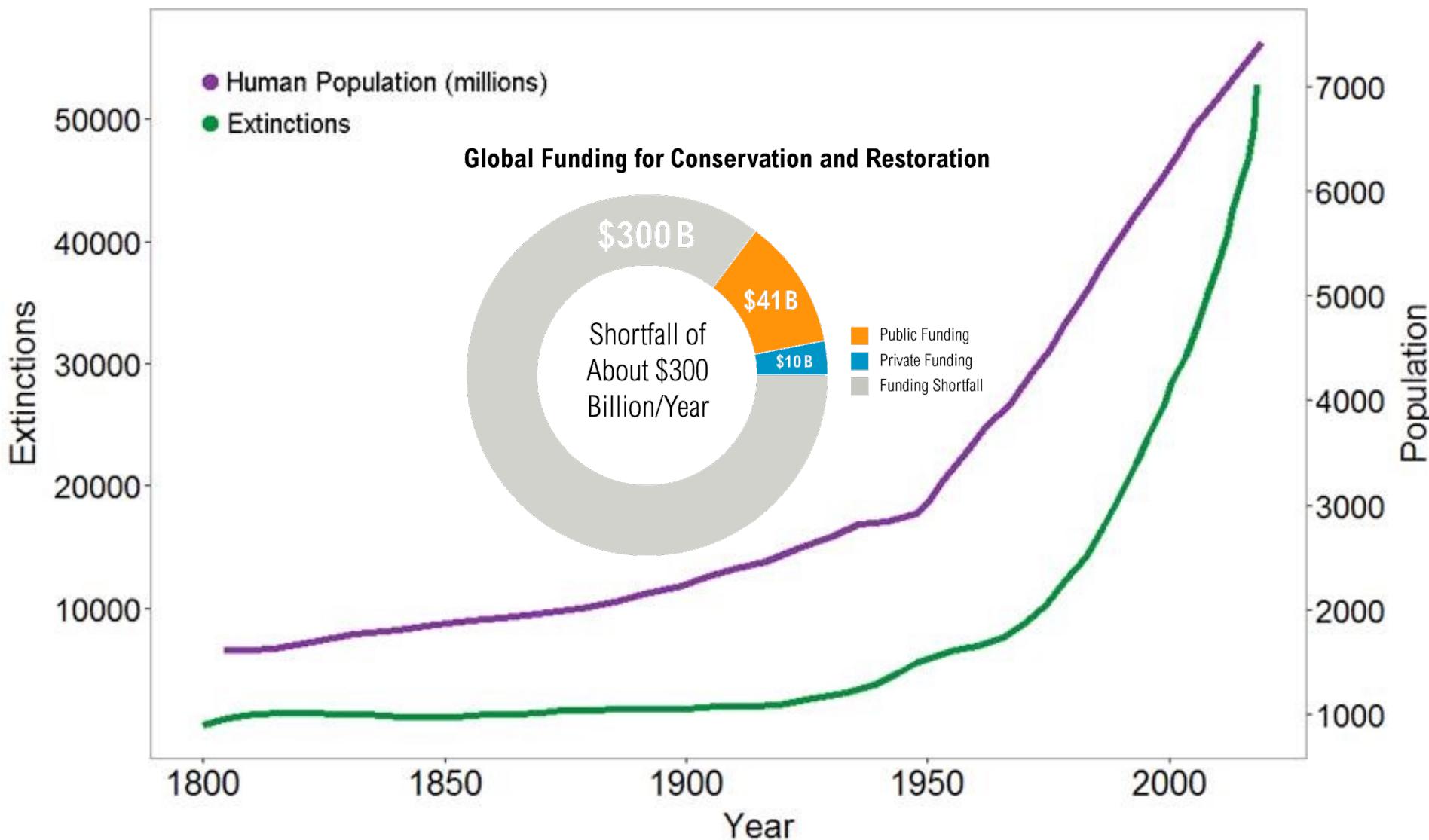




Workshop 1

Applications of game theory to  
problems in conservation

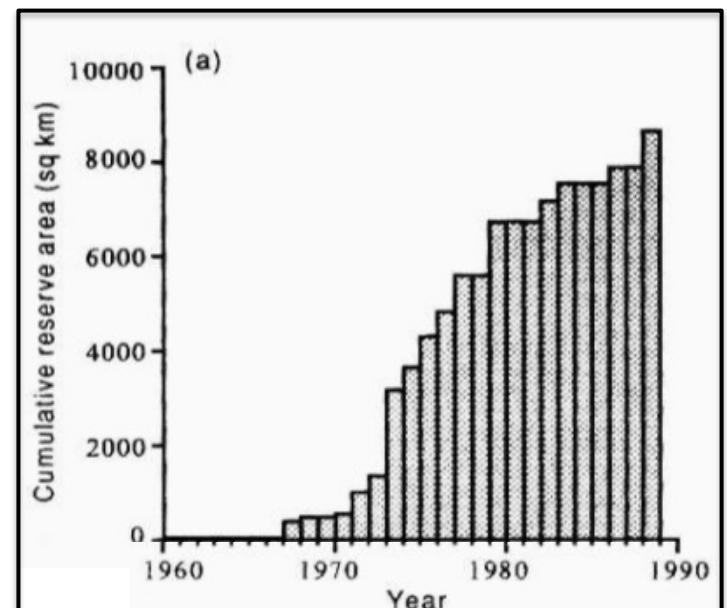
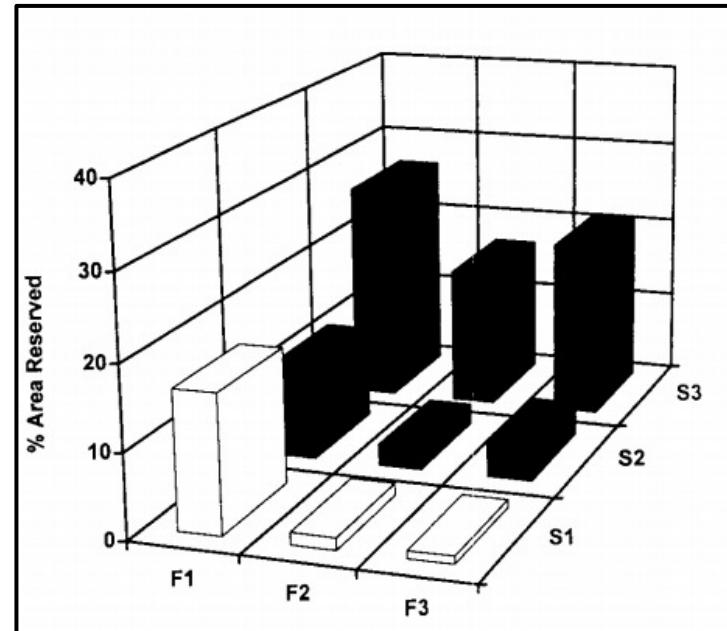
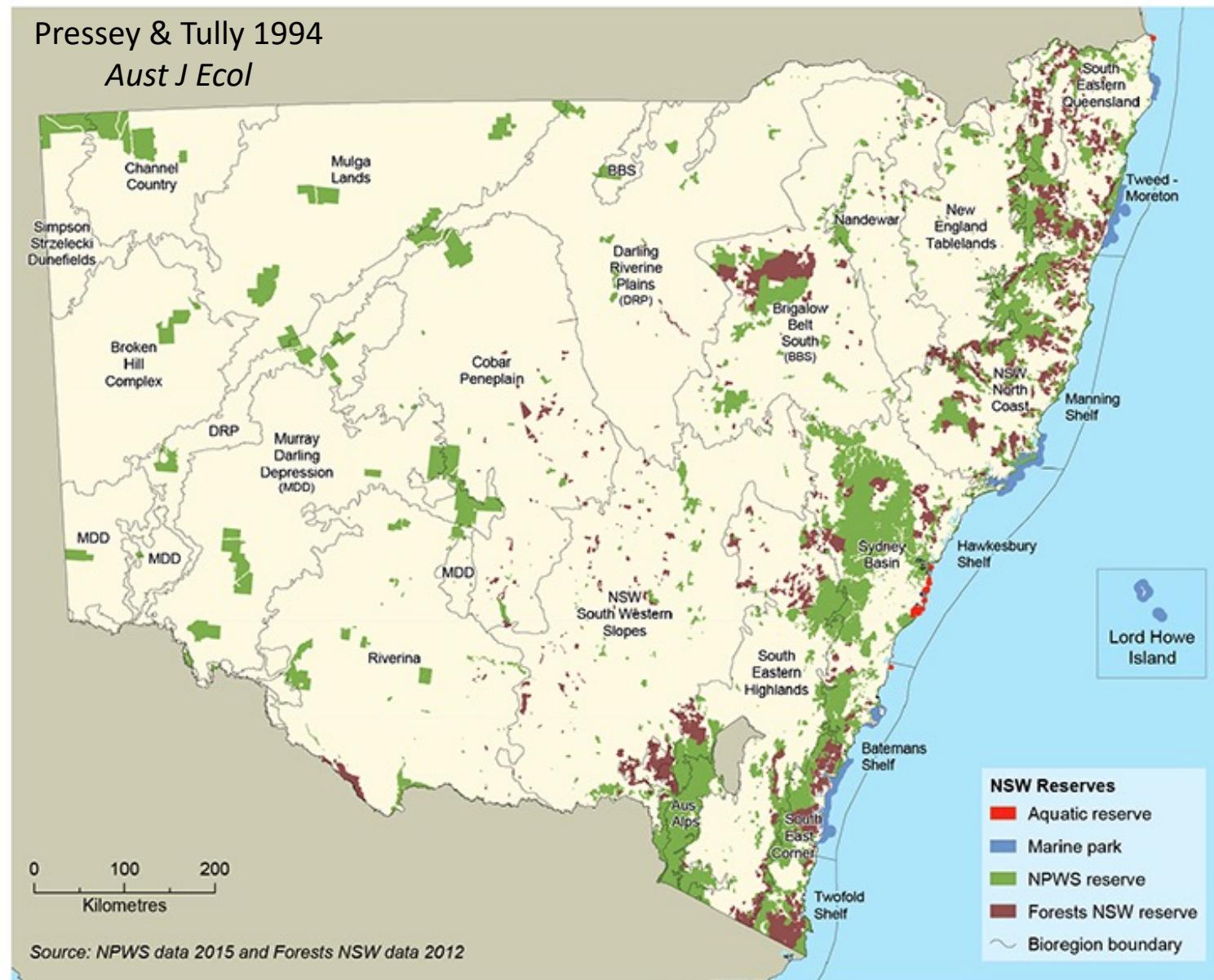
# Why do we optimise in conservation?

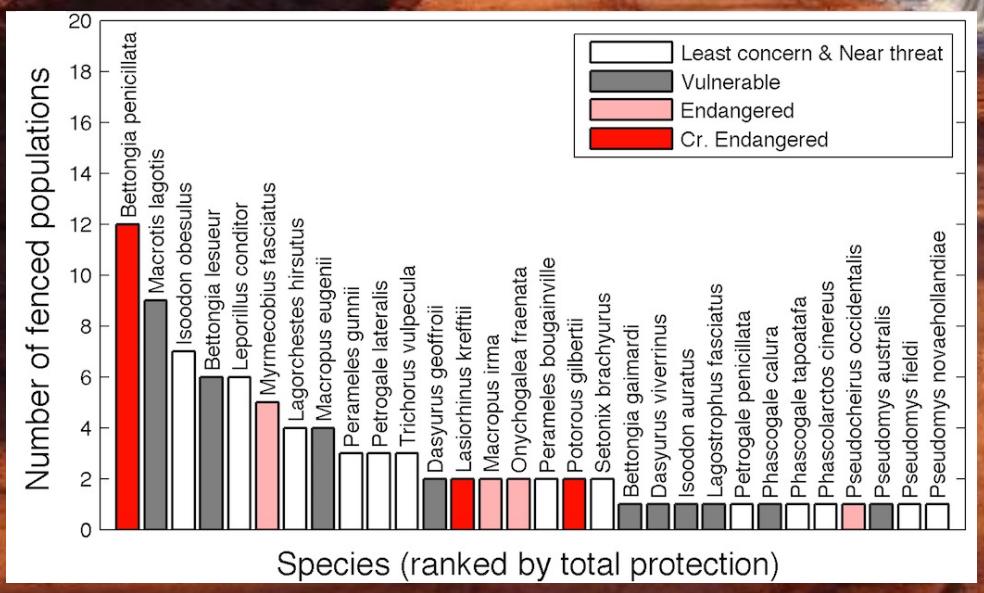


Map 14.1: NSW national parks and forest reserves, marine parks and aquatic reserves

Pressey & Tully 1994

Aust J Ecol





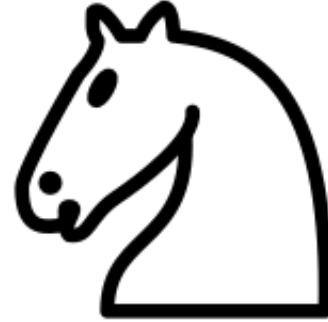
# Combinatorial optimisation: Conservation planning

- Choose a set of land parcels to protect
  - Ensure that all species are inside a protected area
  - Achieve this at a minimum cost



# MARXAN

conservation solutions



Applying game theory to  
problems in conservation



# Workshop outline

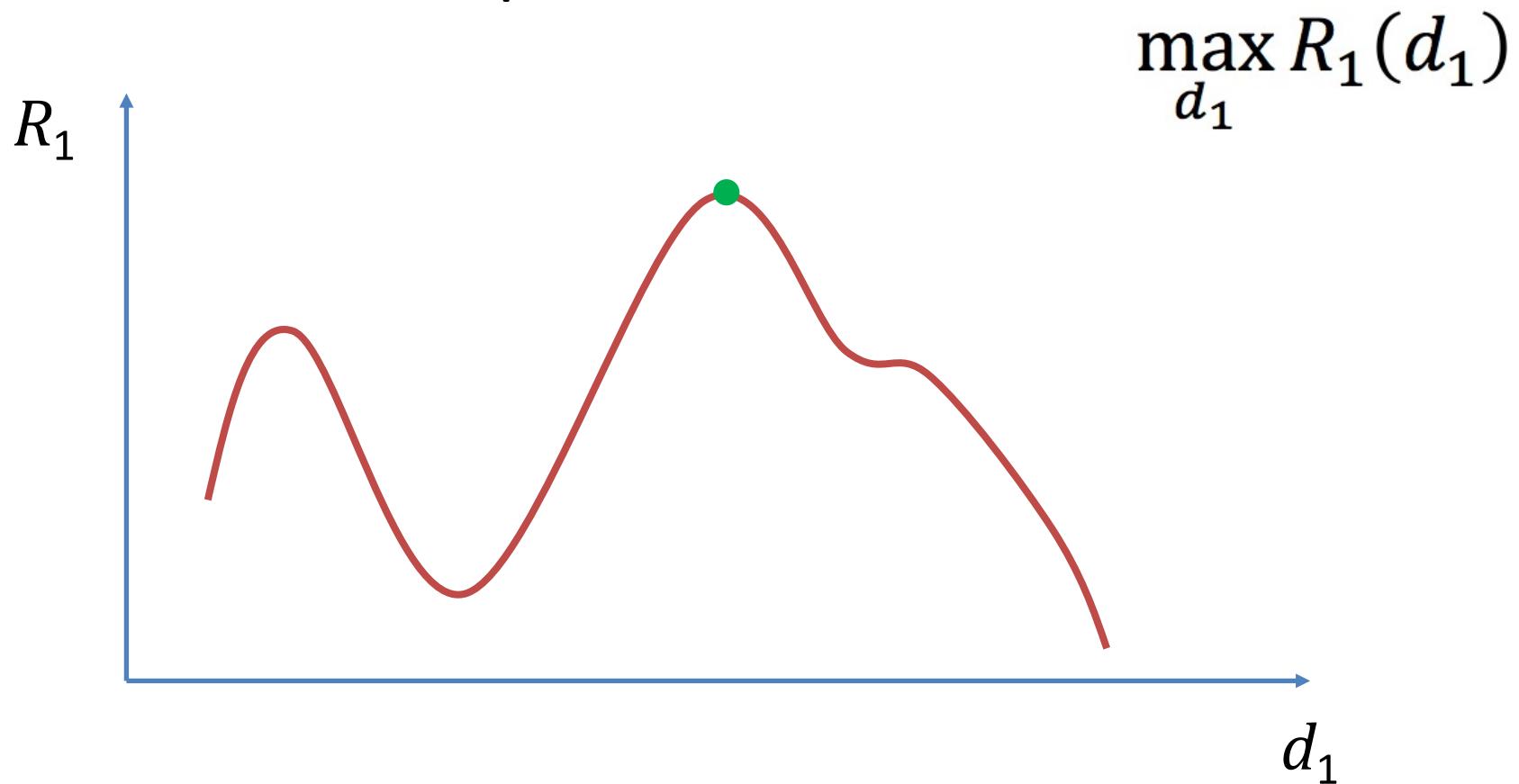
- Introduction to game theoretic concepts
- Simple normal-form (i.e., matrix) game representations
- Strategic interactions in natural resource management
- Strategic interactions between conservation organisations

# What is game theory?

- The mathematical study of strategic interactions among multiple rational decision-makers.
- Often concerned with multi-actor equilibrial **optimisation**
- Its applications are incredibly widespread: economics, politics, sociology, evolution, natural resource management ...
- At its heart, it's simply complicated optimization.

# (Single player) optimisation

- A decision-maker chooses an action against a static landscape



# Simple fisheries model

Let's use a Gordon-Shaefer model

$$n_{t+1} = n_t + r n_t \left(1 - \frac{n_t}{K}\right) - h n_t$$

$n_t$  is the population size at time t

$r$  is the intrinsic growth rate of the population

$K$  is the maximum population possible

$h$  is the harvest rate of the fishes



The total harvests are equal to  $h n_t$

What harvest rate  $h$  maximises the total harvest?

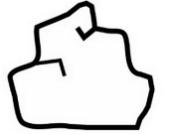
# Interactive optimisation

- A decision-maker chooses an action within a strategic landscape

Not:  $\max_{d_1} R_1(d_1)$

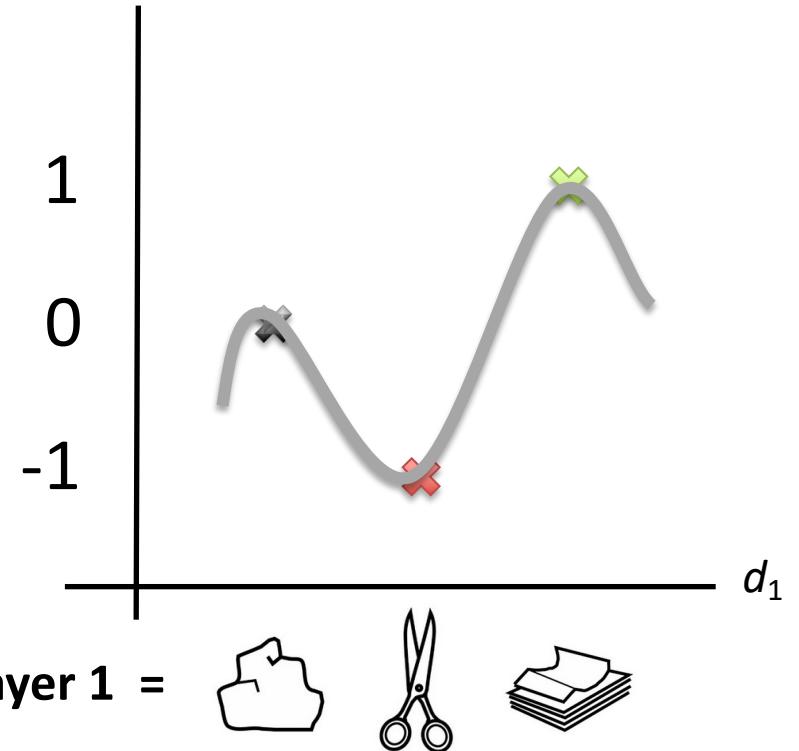
But:  $\max_{d_1} R_1(d_1, d_2)$

Player 2  
chooses  
rock:



If we knew that player 2 was planning to play rock, the optimisation decision would be straightforward: paper.

$R_1(d_1, d_2 = \text{rock})$

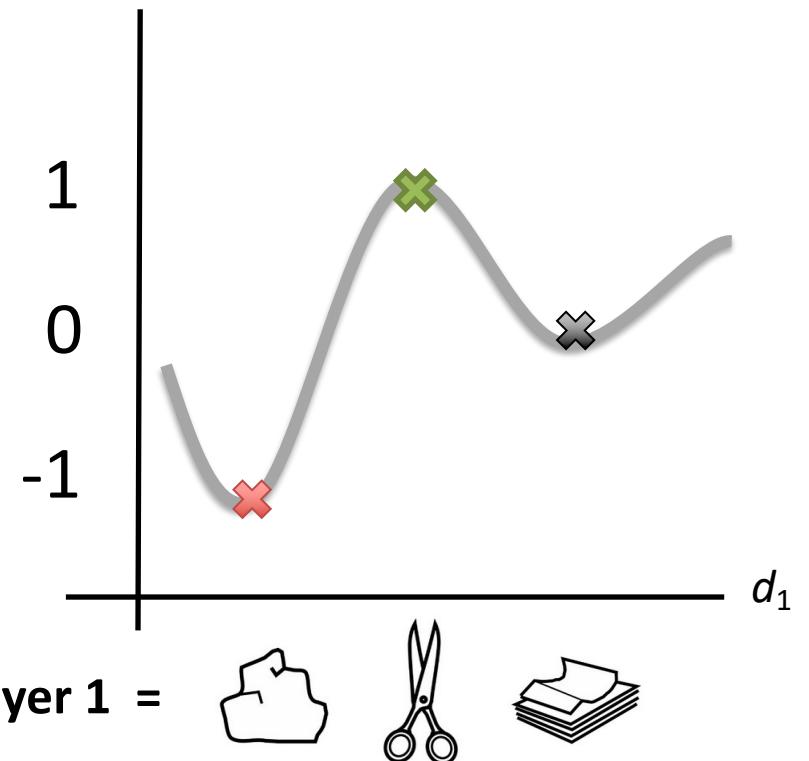


Player 2  
chooses  
paper:



If we knew that player 2 was planning to play paper, the optimisation decision would be straightforward: scissors.

$R_1(d_1, d_2 =$  )

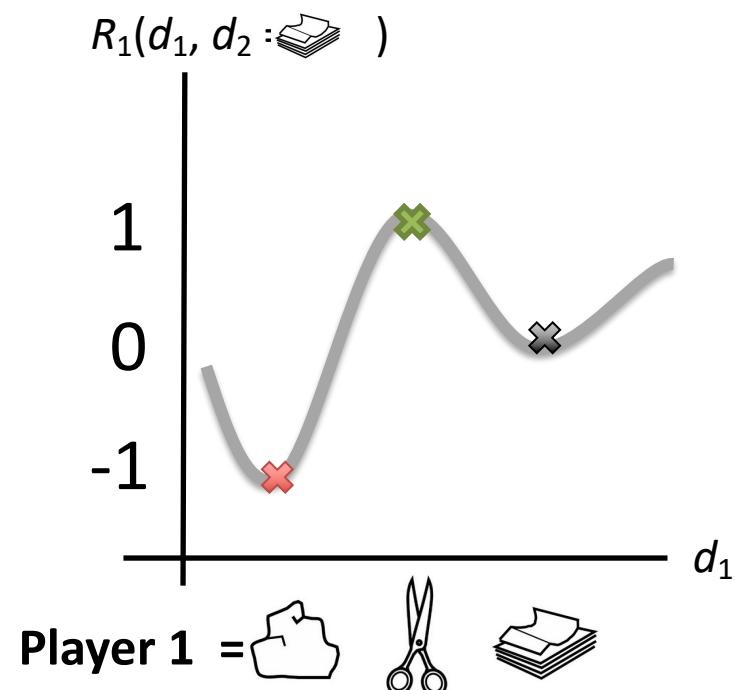


Player 1 =

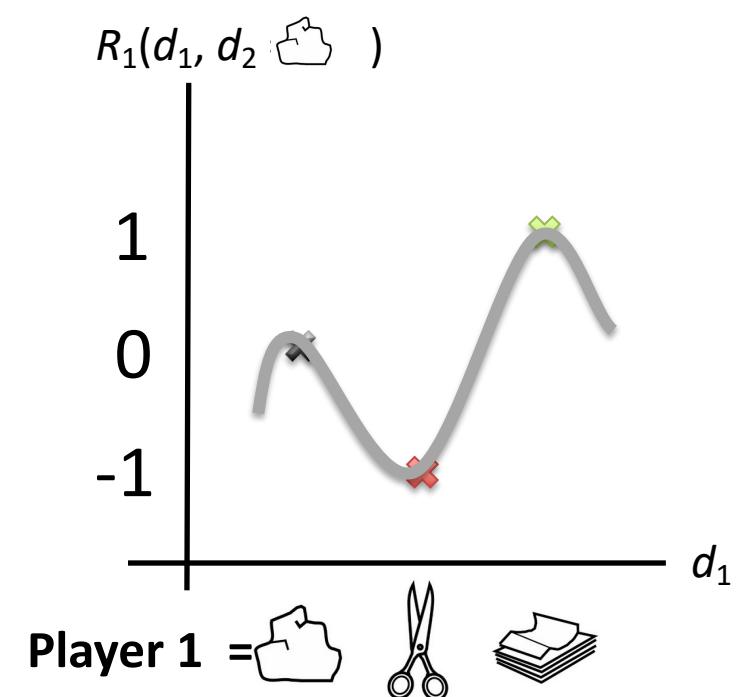
The problem is that player 2 is also thinking about our decision.

All we know for sure is that they will act rationally, in an attempt to optimize their rewards.

Player 2 chooses paper:

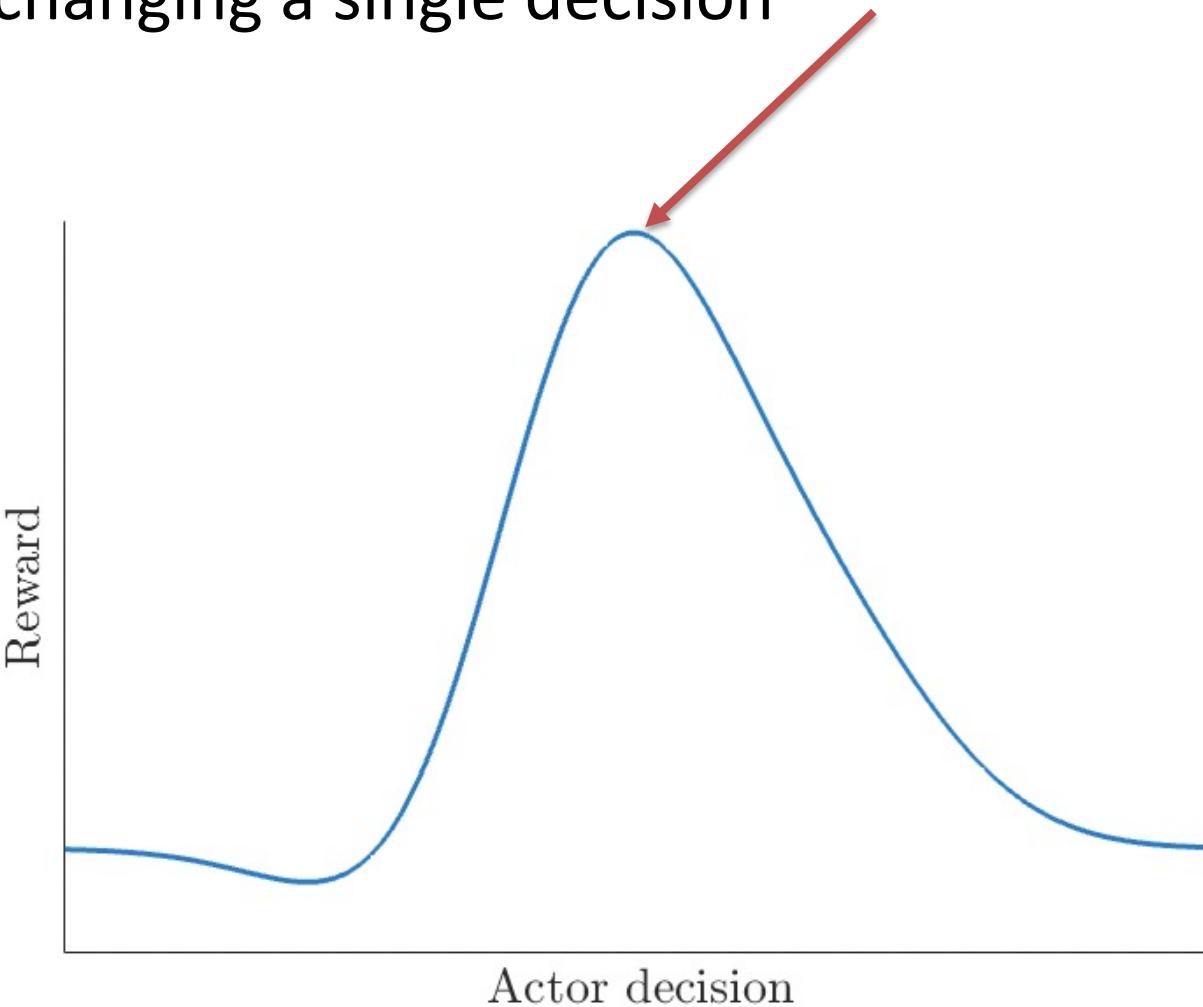


Player 2 chooses rock:

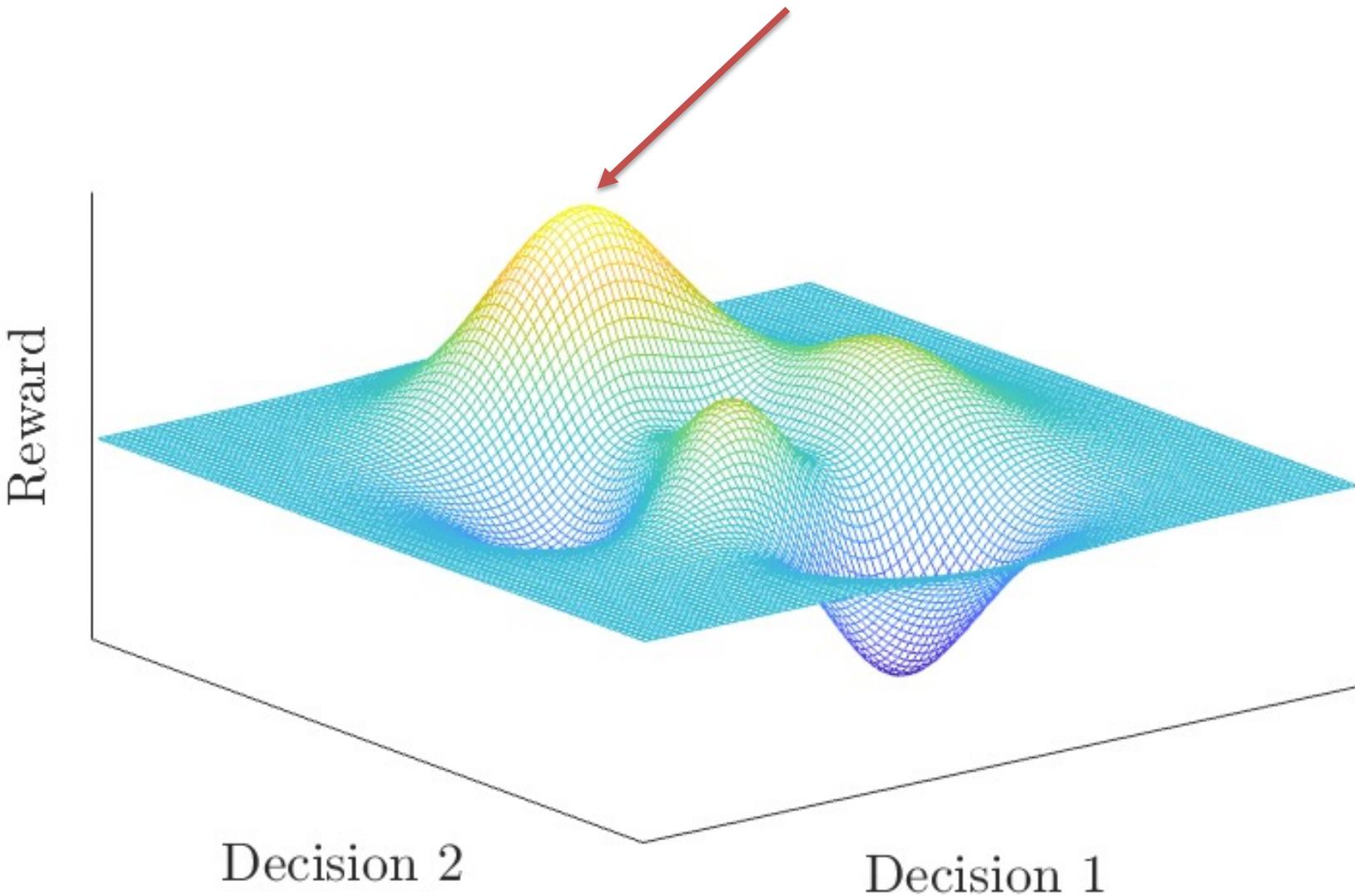


Note that we're still talking about optimisation.

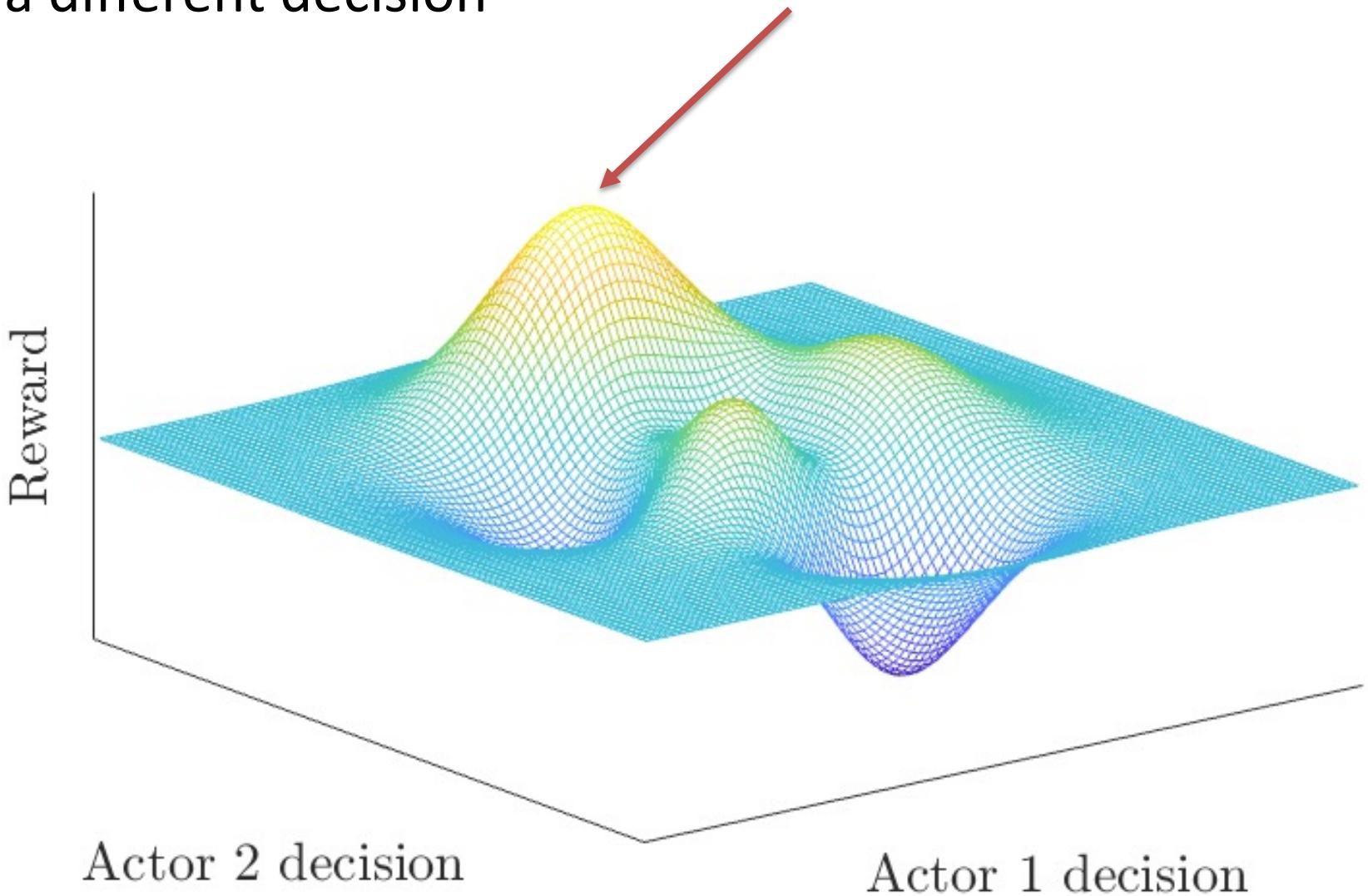
Find the maxima by changing a single decision



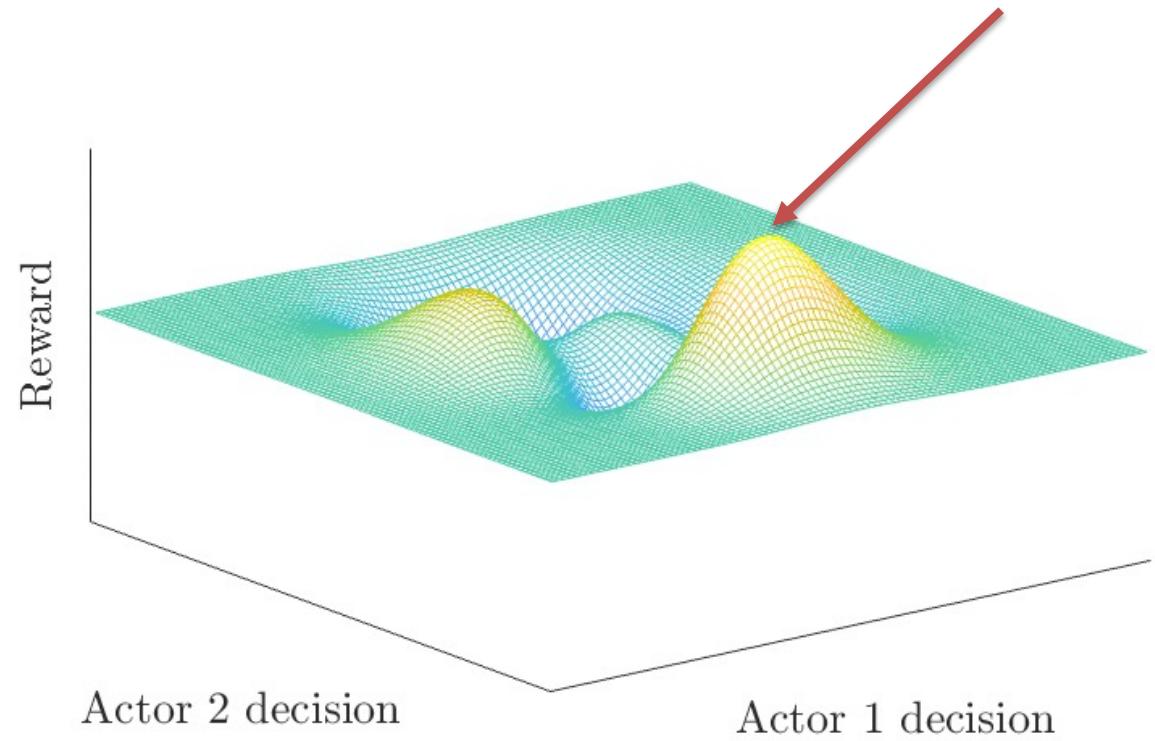
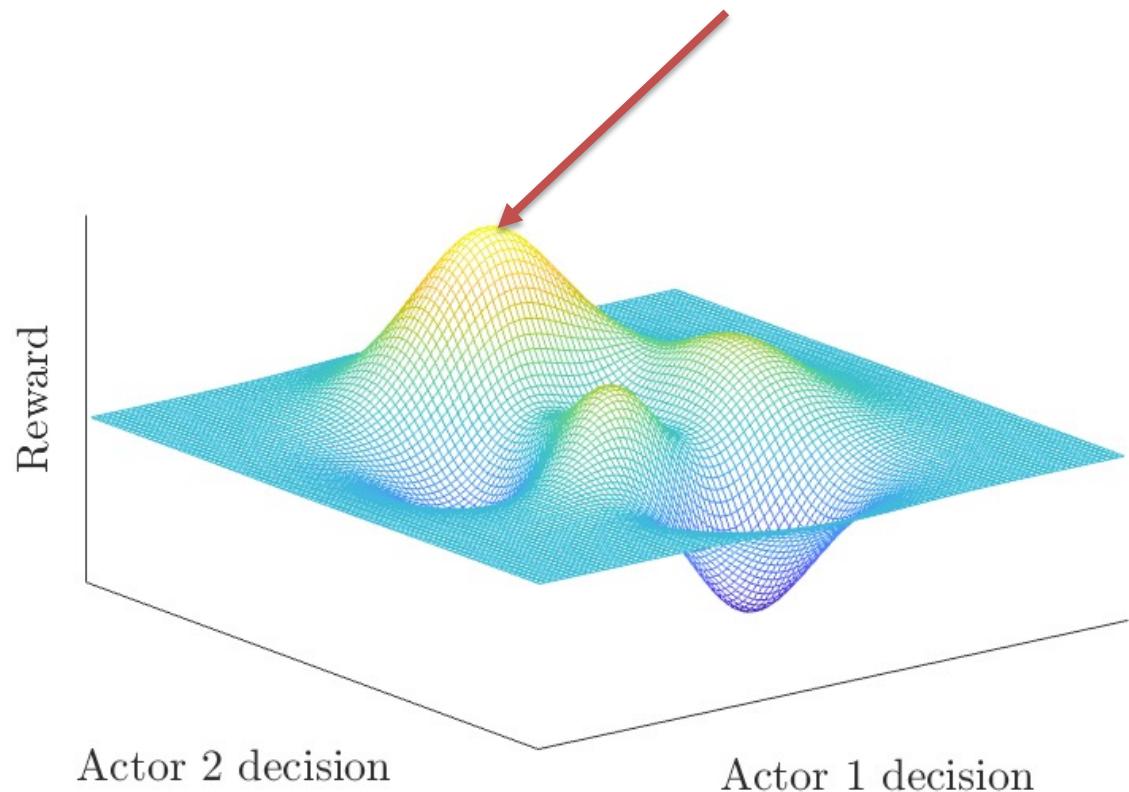
But now we're finding the maxima with two different decisions

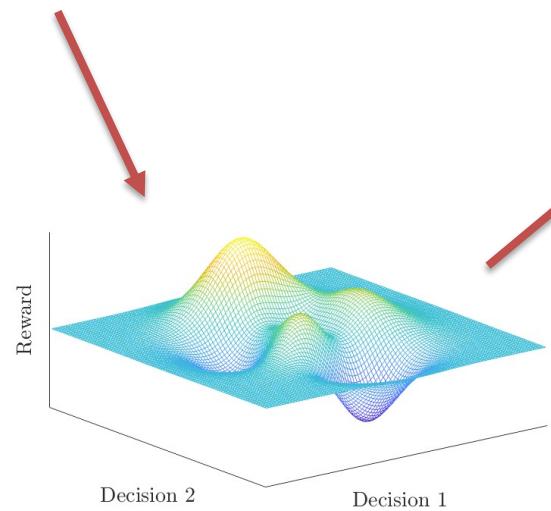
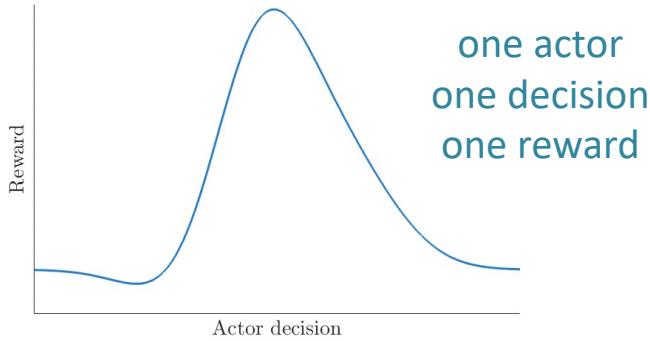


And now we're looking for the maxima when two actors each control a different decision

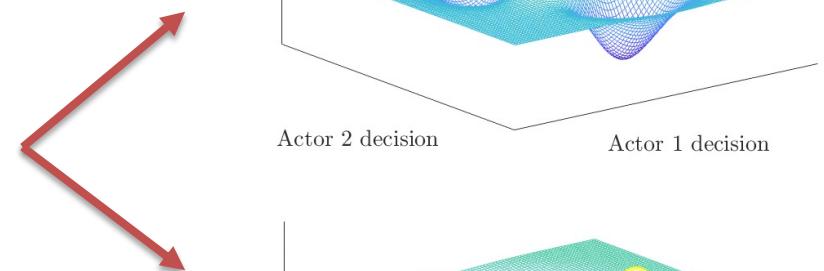
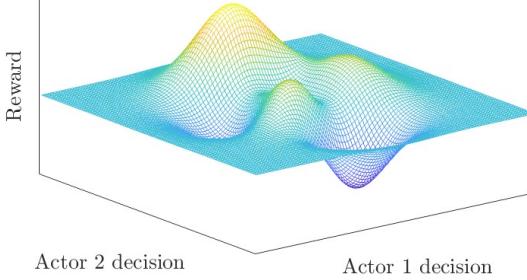


Moreover, we're looking for the maxima when each actor controls a different decision, and is trying to maximise a different reward function.



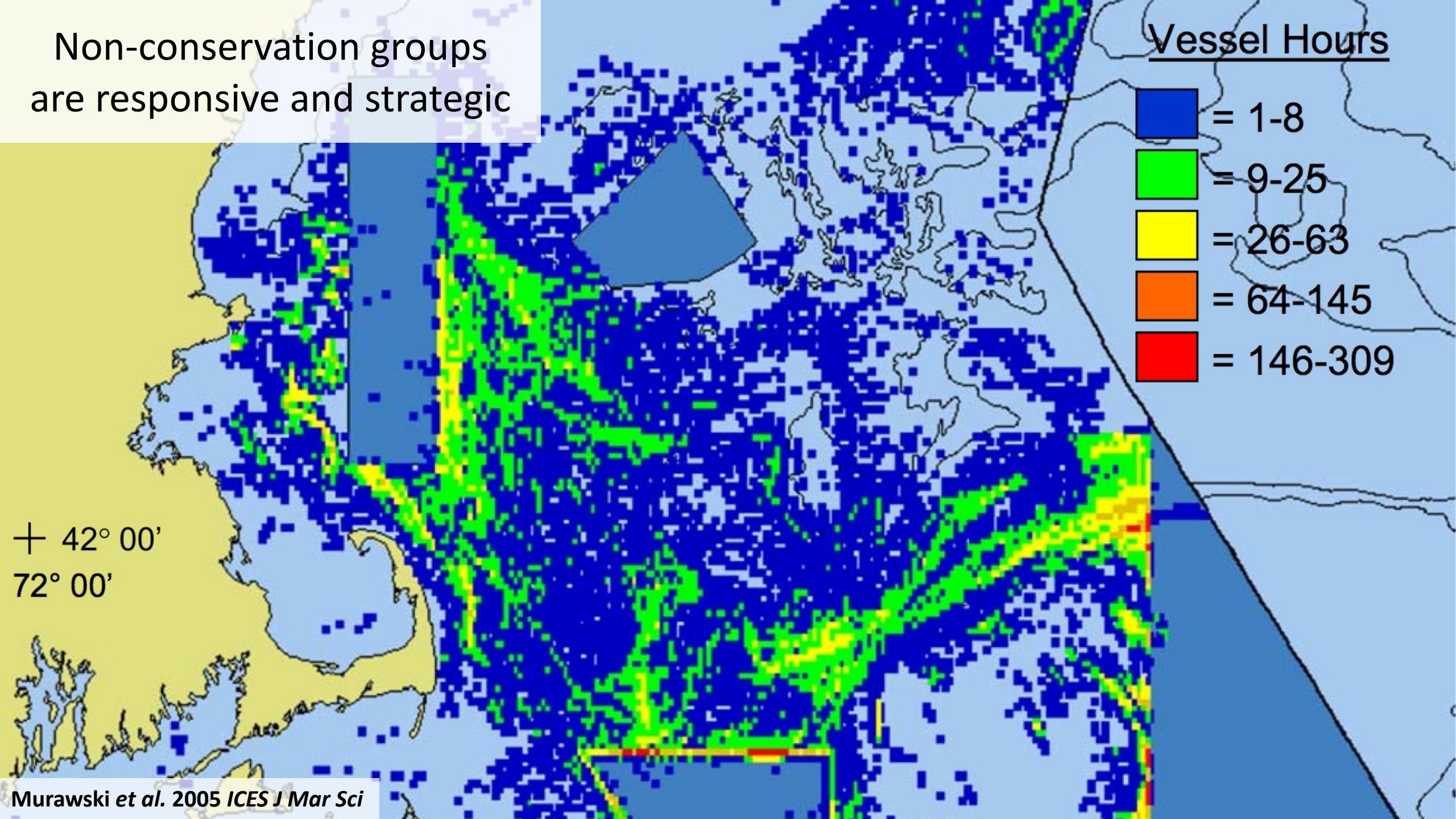


two actors  
two decisions  
one reward



two actors  
two decisions  
two rewards

Non-conservation groups  
are responsive and strategic





*The National Association of  
Home Builders comments on  
Endangered Species  
Regulation*

“The highest level of assurance that a property owner will not face an ESA issue is to maintain the property in a condition such that protected species cannot occupy the property . . . This is referred to as the ‘scorched earth’ technique.”

Lueck & Michael 2003



# INSIGHTS



The Chinese cave gecko,  
*Goniurosaurus luii*, was extirpated  
from its type locality shortly after it  
was first described scientifically.

PERSPECTIVES

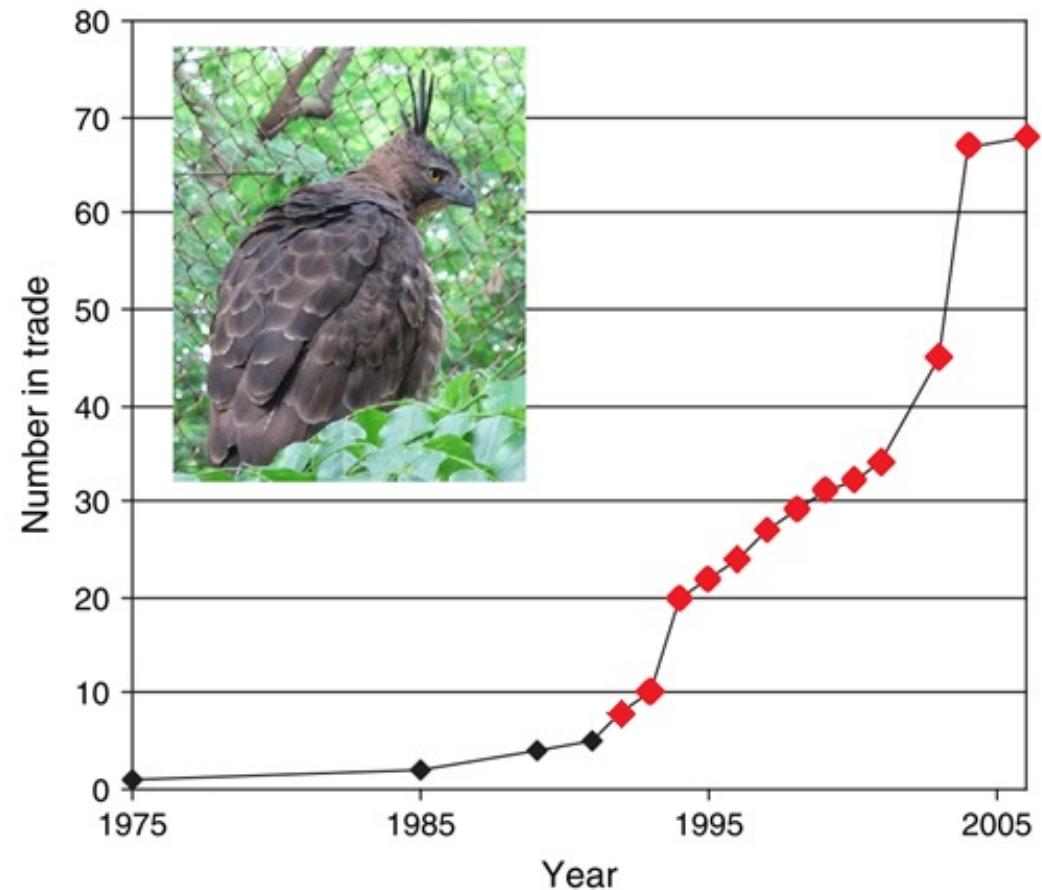
ESSAY

## ***Do not publish***

Limiting open-access information on rare  
and endangered species will help to protect them

By David Lindenmayer and Ben Scheele

## Javan hawk-eagle



Nijman *et al.* (2009) *Oryx* 43:122-8

# Normal form games

- Normal form games are a classic formulation of games.
- Represents all potential strategy combinations, and their associated payoffs for all players.
- Relatively simplistic and dynamically limited.



Special Issue Article: Adaptive management for biodiversity conservation in an uncertain world

## The conservation game

Mark Colyvan <sup>a,\*</sup>, James Justus <sup>a,b</sup>, Helen M. Regan <sup>c</sup>

**Table 1.** Two-Agent Game with Pareto-inefficient Nash Equilibrium.

	$K$	$\neg K$
$T$	3,3	1,4
$\neg T$	4,1	2,2

OPEN ACCESS Freely available online

PLOS ONE

## Group Decisions in Biodiversity Conservation: Implications from Game Theory

David M. Frank<sup>1</sup>, Sahotra Sarkar<sup>2\*</sup>

**Table 1**  
Simple cooperative game.

		Player 2 "column"	
		Cooperate	Defect
Player 1 "row"	Cooperate	2, 2	1, 1
	Defect	1, 1	0, 0

**Table 2**  
The game of chicken.

		Player 2 "column"	
		Cooperate	Defect
Player 1 "row"	Cooperate	1, 1	1, 2
	Defect	2, 1	0, 0

		Group Y	
		Action 1	Action 2
Group X	Action 1	[x1,y1]	[x1,y2]
	Action 2	[x2,y1]	[x2,y2]

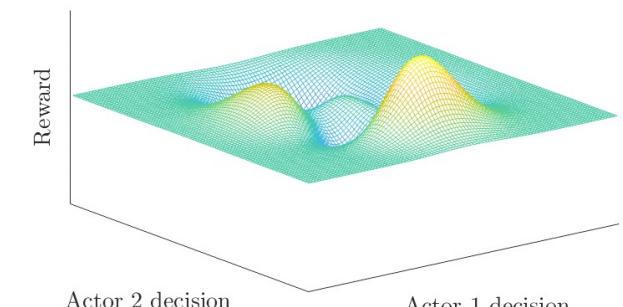
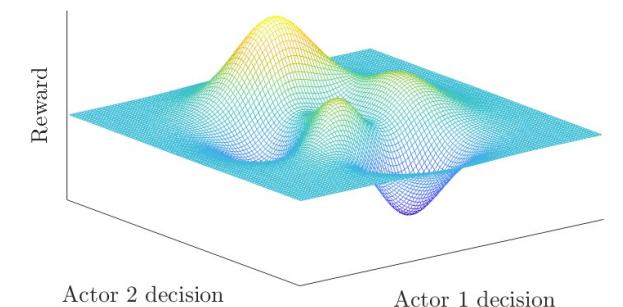
The row heading tells me what action the first group takes.

In each cell there is an ordered pair.

The first number corresponds to the rewards achieved by the first actor.

The second number indicates the rewards achieved by the second actor.

The column heading tells me what action the second group takes.



two actors  
two decisions  
two rewards

# Ecotourism & farming

- Wild dogs were reintroduced into Hluhluwe-iMfolozi park in ZA in 1980.
- The park attracts ecotourists who are willing to pay more to see wild dogs.
- Wild dogs are responsible for 15% of livestock losses in adjacent pastoral communities.
- Conservation / ecotourism must decide whether to continue or desist from conservation actions
- Pastoralists must decide whether to continue to kill wild dogs, or cease.



## Group 1: Conservationists

## Group 2: Pastoralists

	Kill wild dogs	Stop killing
Continue conservation	[1,1]	[4,0]
Halt conservation	[0,4]	[3,3]

Conservation actions (translocation and habitat) are expensive, but cannot succeed in the face of pastoral killing.

Killing is difficult and dangerous, but depredation continues as new dogs arrive.

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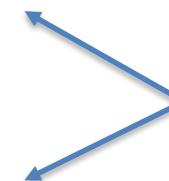
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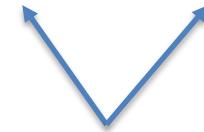
## Group 1: Conservationists

	Kill wild dogs	Stop killing
Continue conservation	[1,1]	[4,0]
Halt conservation	[0,4]	[3,3]

## Group 2: Pastoralists



- Group 1 gets to choose what row we evaluate.
- If group 2 chooses “kill”, the best choice for group 1 is to **continue conservation**.
  - If group 2 chooses “stop”, the best choice for group 1 is to **continue conservation**.



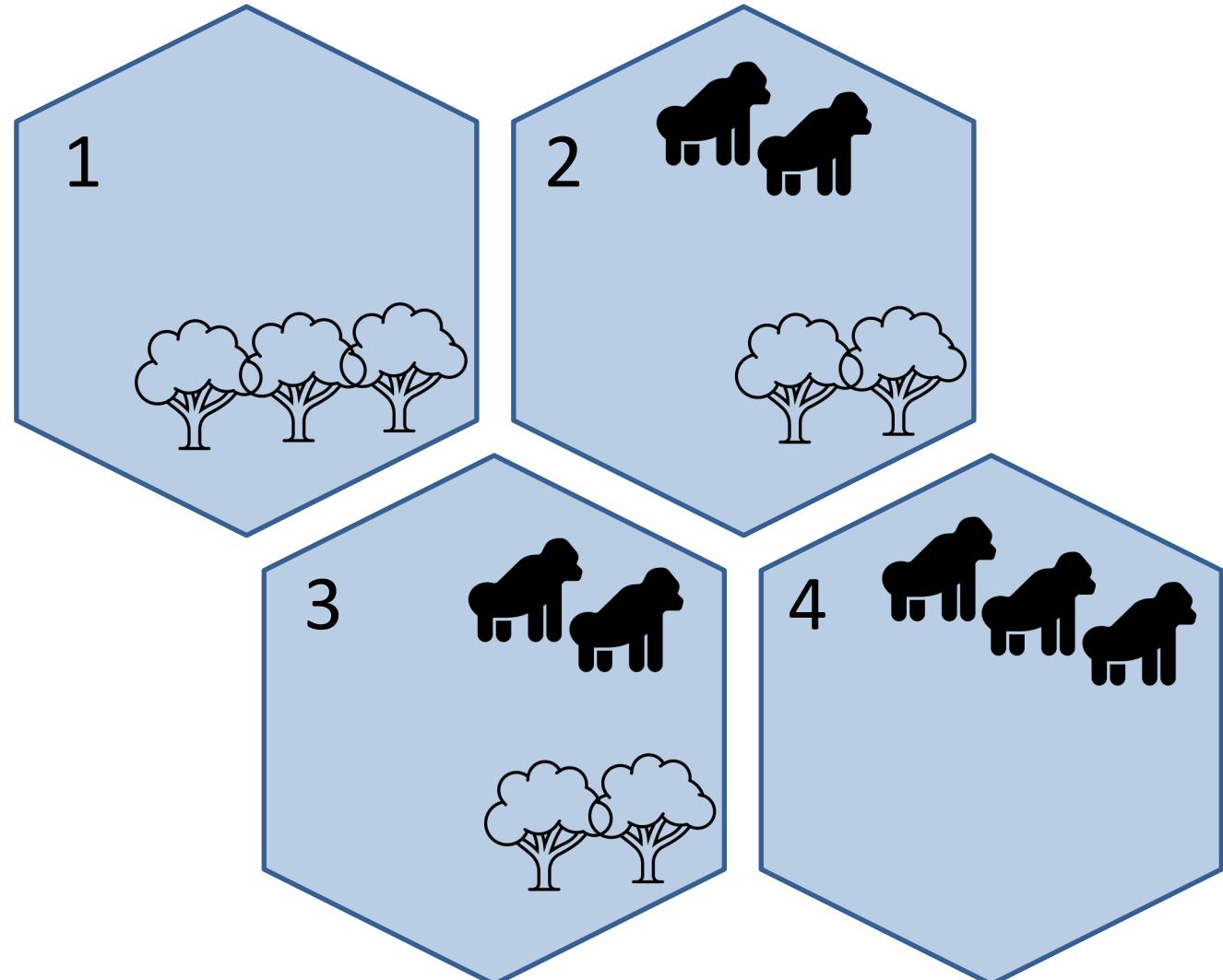
- Group 2 gets to choose what column we evaluate.
- If group 1 chooses “continue”, the best choice for group 1 is to **kill wild dogs**.
  - If group 1 chooses “halt”, the best choice for group 1 is to **kill wild dogs**.

Continue / Kill is called a “Nash equilibrium” of the game. Neither group can achieve a better outcome by changing their decision

However, it is clearly not the best outcome for either group, nor a social good optima.

# Practical example problem

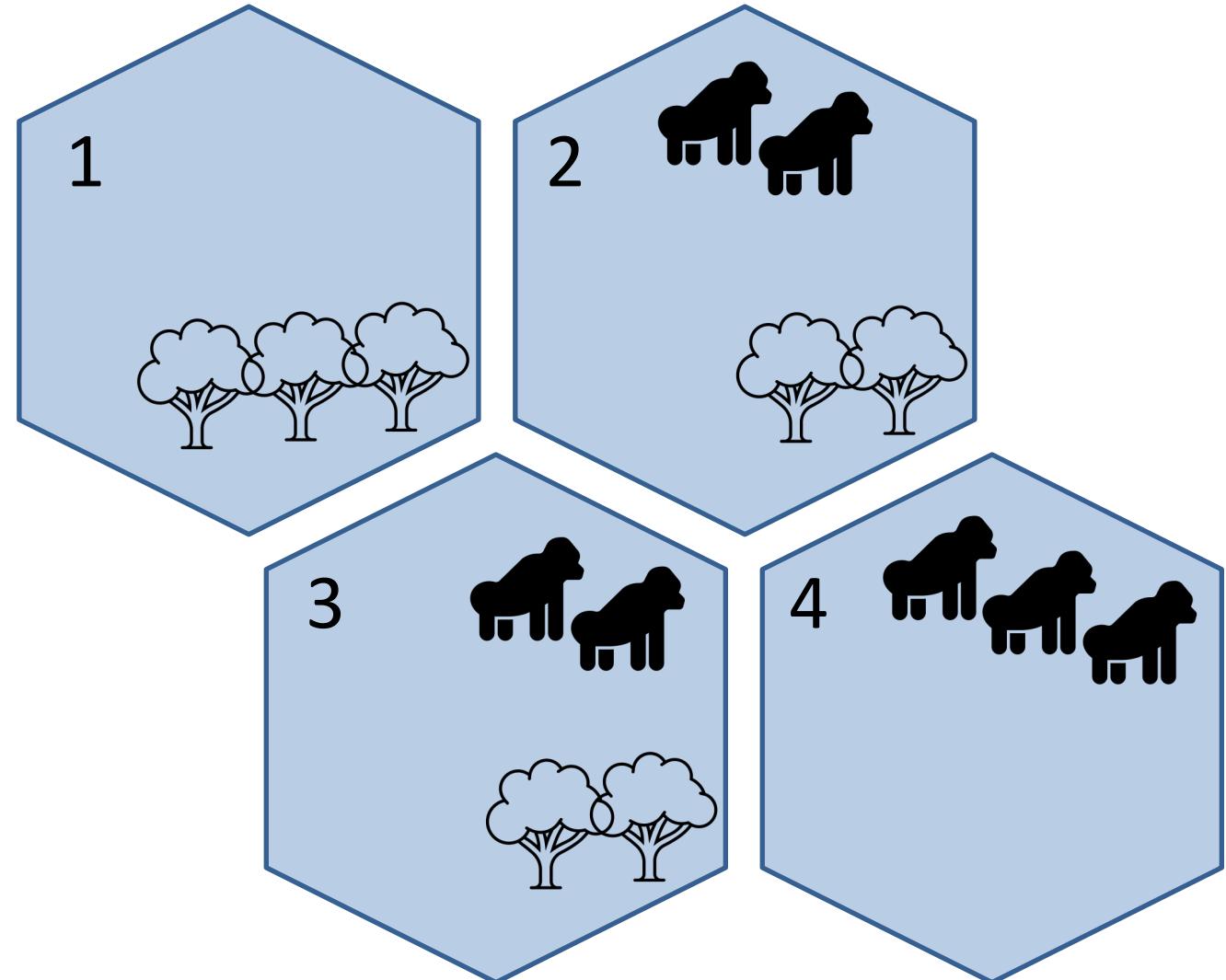
- Consider two NGOs working in the same landscape.
- NGO 1 wants to protect rainforests from clearing for palm oil plantations.
- NGO 2 wants to conserve orangutan populations
- Four production sites are available for purchase
- Both NGOs can only afford to protect a single site.



- Construct the normal form representation of this game.
- Identify social good optima, assuming both NGOs are equally important.
- Identify any Nash equilibria



	Parcel 2	Parcel 4
Parcel 1		
Parcel 3		

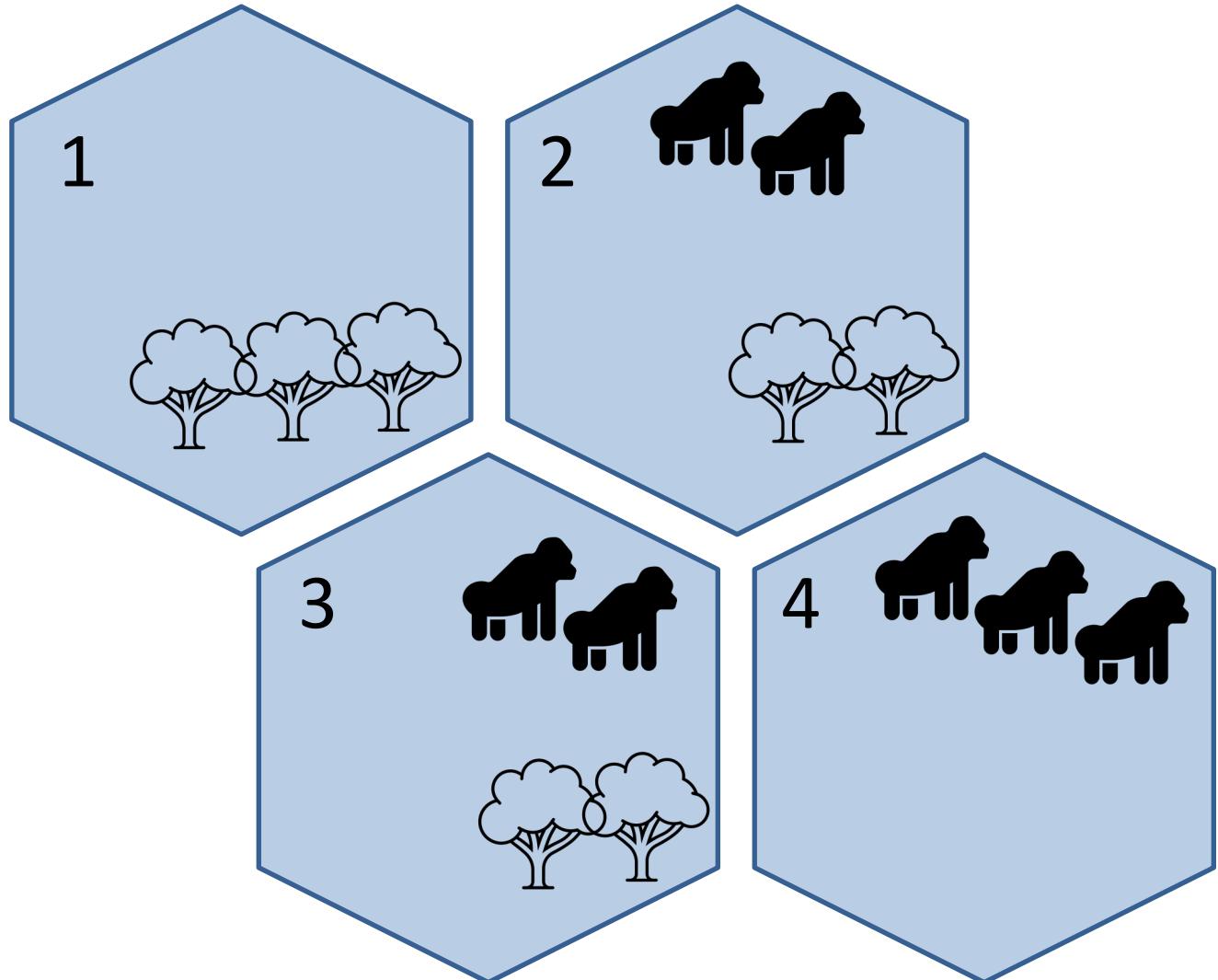




		NGO 2
		Cooperation (#2)
		No cooperation (#4)
Cooperation (#3)		[4,4]
No cooperation (#1)		[5,2] [3,3]



NGO 2



# Game theory as optimisation

- Normal-form games portray game theory as qualitatively distinct from simulation modelling and optimisation
- Focus unnecessarily on Nash, rather than strategic dynamics and responses.
- Simple extensions to existing models can create strategic game theoretic elements



	Cooperation (#2)	No cooperation (#4)
Cooperation (#3)	[4,4]	[2,5]
No cooperation (#1)	[5,2]	[3,3]

# Dual fisher model

$$n_{t+1} = n_t + r n_t \left(1 - \frac{n_t}{K}\right) - (h_1 + h_2) n_t$$

Fisher  $i$  harvests are equal to  $Y_i = h_i n_t$

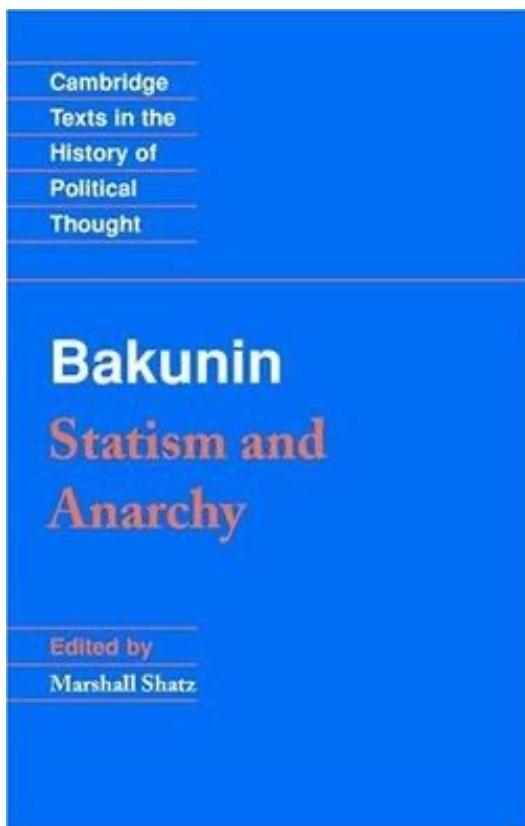
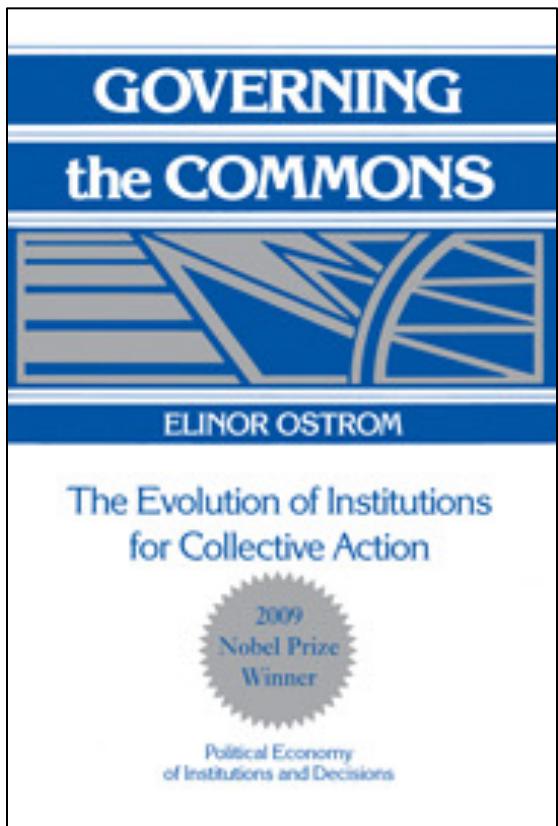


A new fisher enters our previous single-owner fishery. If fisher 1 doesn't change their behaviour:

- What will fisher 2 set their harvest  $h_2$  at?
- What is the consequence for the fish stock ( $n_t$ )?
- The total yield ( $Y_1 + Y_2$ )?

What harvest rates  $h_1$  and  $h_2$  are Nash equilibria?

# What is game theory?



ARTICLE

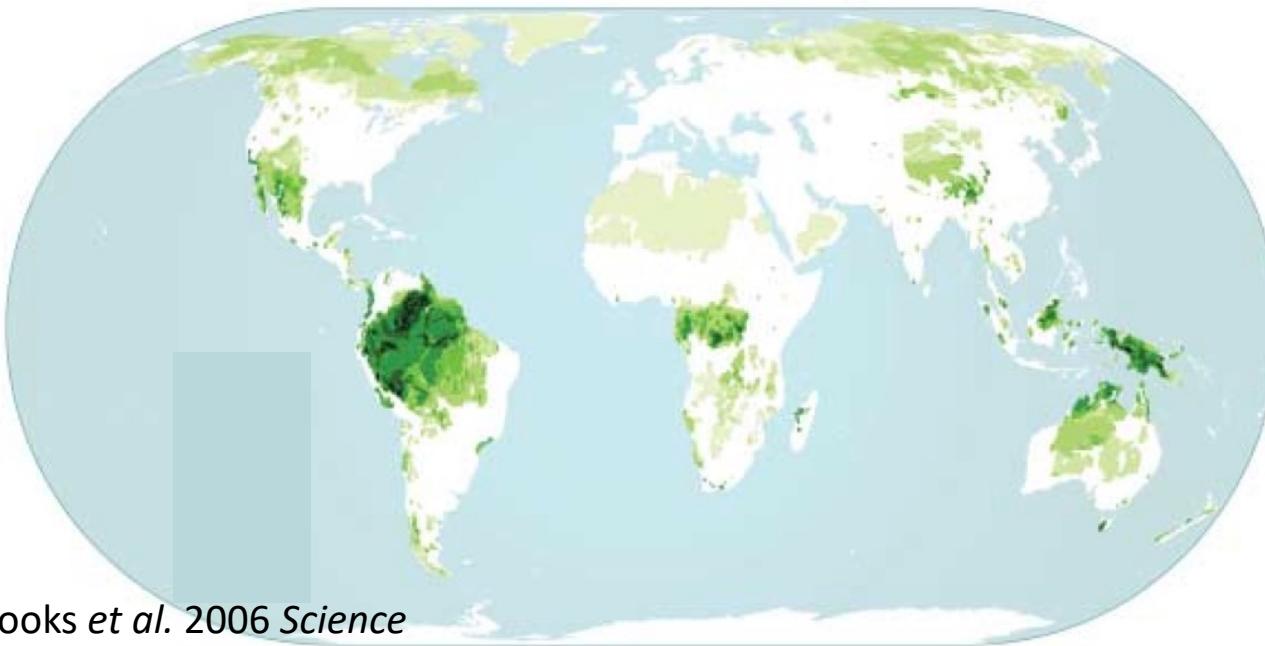
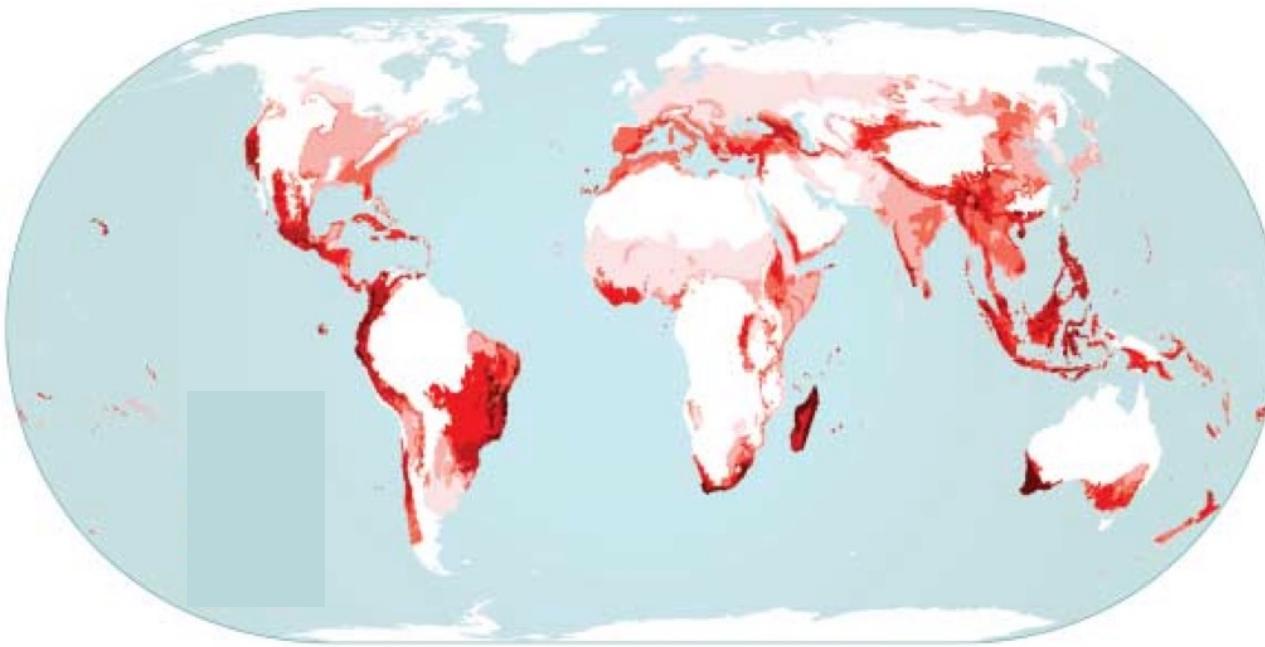
## The Tragedy of the Commons

Garrett Hardin

---

The book cover features a black and white photograph of chess pieces on a board. The title 'von Neumann and Morgenstern' is at the top, followed by 'Theory of Games and Economic Behavior' in large red letters, and 'SIXTIETH-ANNIVERSARY EDITION' in smaller red letters at the bottom.

The book cover has a dark background with white text. It features silhouettes of birds flying over tall grass at the top. The title 'The Logic of Collective Action' is in large white letters, followed by 'PUBLIC GOODS AND THE THEORY OF GROUPS' in smaller white letters, and the author's name 'Mancur Olson' in white at the bottom.



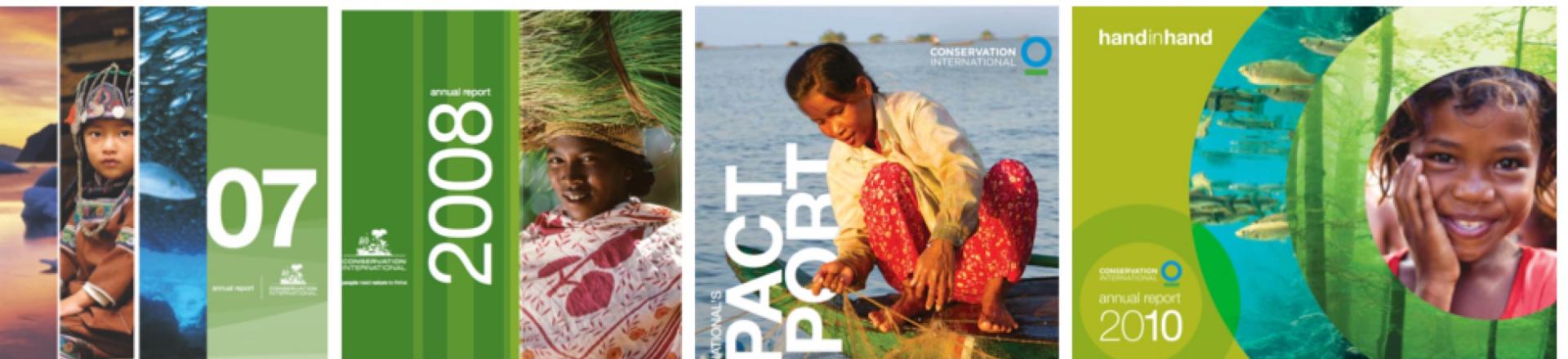
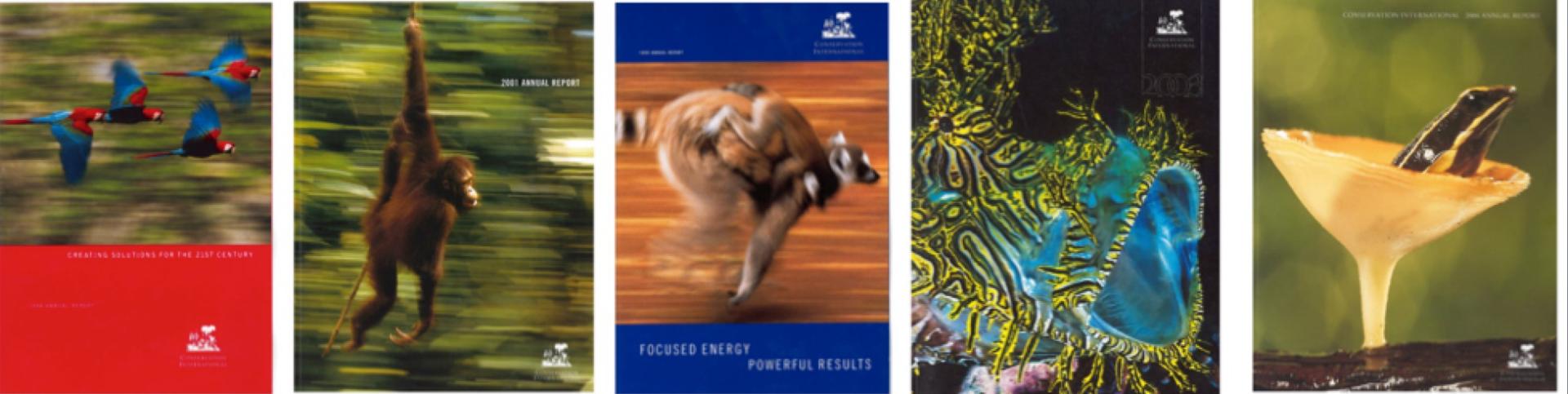
Conservation organisations act strategically towards each other

CONSERVATION  
INTERNATIONAL



Wildlife  
Conservation  
Society

Conservation  
NGOs act  
strategically  
towards donors



The Nature Conservancy®



SAVING THE LAST GREAT PLACES ON EARTH



The Nature Conservancy



Protecting nature. Preserving life.™

# Practical example of strategic NGOs



Western Africa		Central Africa		Eastern Africa		Southern Africa	
Country	NGOs	Country	NGOs	Country	NGOs	Country	NGOs
Nigeria	13	DRC	29	Kenya	64	South Africa	55
Ghana	7	Cameroon	12	Tanzania	39	Namibia	27
Liberia	6	Congo	9	Uganda	17	Zambia	25
Burkina Faso	6	Rwanda	8	Ethiopia	12	Botswana	23
Ivory Coast	5	Angola	6	Somalia	3	Madagascar	22
Mali	5	CAR	6	Sudan	3	Zimbabwe	18
Gambia	4	Gabon	4	Djibouti	2	Malawi	15
Guinea-Bissau	4	Burundi	2	Eritrea	1	Mozambique	10
Sierra Leone	4	Chad	1			Swaziland	5
Guinea	3	Eq Guinea	1			Lesotho	1
Niger	3	S. Tome & P'pc	1				
Senegal	3						
Benin	2						
Togo	2						
Cape Verde	1						
<b>Total</b>	<b>68</b>	<b>Total</b>	<b>79</b>	<b>Total</b>	<b>139</b>	<b>Total</b>	<b>201</b>

rica Conservation Fund UK  
rica Conservation Fund US  
rica Parks Foundation  
rica Predator Conservation Research Organisation  
rican Conservancy  
rican Conservation Centre  
rican Conservation Trust  
rican Ele-Fund  
rican Fund for Endangered Wildlife  
rican Impact  
rican Mangrove Network (AMN),  
rican Wild Dog Conservancy  
rican Wild Dog Foundation  
rican Wildlife Foundation  
ricat Foundation  
nara Conservation  
mbassadors for Wildlife through Education (AWE)  
mboseli Community Wildlife Tourism Project (ACWTP)  
mboseli Trust for Elephants  
COS - Albertine Rift Conservation Society.  
ociation Burundaise pour la Protection des Oiseaux  
ociation 'Les Amis des Oiseaux' (AAO)  
ociation National Pour la Gestion Des Aires Pro  
ociation pour la Conservation de la Nature au  
fady UK  
nt Interest Group of KwaZulu-Natal (Bats K  
l Jordan Foundation  
odiversity Foundation for Africa (BFA)  
dLife Botswana (BLB)- Birdlife Internati  
dLife Denmark  
dLife Germany  
dLife International (Secretariat)  
dLife Netherlands VPN  
dLife South Africa  
dLife Zimbabwe (BLZ)  
ouburg Conservation Project  
nobo Conservation Initiative (BCI)  
rn Free Foundation UK  
rn Free Foundation USA  
own Hyena Research Project  
shmeat Crisis Taskforce  
shmeat Project  
A.R.E. - Centre for Animal Rehabilitation and Educ  
meroon Environmental Watch  
meroon Mountains Conservation Foundation (CAMCON)  
meroon Wildlife Aid Fund  
pe Peninsula Baboon Project (CPBP)  
racal  
re for the Wild International  
nderburg Amphibians and Reptiles (Cape Nature Conservati  
RCOPAN  
heetah Conservation Botswana  
heetah Conservation Foundation  
heetah Conservation Fund  
impanzee Rehabilitation Trust  
obe Wildlife Trust  
lobus Trust  
logne Zoo  
OMPASS  
nervation Force

nservation Foundation Zambia  
nservation International  
nservation Society of Sierra Leone (CSSL)  
nservation through Poverty Alleviation  
nserve Africa International  
lman & Hurt Wildlife Conservation Trust  
avid Sheldrick Wildlife Trust  
avid Shepherd Wildlife Foundation  
Wildt Cheetah Centre  
n Fossey Gorilla Fund International  
rrell Wildlife Conservation Trust  
rthwatch Institute  
st African Wild Life Society  
phant Pepper Development Trust  
AOA (Elephant Management and Owners Association)  
dangered Wildlife Trust (EWT)  
vironmental Foundation for Africa, Sierra Leone  
niopian Wildlife and Natural History Society (EWNHS)  
niopian Wolf Conservation Programme  
amby  
una and Flora International  
ondation des Amis de la Nature (NATURAMA)  
ndation Pour les Aires Protegees at la Biodiversite de Madagascar  
ation Tany Meva  
Resources and People (FOREP)  
Zoological Society  
nservation Fund  
nservation (UK)  
nservation (USA)  
phant/Vrienden van de Olifant (Netherlands),  
nya / Marafiki Wa Kenya (FOK)  
Hippo and The Turgue Hippo Trust  
orial Foundation (GMF)  
son Wildlife Preservation Trust  
e Society (GWS)-Birdlife International partner  
e Environment (MATE),  
ora Karatu

Wildlife Foundation  
Kenya Wildlife Conservancy  
ain Gorilla Conservation Fund (MGCF)  
ia Wildlife Foundation  
lanje Mountain Conservation Trust (MMCT)  
rulla Foundation  
y Acre of Africa  
ACOBTA - Namibian CBNRM Tourism Association  
ture Conservation And Environmental Development ('  
ture Djibouti  
ture Kenya: The East Africa Natural History Society  
ture Seychelles  
tureUganda (NU)-  
GO Arboretum D'Antsokay  
gerian Conservation Foundation (NCF)  
gerian Montane Forests Project  
NF (Namibia Nature Foundation)  
é Conservation  
northern Rangelands Trust  
nouvelles Approches  
Tukai Conservancy

# Why are there so many NGOs in Kenya?

- Construct a simple strategic model of interactions between NGOs
- Avoid the numbing simplicity of normal form games
- Allow for both strategic and responsive actions



Western Africa		Central Africa		Eastern Africa		Southern Africa	
Country	NGOs	Country	NGOs	Country	NGOs	Country	NGOs
Nigeria	13	DRC	29	Kenya	64	South Africa	55
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Mali	5	CAR	6	Sudan	3	Zimbabwe	18
Gambia	4	Gabon	4	Djibouti	2	Malawi	15
Guinea-Bissau	4	Burundi	2	Eritrea	1	Mozambique	10
Sierra Leone	4	Chad	1			Swaziland	5
Guinea	3	Eq Guinea	1			Lesotho	1
Niger	3	S. Tome & P'pe	1				
Senegal	3						
Benin	2						
Togo	2						
Cape Verde	1						
Total	68	Total	79	Total	139	Total	201