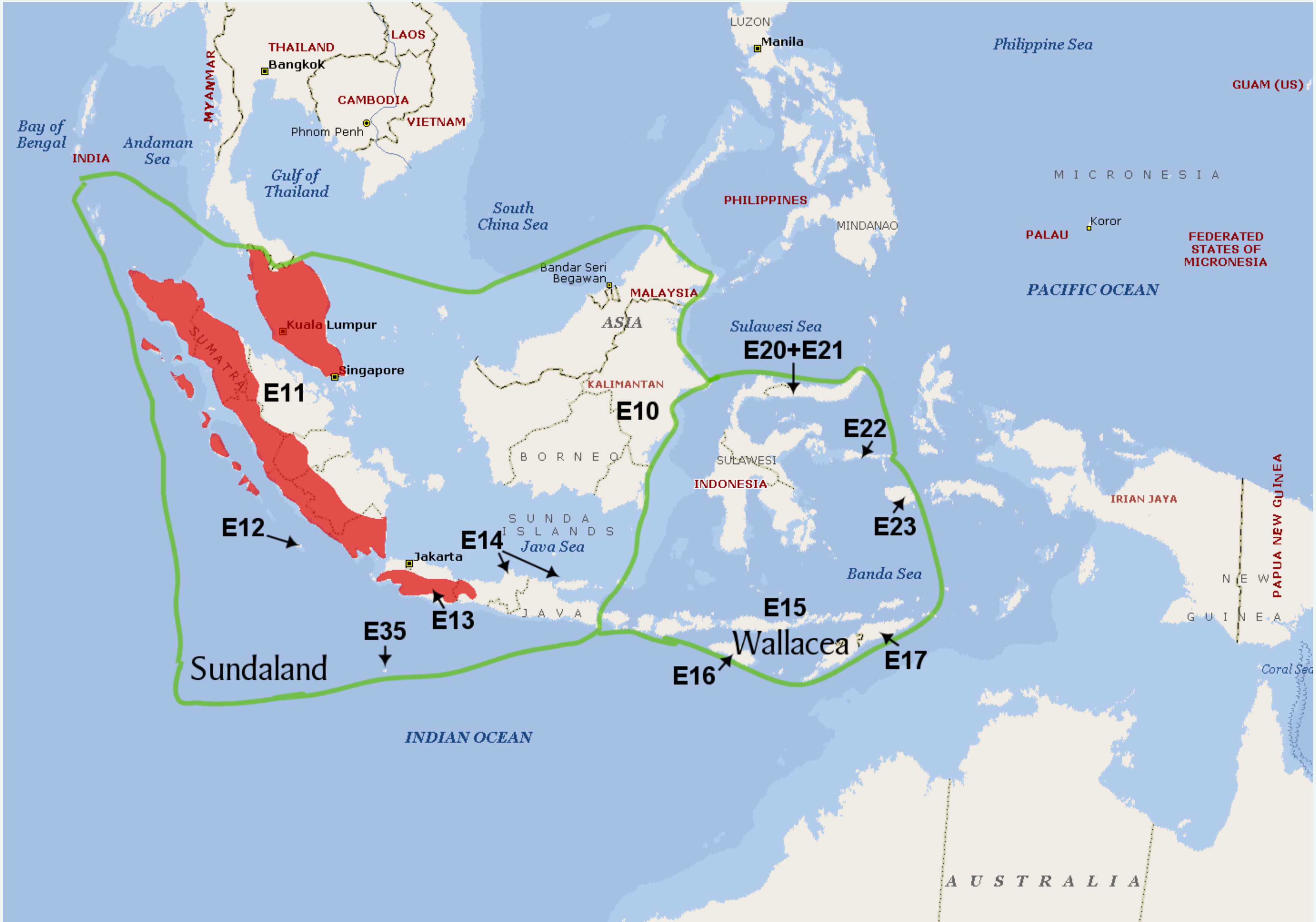
Existing hotspots answer the question of where biodiversity levels are highest and where threat was, and probably is, high

Like threatened species lists, Hotspots were never intended to account for

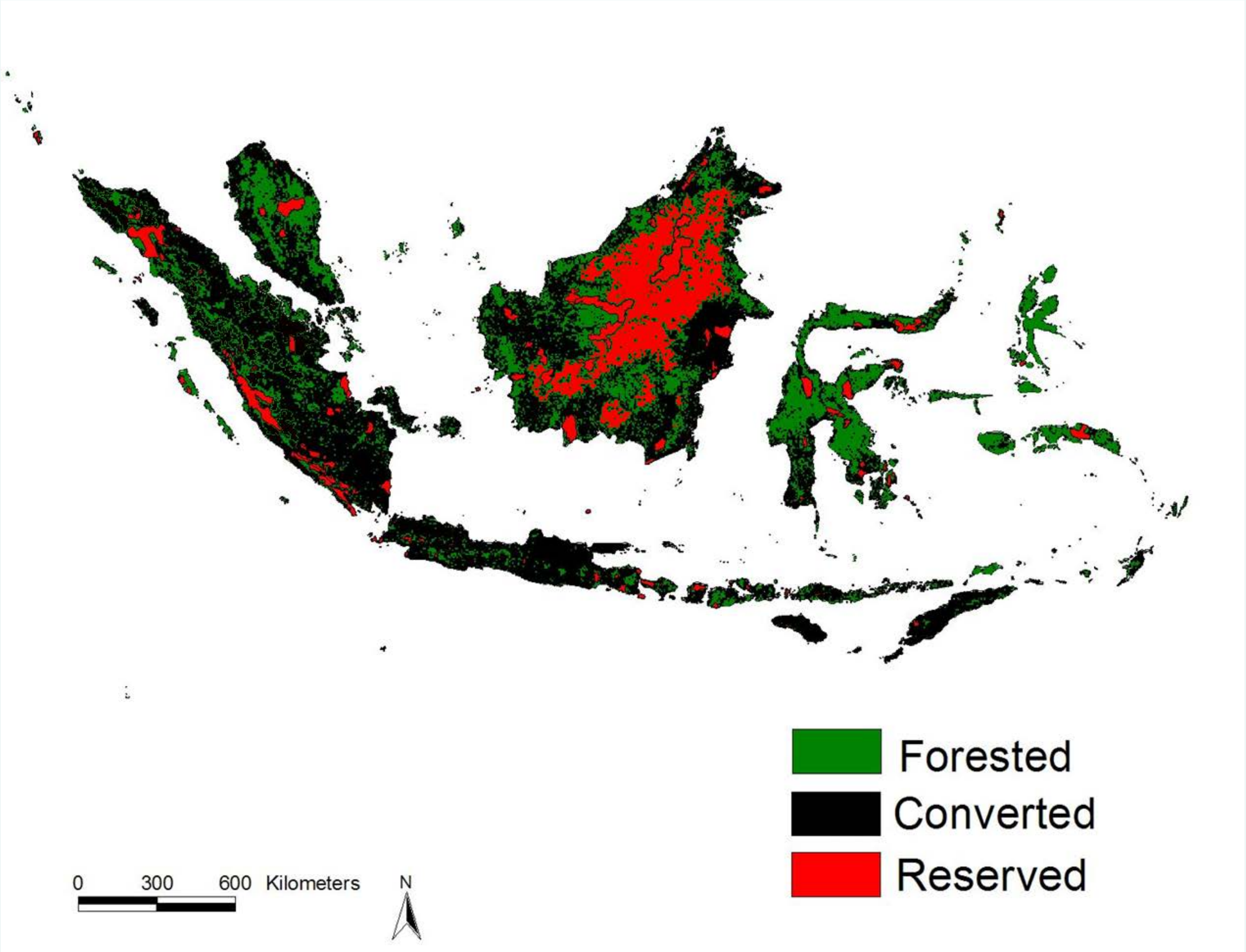
1. The cost of action
2. How returns for conservation investment change through time, or
3. The dynamic nature of landscapes and the existence of uncertainty

All of these things are needed to get you the biggest bang for your buck

Asia-Pacific Region



A dynamic system



Formulating the RIGHT problem…

- **Objective:** minimise the loss of biodiversity within a set of priority areas, given an ongoing loss of habitat, and a fixed budget for conservation investment

- **Management decision:** how many land parcels to reserve in the different priority areas at a given time

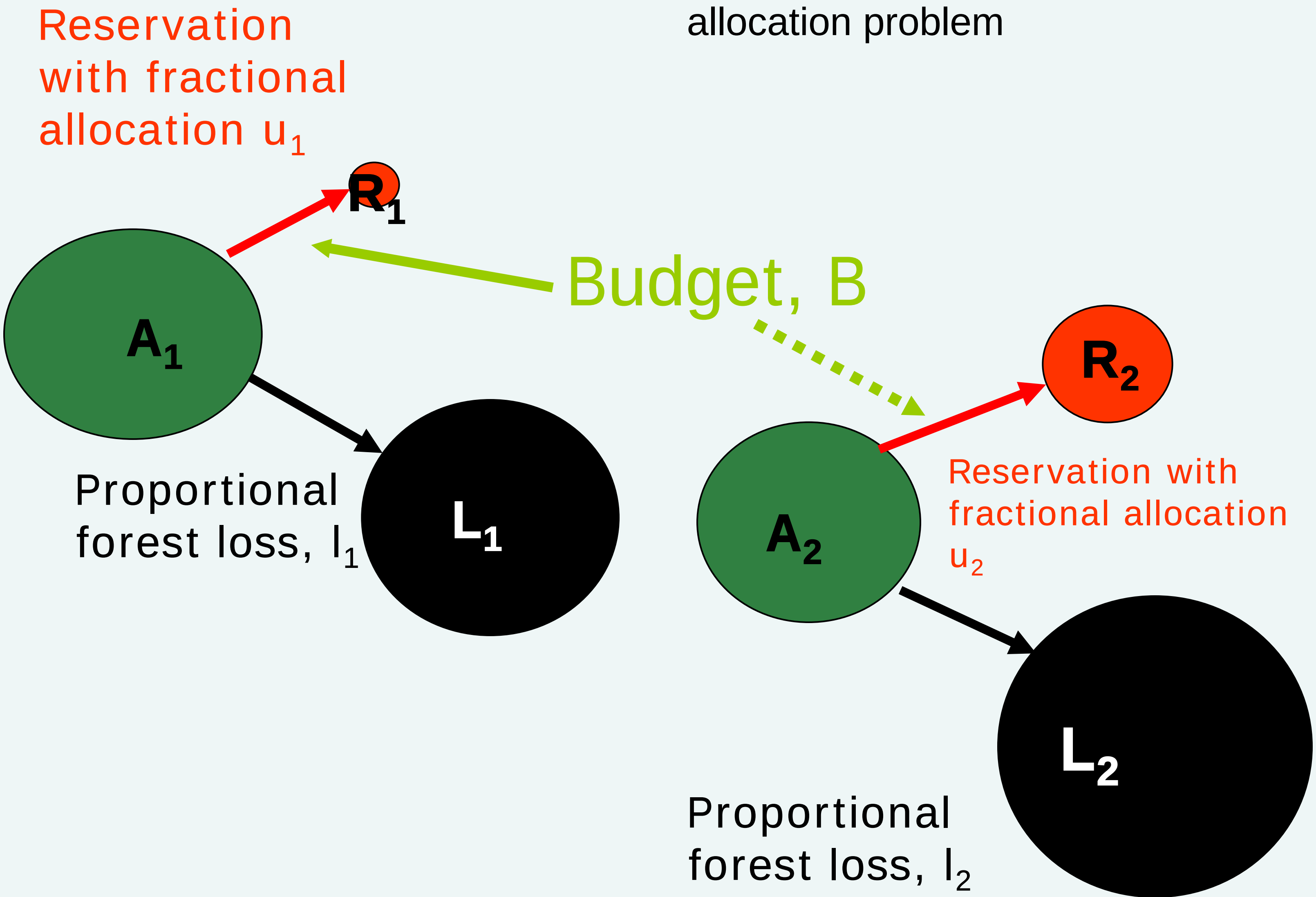
- **Constraint:** the annual budget

Formulating the RIGHT problem…

- **System properties:** endemic species richness, rate of forest conversion, and cost of land acquisition
- **System dynamics:** parcels are subject to a annual conversion rate, budget is allocated to one or more regions, which increases the reserved area and decreases conservation returns with time
- **Uncertainty** associated with the forest conversion data is incorporated by representing it as a stochastic process.

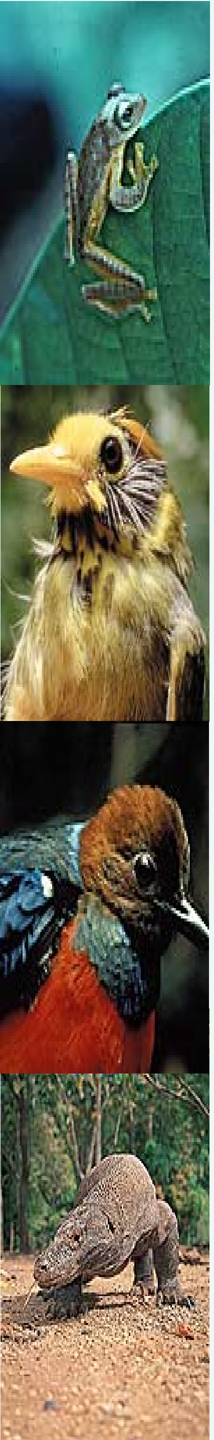
Formulating the RIGHT problem…

5 regions, a dynamic allocation problem



The Data

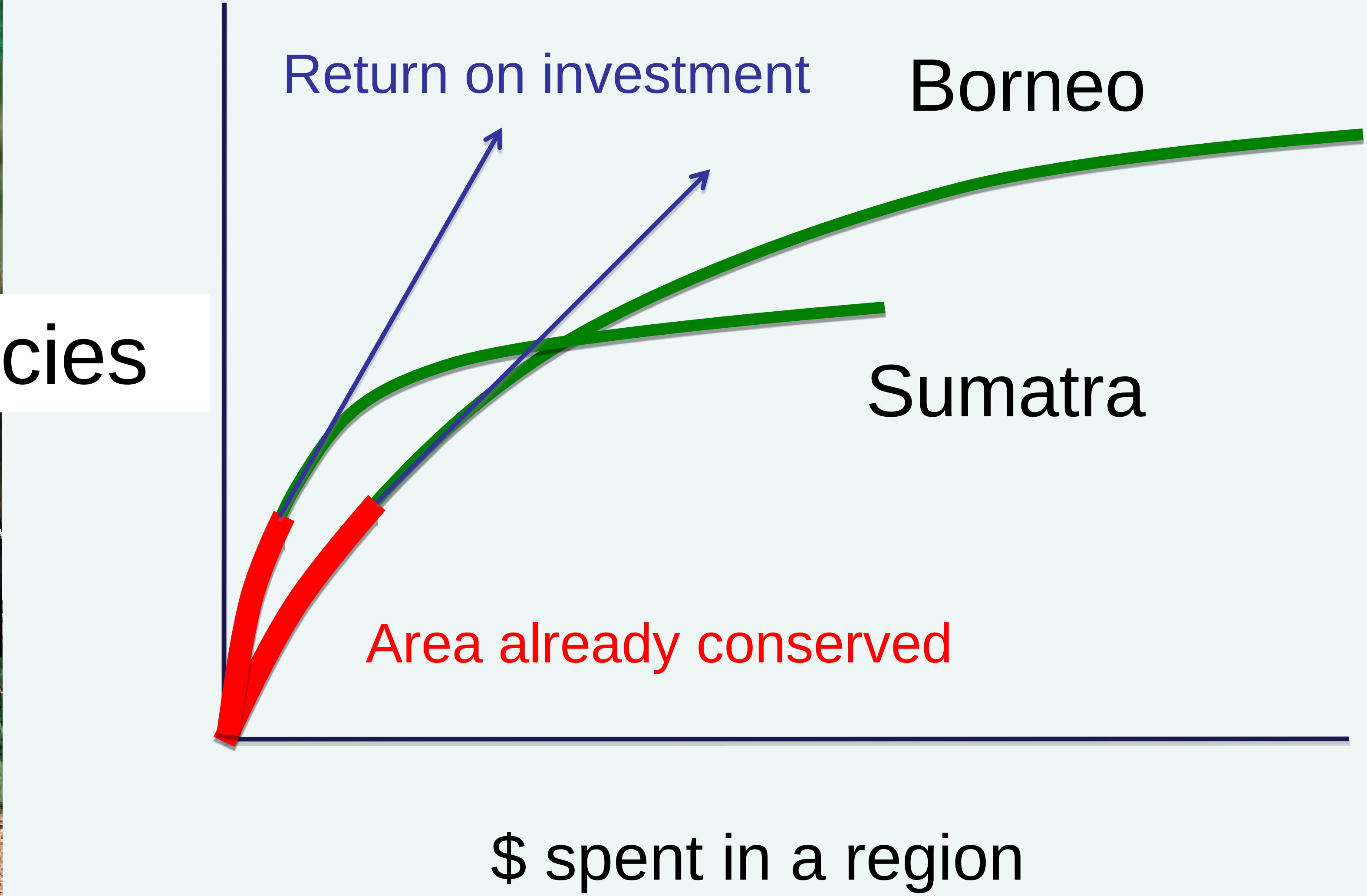
Priority Area	Number endemic birds	Conversion rate (%/yr)	Cost (US$ km-2 year-1)
Sulawesi	67	-2.4	76
Java/Bali	24	-1.7	782
Sumatra	18	-2.3	95
Southern Peninsular Malaysia	4	-1.2	2746
Borneo	29	-2.1	110



Solution Method

- Stochastic dynamic programming will give optimal results but is limited to low-dimensional problems
- Simpler heuristics
  - Maximise short term gain of species (ignores threat)
  - Minimise short term loss of species (accounts for threat)

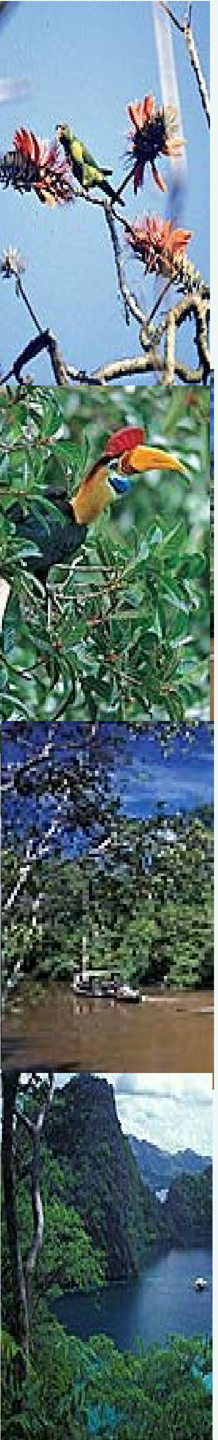
Multimedia


species
Return on investment
Borneo
Sumatra
Area already conserved
$ spent in a region

Results

- The minimisation of short term loss closely approximates the optimal solution

- Answer
  - Spend all your money in Sulawesi until nothing left to do there
  - Then Sumatra, then Java/Bali, then Borneo
  - Finally Peninsular Malaysia



Summary

- We properly formulated the problem
- Found simple solutions that perform well using just a spreadsheet
- Tells you not only how much to spend where, but when!
- Scoring systems provide an inefficient answer

What about the whole world?

Bode M., Wilson K.A., Brooks T.M., Turner W.R., Mittermeier R.A., McBride M.F., Underwood E.C. & Possingham H.P. (2008). Cost-effective global conservation spending is robust to taxonomic group. ***Proceedings of the National Academy of Sciences of the United States of America***, 105, 6498-6501 (plus 3-4 other papers on related topics).

Considerations

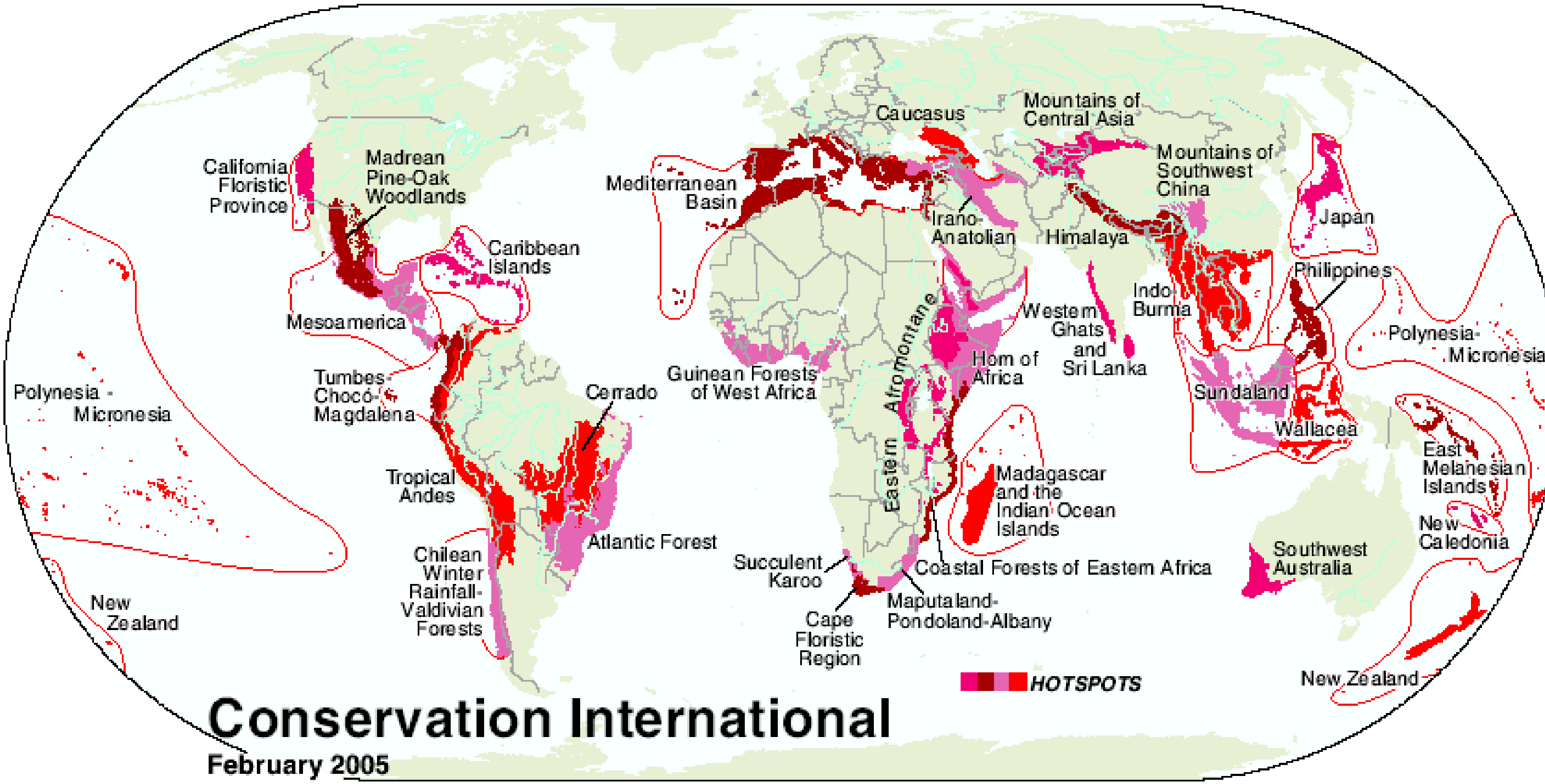
- The world’s 34 biodiversity hotspots
- Create a proper mathematical problem with an objective – save as many endemic species in the world’s hotspots as possible
- Take into account
  – Threat (rate of conversion)
  – Endemic species (number of)
    - Mammals, Amphibian, Birds, Reptiles,Freshwater Fish, Tiger Beetles, Vascular Plants, All vertebrates
  – Cost

Some of data

	Plants	Cost	Free	Res
Tropical Andes	15000	20	17%	8%
Cape Floristic	6000	210	15%	10%
Philippines	6000	260	1%	6%
Cerrado, Brazil	4000	10	20%	1%
Melanesia	3000	20	30%	0%
East Afromontane	2000	2	5%	6%
California	2000	900	15%	10%
New Caledonia	2000	600	24%	3%

We could turn these numbers into scores and add them?!

Where should I put my $500 million over the next 20 years?



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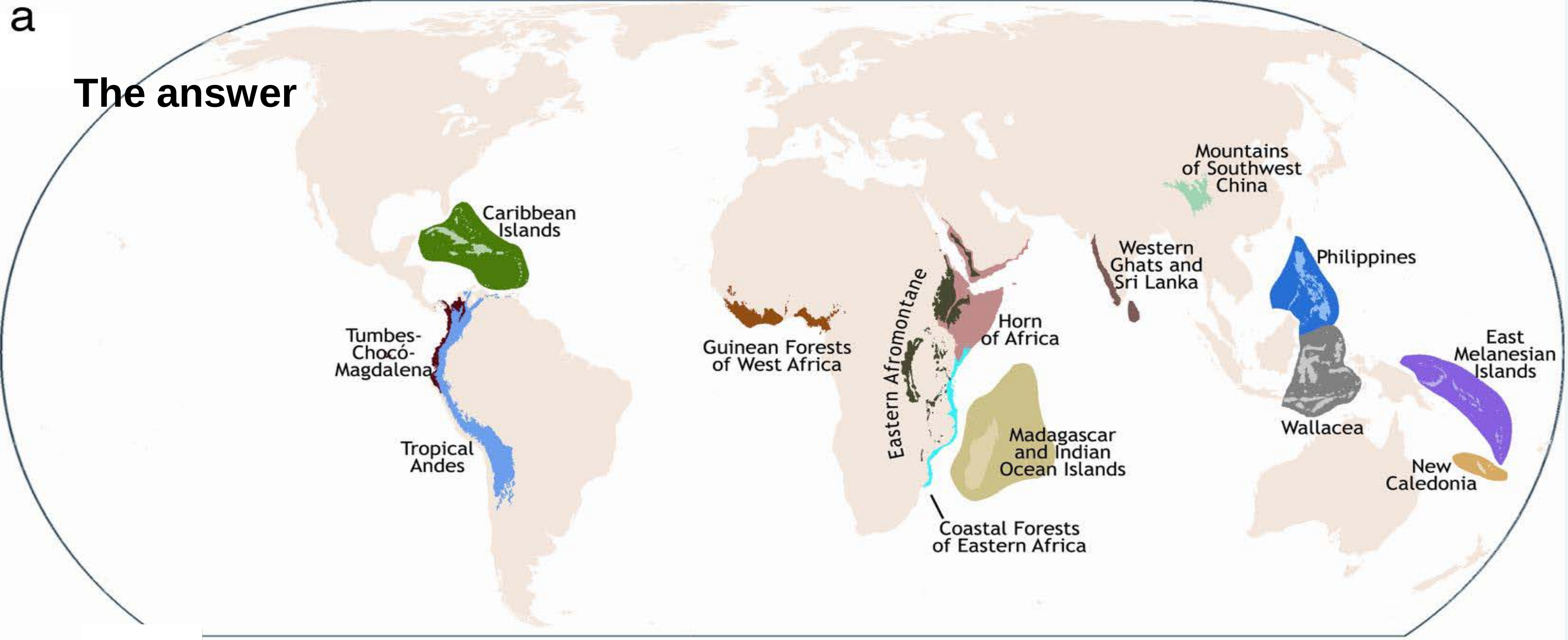
The answer



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Take home

- **Money matters a lot more that the other parameters**, and to a lesser extent % reserved, threat and endemic species richness
- With costs we allocate funds consistently to seven or eight regions relatively independently of the taxa used to set priorities:
  - Tropical Andes
  - Guinea Forests of West Africa
  - East Afromontane
  - East Melanesian Islands
  - Madagascar …

Restore or Protect, modifying the basic equations and noting the extinction debt

4 Decision science tools for *assisted colonisation*

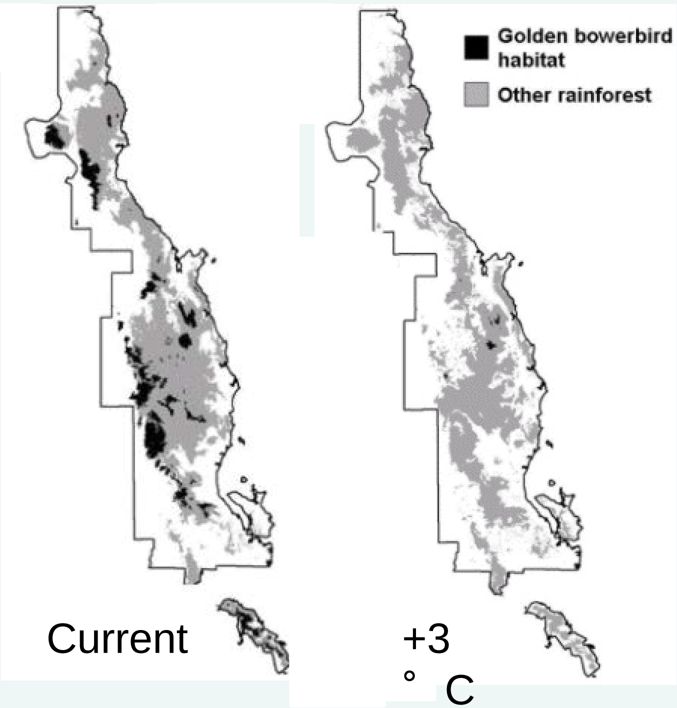
Eve McDonald-Madden, CSIRO/UQ

Tara Martin, CSIRO Ecosystem Sciences

Tracy Rout, Univ Melb

Doug Armstrong, Massey Univ, NZ

Mike Runge, USGS, USA



Hilbert *et al*. (2004) *Biol. Conserv*. 116: 367-377

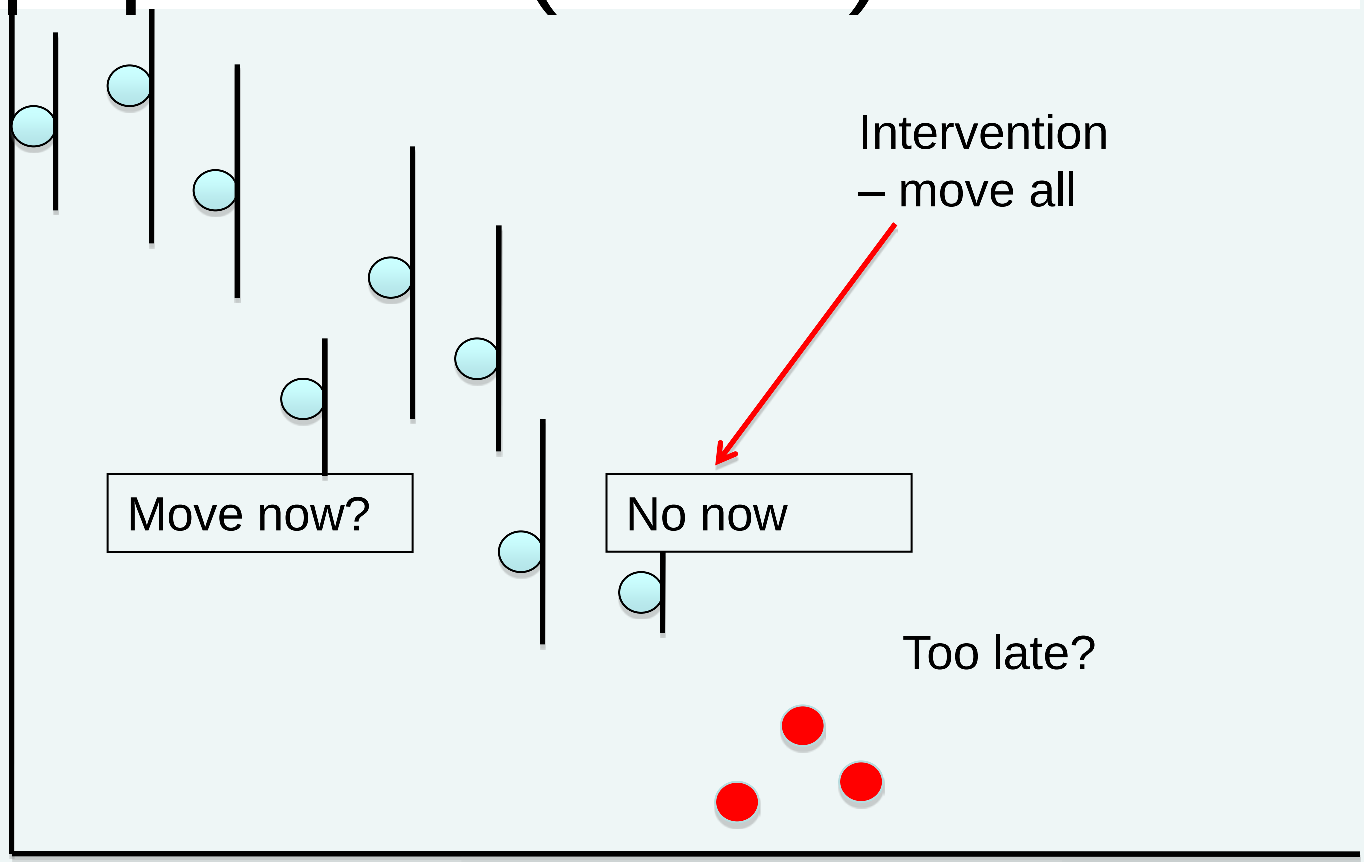
Unanswered questions:

How much monitoring is needed?

What risks are acceptable?

Which species should be selected for assisted colonisation?

Part 2 – when shall I move the entire population (if ever)?

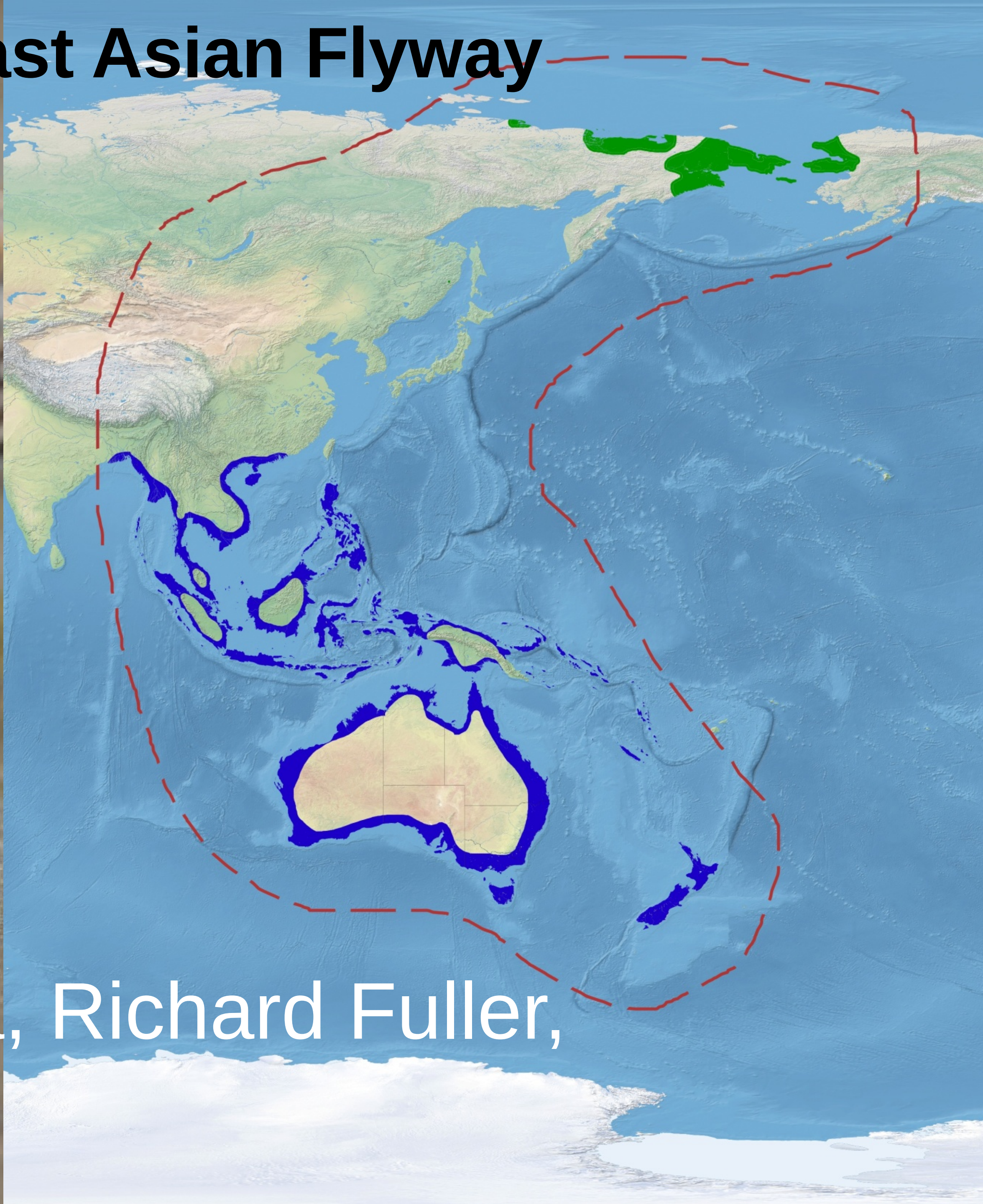


Messages

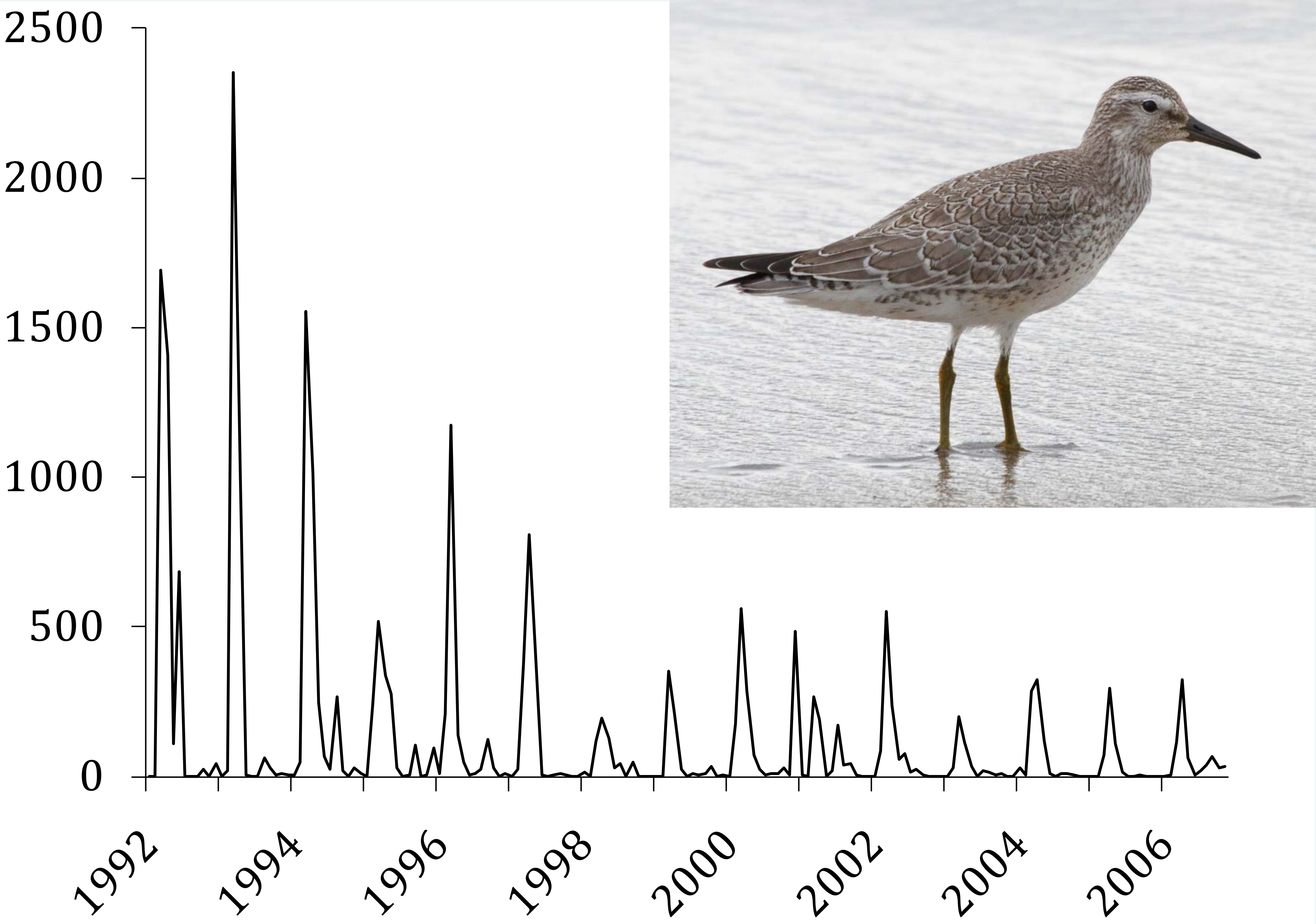
- The decision to move a species depends a lot on the expected losses in making the move – translocation deaths
- If there is a great deal of uncertainty about whether or not the source carrying capacity is in decline then an adaptive manager may wait a bit longer to confirm, or otherwise, that a decline is happening (reduce uncertainty)
- We did NOT look at partial moves

McDonald-Madden, E., Runge, M., Possingham, H.P. and Martin T. (2011) Optimal timing for managed relocation of species faced with climate change. ***Nature Climate Change*** July 24.

5 Managing the **East Asian Flyway**

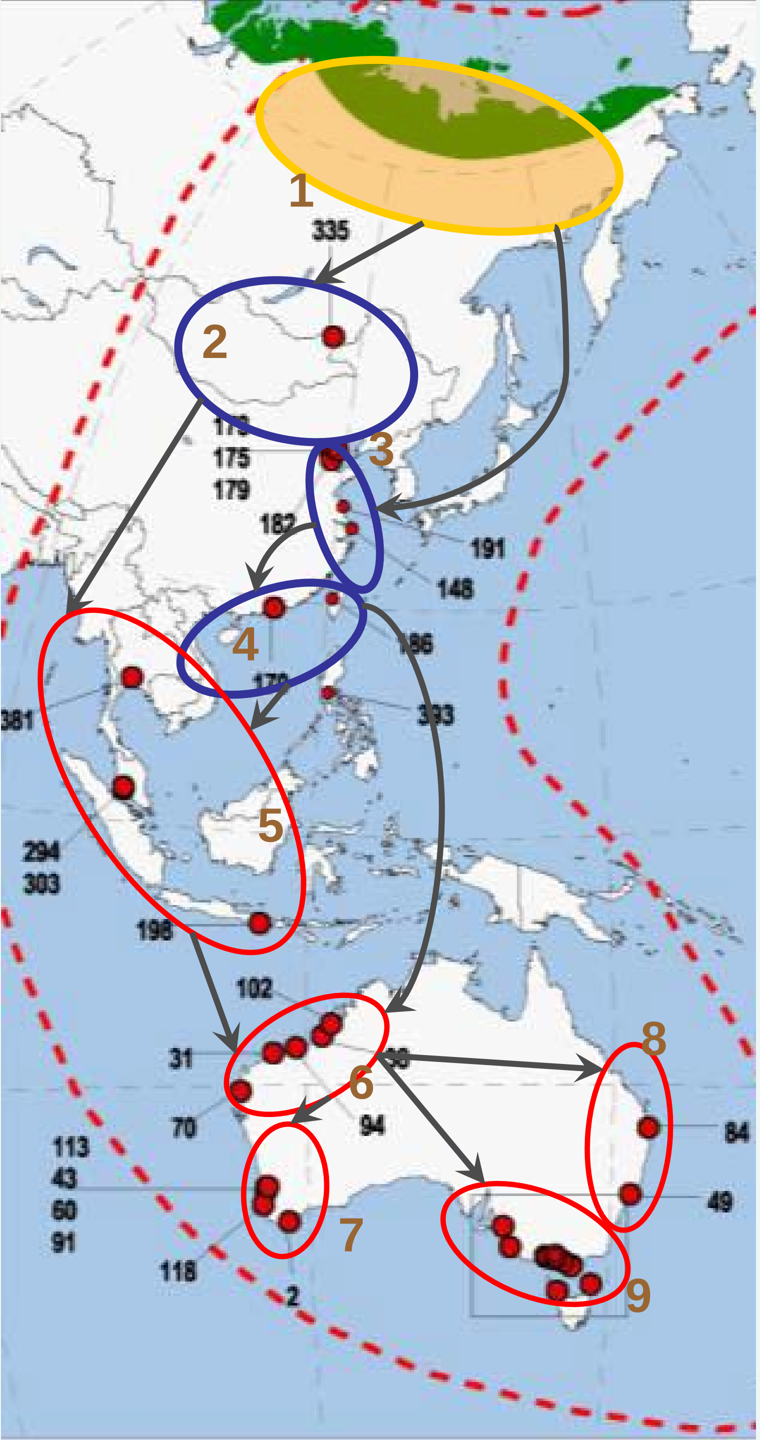


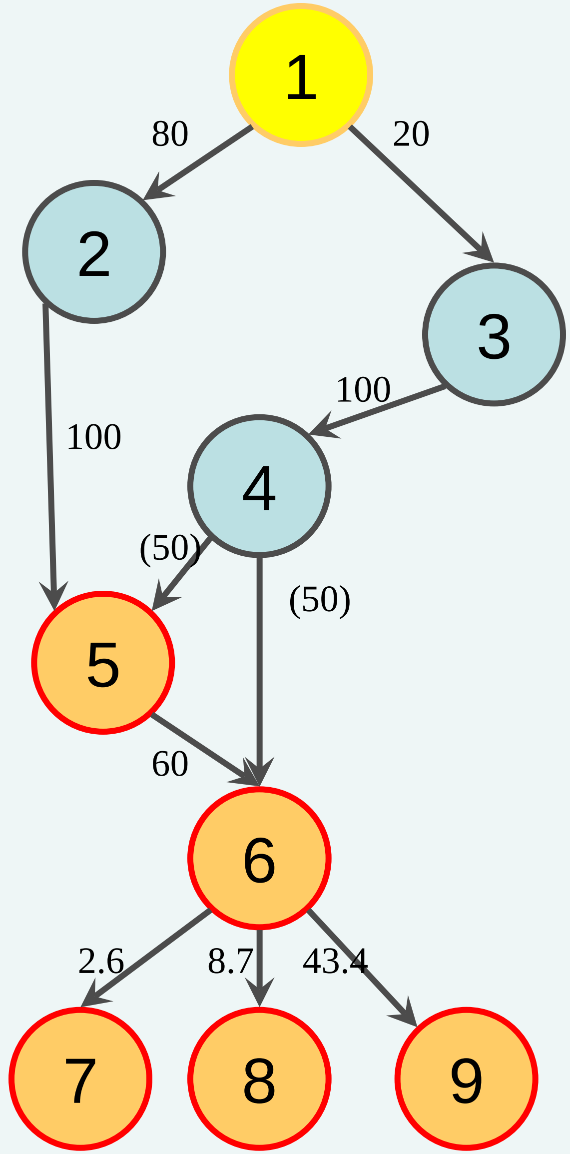
(Takuya Iwamura, Richard Fuller, Howard Wilson)



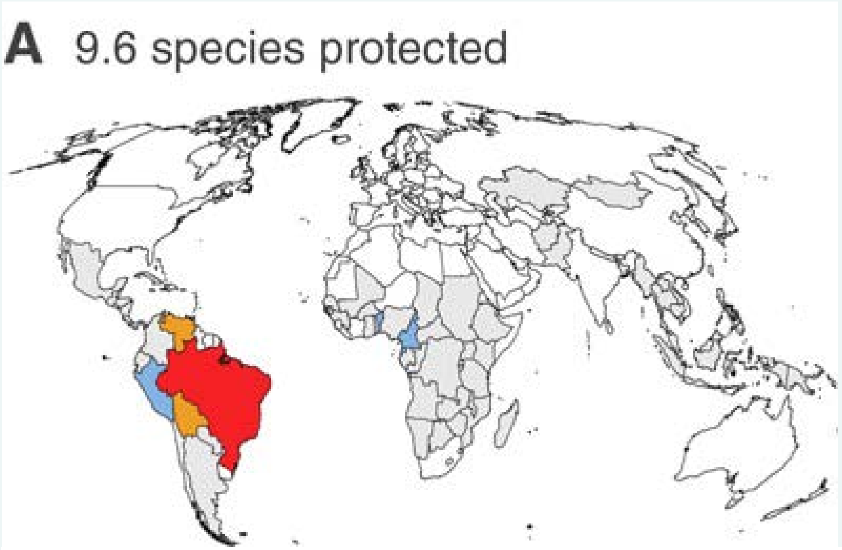
Wilson *et al*. Just out this week in ***Conservation Biology***.

Takuya Iwamura et al., in prep





Curlew Sandpiper



Harnessing Carbon Payments to Protect Biodiversity

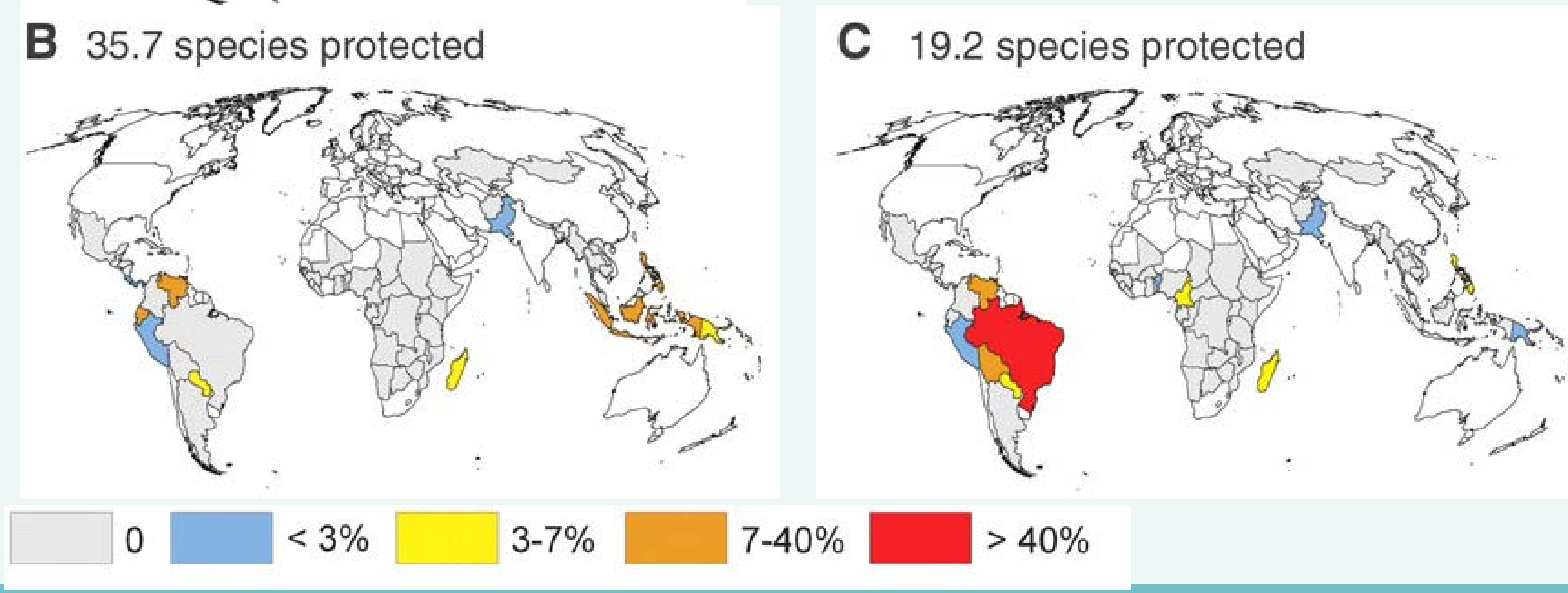
Oscar Venter,[1]* William F. Laurance,[2,3] Takuya Iwamura,[1] Kerrie A. Wilson,[1] Richard A. Fuller,[1] Hugh P. Possingham[1]

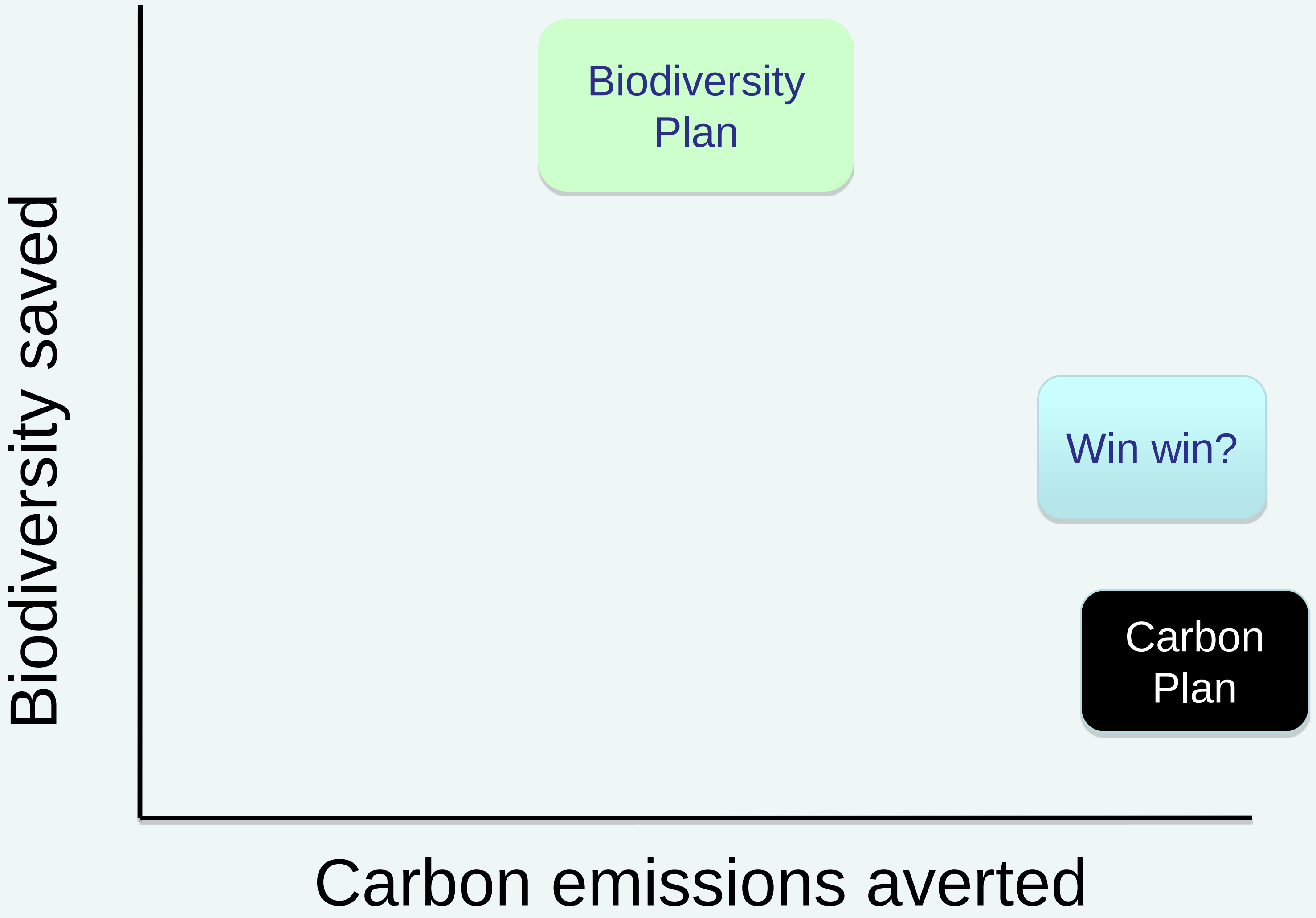
The rapid destruction of tropical forests produces ~20% of anthropogenic carbon

go almost entirely to South An

Brazil (74%), where agricultural c

4 DECEMBER 2009 VOL 326 SCIENCE www.sciencemag.org




Biodiversity Plan
Win win?
Carbon Plan
Biodiversity saved
Carbon emissions averted

Decision science for conservation – many new and challenging problems that sometimes make a difference, *eventually*

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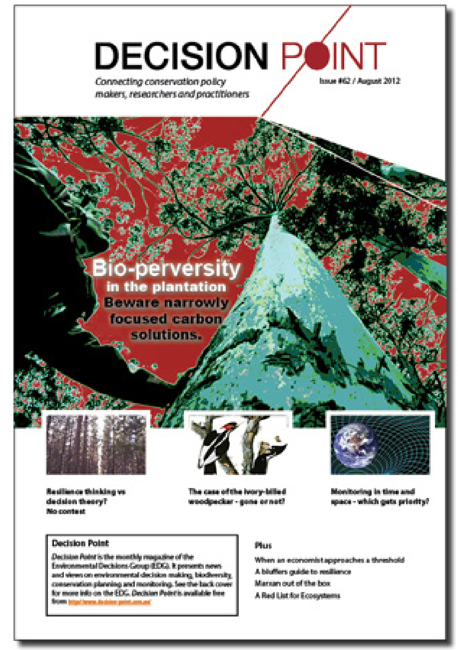

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Aside: Six objections to decision theory for conservation

- **Objection 1: Ecological models are all wrong**
- **Objection 2: Decision theory is economics; economics is the tool of the devil**
- **Objection 3: Decision theory takes too long**
- **Objection 4: 'Black-box' solutions aren't acceptable for politicians or people**
- **Objection 5: There is too much uncertainty and risk to use decision theory**
- **Objection 6: Can we test decision science?**

Answers in "Decision Point" - http://decision-point.com.au/dpoint-index.html