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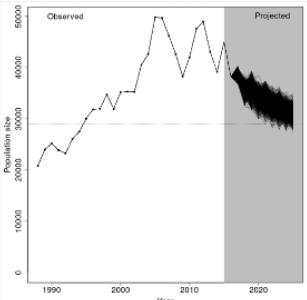
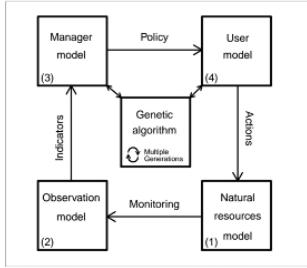
Biodiversity & Ecosystem Services 2020

Simulation modelling & management strategy evaluation

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Overview



- Revisiting conservation management complexity
 - Not all animals are alike...
 - Not all humans are alike...
 - Socio-economic systems
- Need to consider stakeholders
- Management Strategy Evaluation
- GMSE, its features & methods
- Application of GMSE: goose population management

Management complexity



Management complexity



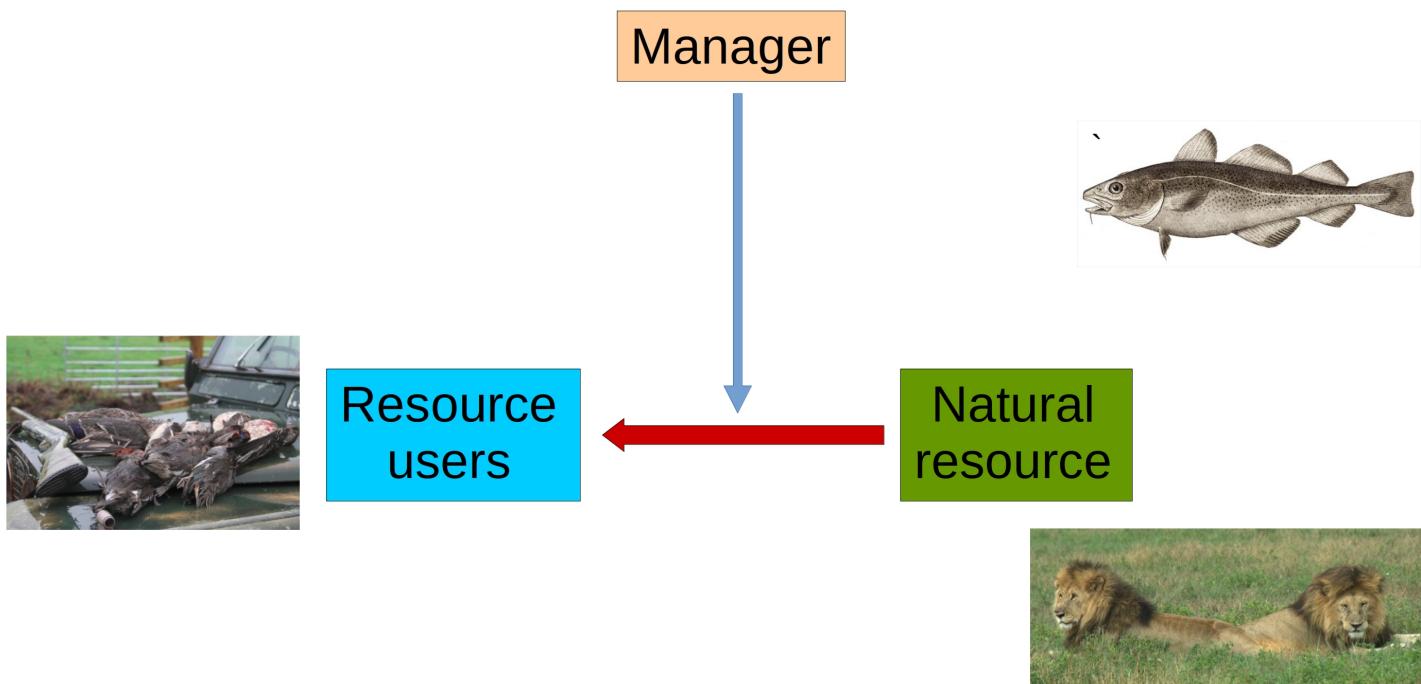
Resource
users



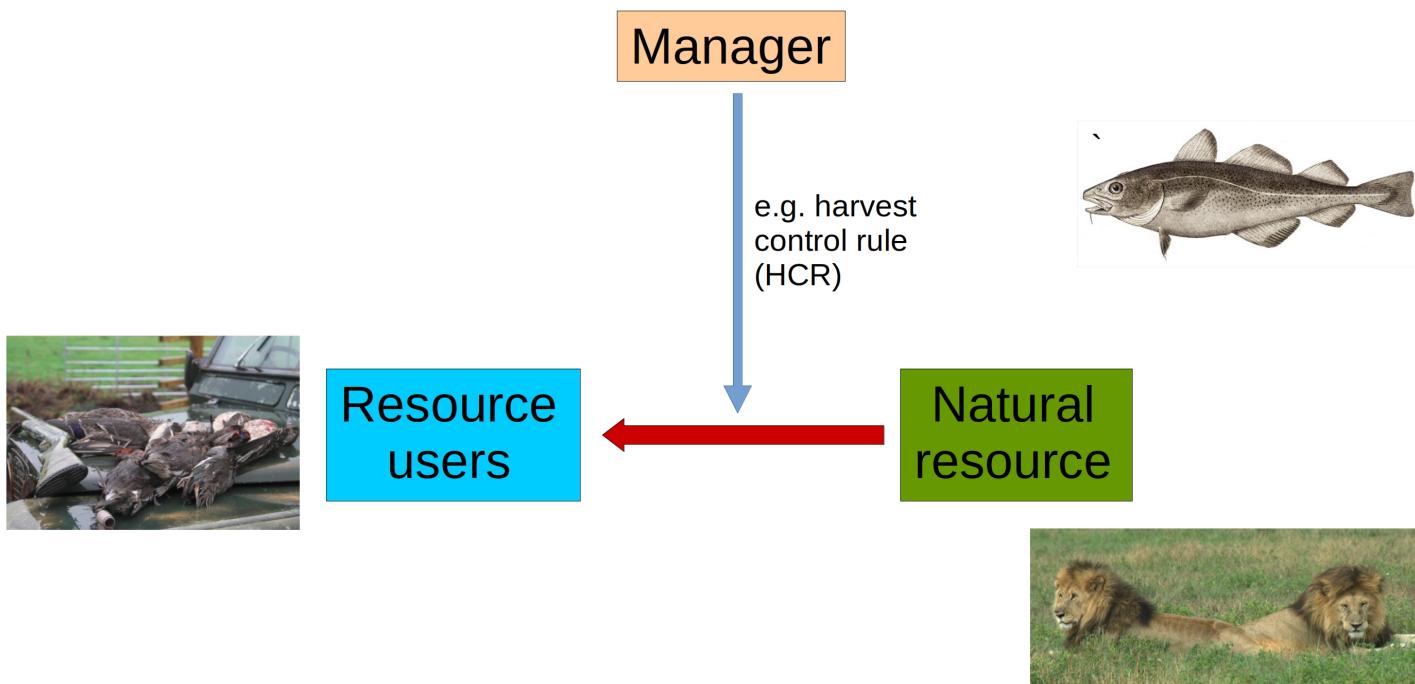
Natural
resource



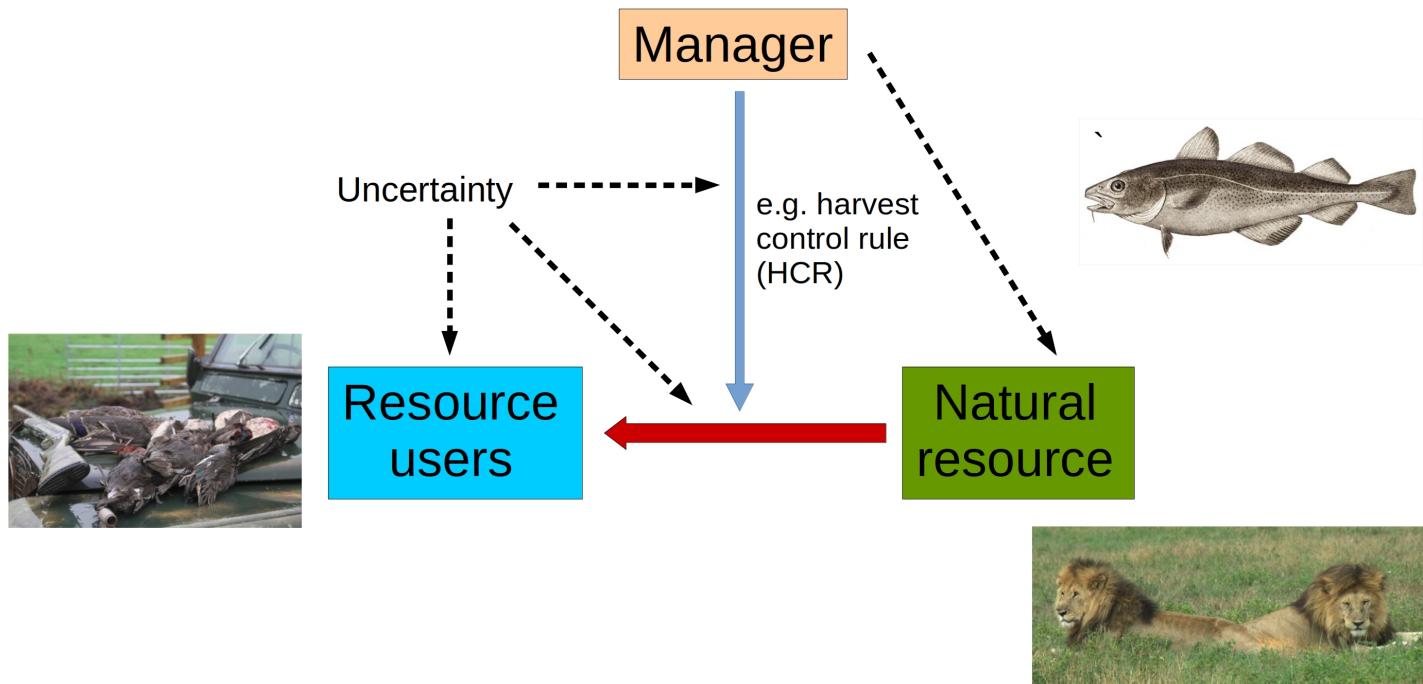
Management complexity



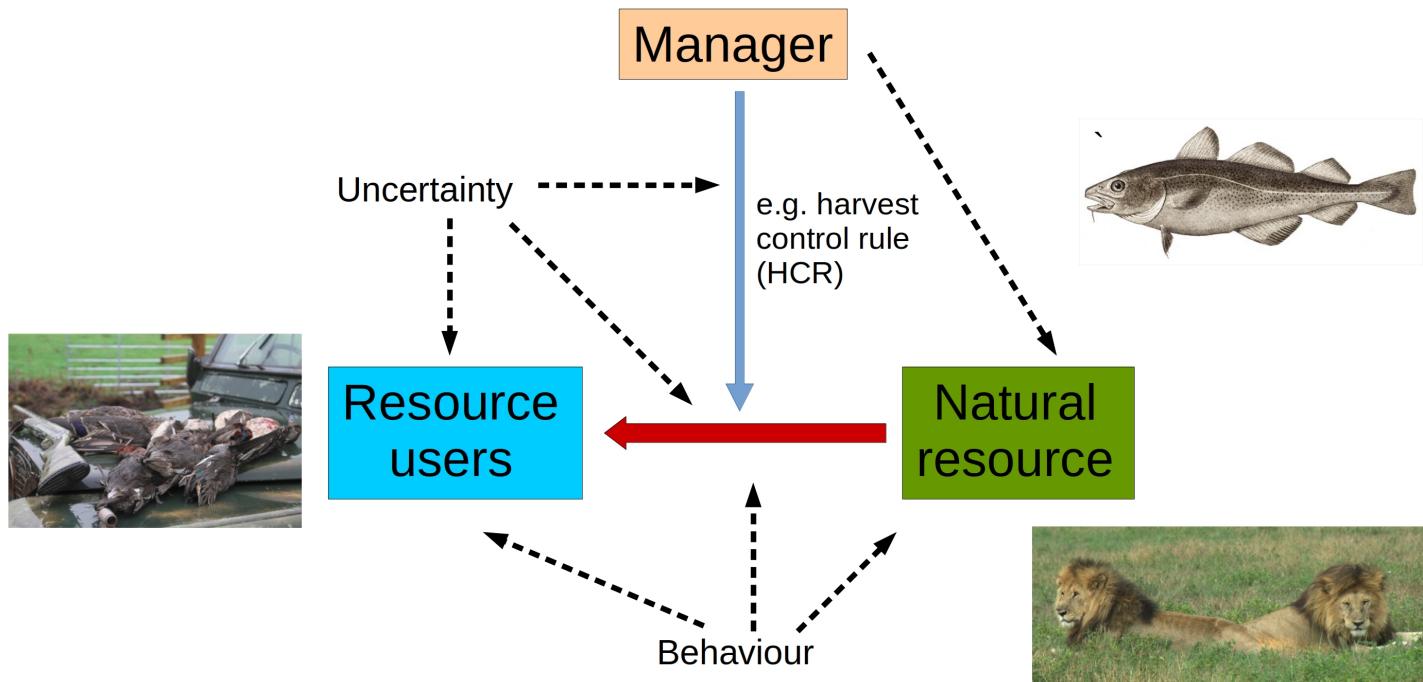
Management complexity



Management complexity

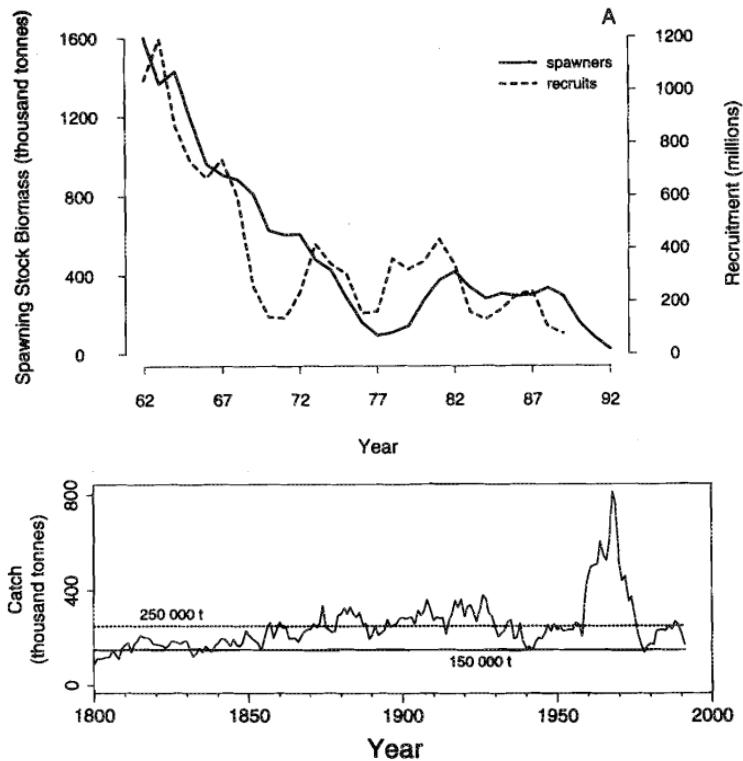


Management complexity



Management complexity

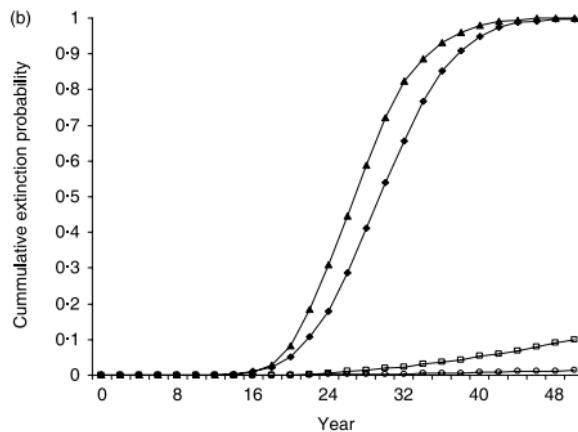
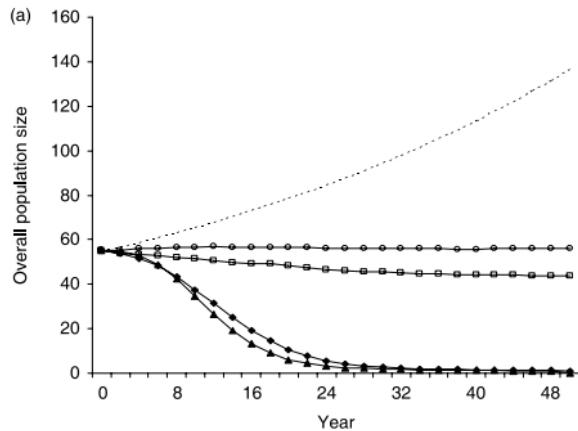
Simple harvest rules can lead to population collapse



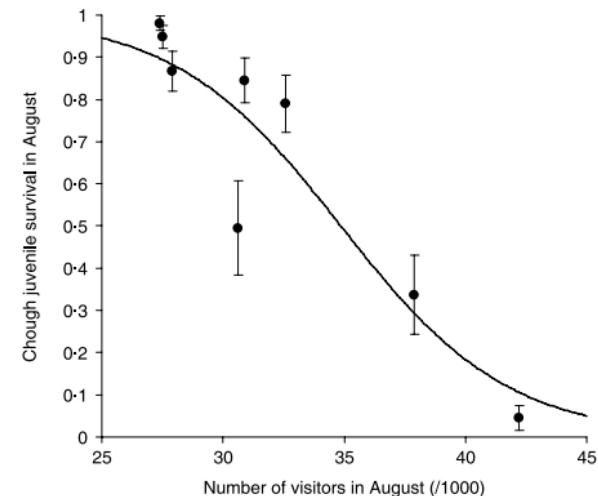
Atlantic cod (*Gadus morhua*)
Hutchings & Myers 1994

Management complexity

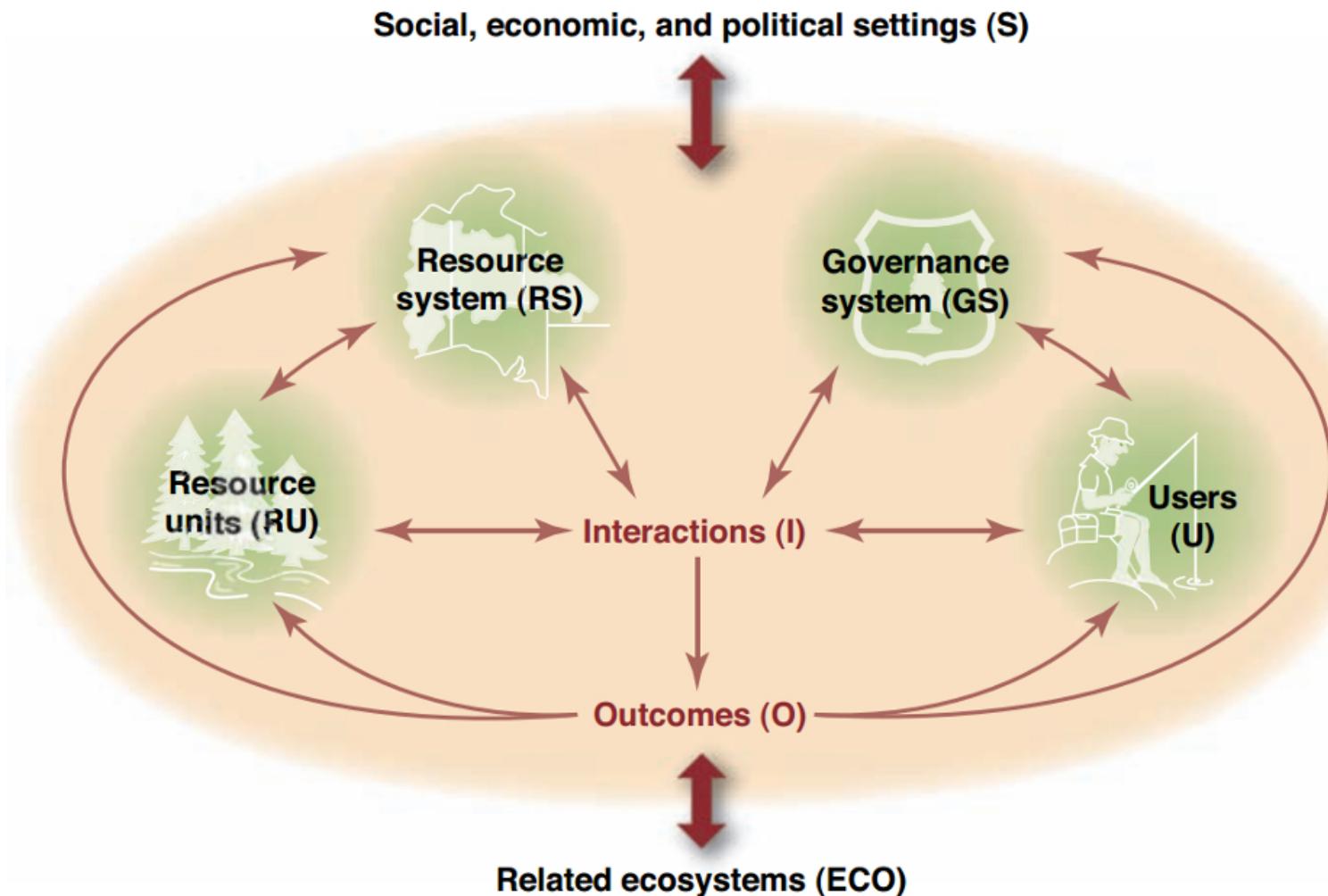
Ignoring individual behaviour affects projections



Red-billed chough (*Pyrrhocorax pyrrhocorax*) Kerbiriou et al 2009



Management in socio-economic systems



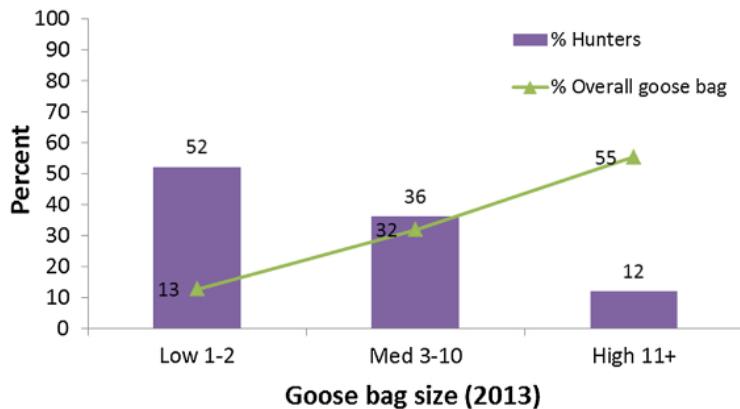
Management in socio-economic systems

Consideration of **wildlife** as well as **people**



Importance of stakeholders (1)

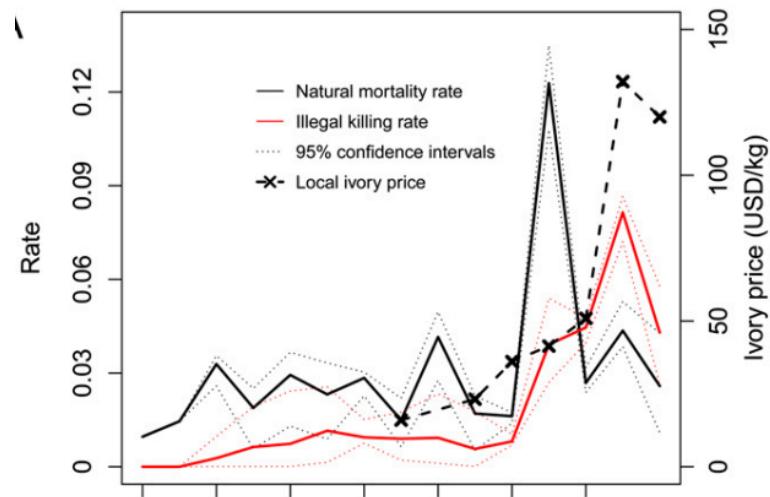
Variation in behaviour: motivations



Pink-footed goose (*Anser brachyrhynchus*) hunters in Denmark ([Williams et al. 2019](#))

Importance of stakeholders (2)

Variation in behaviour: compliance



Illegal killing for ivory drives global decline in African elephants
([Wittemeyer et al. 2014](#))

Adaptive Management

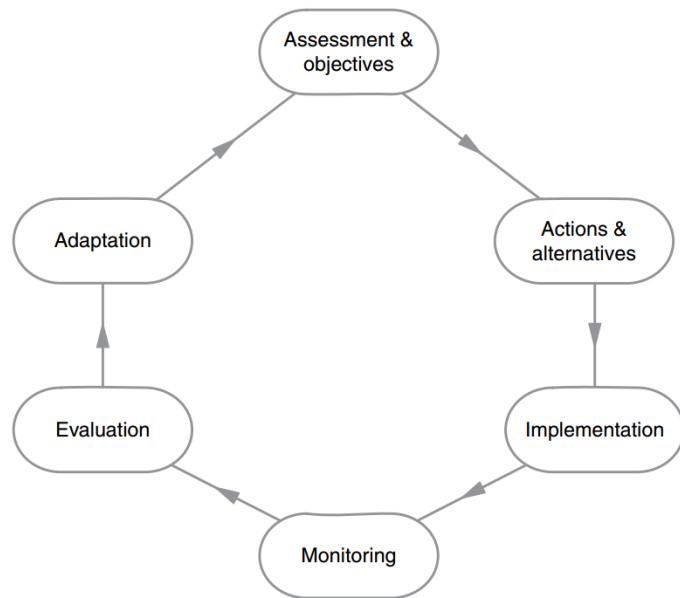


Diagram from [Bunnefeld et al.
\(2015\)](#)

- Cyclical process aimed at updating strategy based on previous results
- Consideration of stakeholder responses usually limited to purely economic drivers (e.g. fishing fleets).
- **Individual stakeholder behaviour** rarely (if ever) included

Management Strategy Evaluation (MSE)

Definition?

"..assessing the consequences of a range of management strategies or options and presenting the results in a way that lays bare the trade-offs in performance across a range of management objectives" (Smith *et al.* 1999)

"MSE uses simulation models within an adaptive framework that enables the comparison of alternative strategies in a virtual world under multiple (and often conflicting) objectives" (Bunnefeld *et al.* 2011)

- Focus on **identification of trade-offs** rather than "optimal" solution
- Allows decision makers to make trade-offs depending on context, preferences, etc.

Management Strategy Evaluation (MSE)

Structure

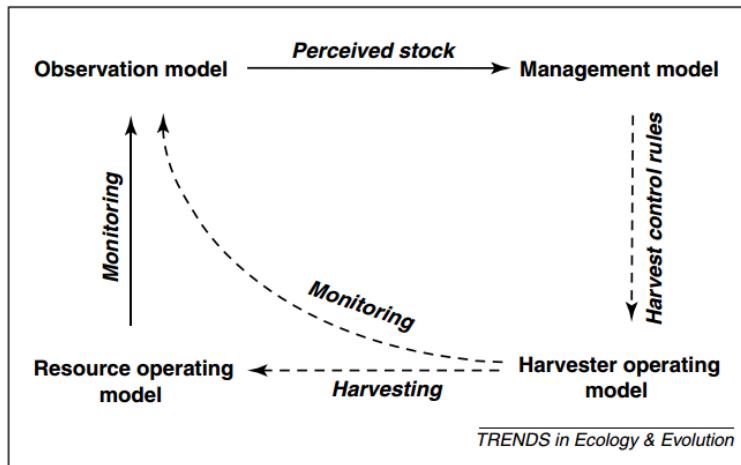


Figure from [Bunnefeld et al. 2011](#)

Explicitly accounts for and separates..

1. Resource dynamics

2. Observation process

- Detection? Biases?

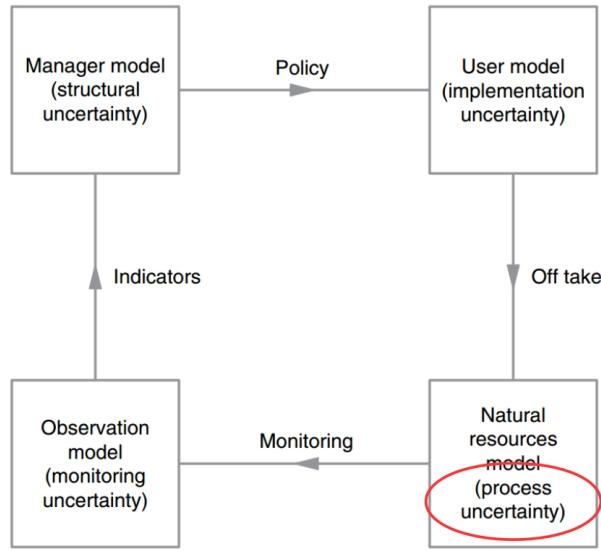
3. Manager decisions

- Preference? Bias?

4. User decisions

- Behaviour? Compliance?

MSE key advantage: uncertainty

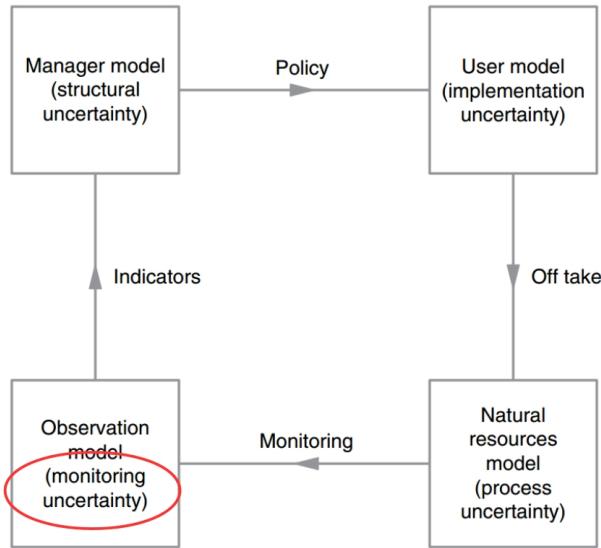


Process uncertainty

- Stochasticity in natural populations
- "Error"
- What are the "correct" parameters?
- c.f. parameter estimation error, residual error

Milner-Gulland & Rowcliffe 2007, Bunnefeld *et al.* 2011

MSE key advantage: uncertainty

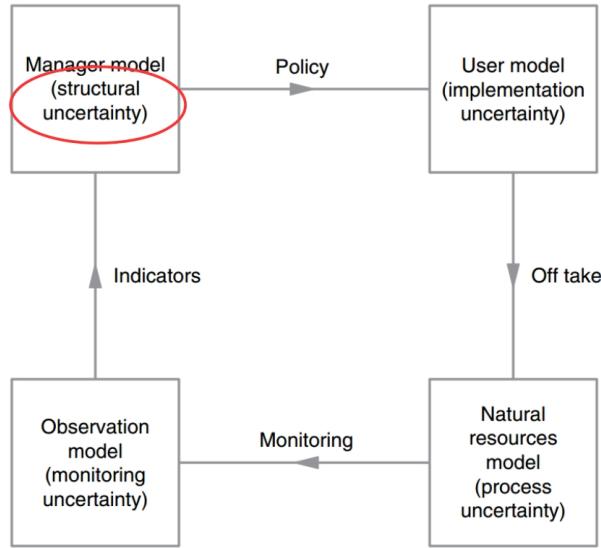


Monitoring uncertainty

- Irrespective of process uncertainty
- Observations naturally imperfect (poor/limited survey etc)
- Note - not accounted for in "classic" statistical population models

Milner-Gulland & Rowcliffe 2007, Bunnefeld *et al.* 2011

MSE key advantage: uncertainty

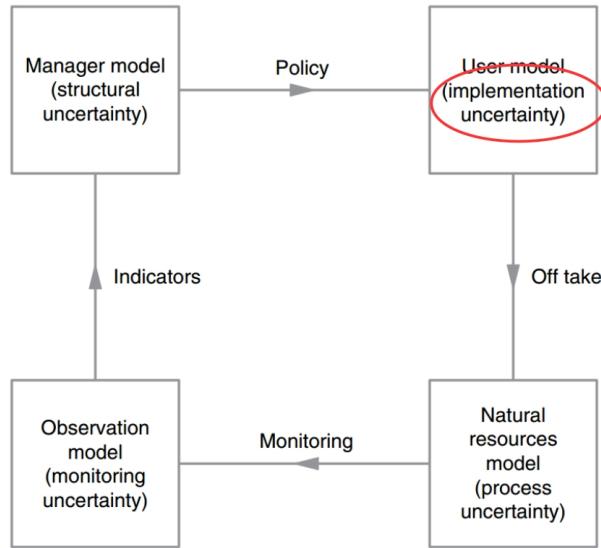


Structural uncertainty

- Lack of understanding of the "true" system
- How does it respond to changes in management/environment?
- "Model uncertainty"
- c.f. statistical model selection

Milner-Gulland & Rowcliffe 2007, Bunnefeld *et al.* 2011

MSE key advantage: uncertainty



Implementation uncertainty

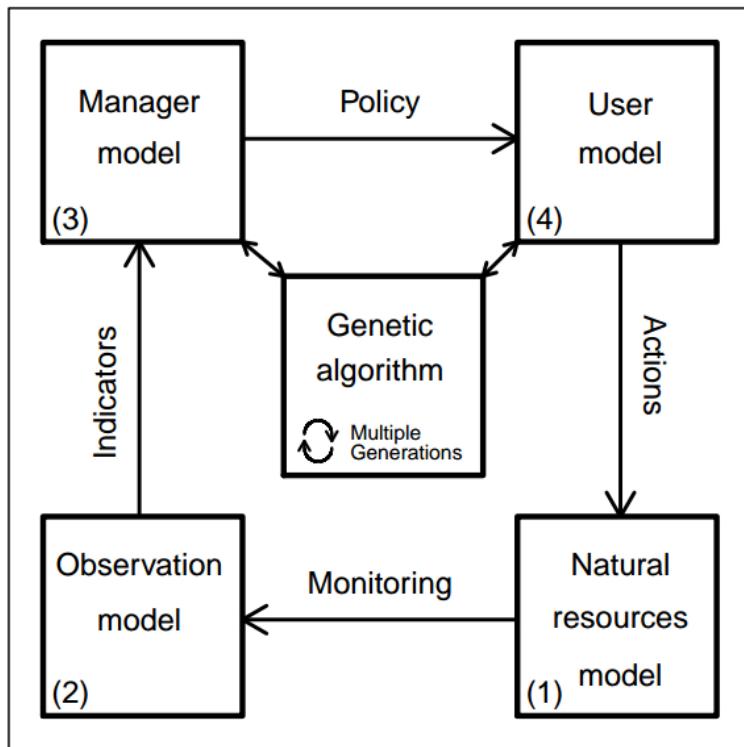
- Impartial or poor implementation of management/policy
- e.g...
 - Practical limits to reaching quotas
 - Limited compliance
 - Institutional inertia

Milner-Gulland & Rowcliffe 2007, Bunnefeld *et al.* 2011

GMSE: introduction

GMSE: methods

Basic structure (1)



Duthie et al. 2018

1. Individual resources on landscape "cells"

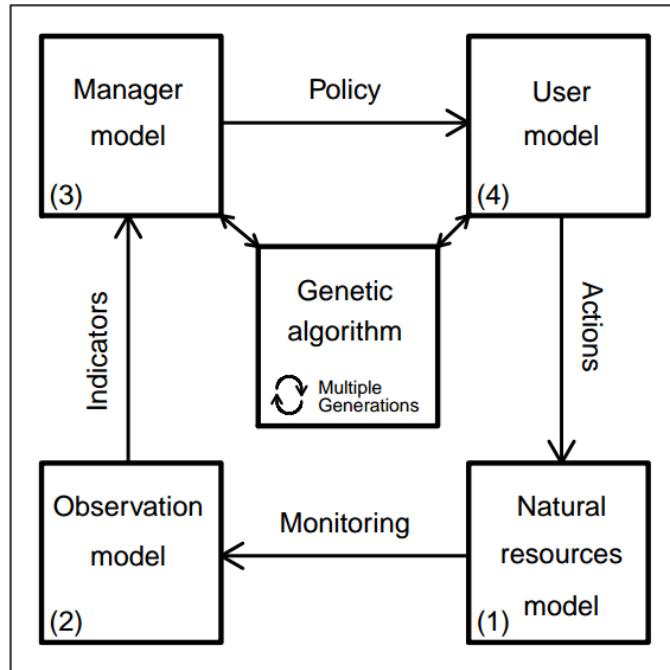
- Births, deaths, movement between cells, interaction with landscape

2. Observations of resource

- incl. sampling error

GMSE: methods

Basic structure (2)



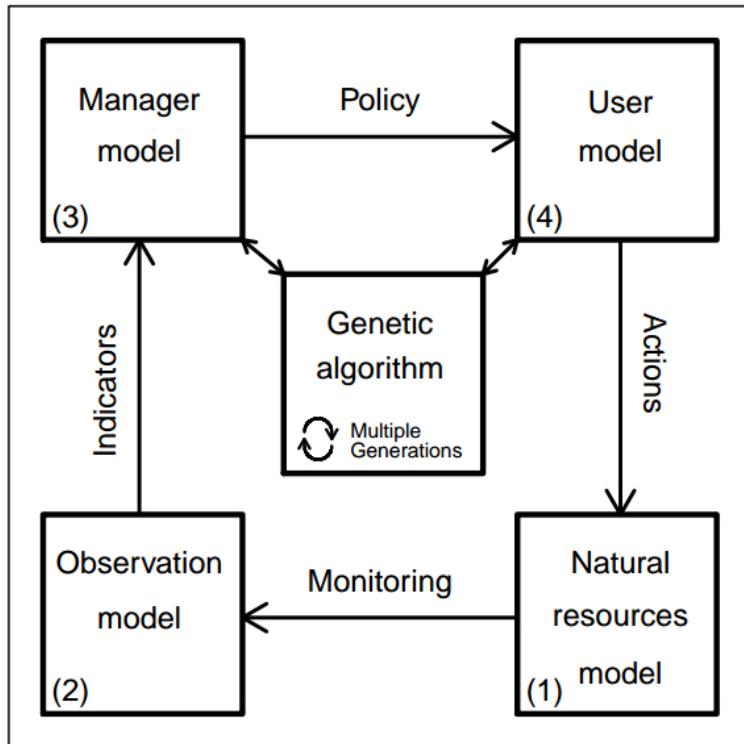
Duthie et al. 2018

3. Managers

- Compare observation with target
- Given constraints (maximum "budget")...
- Set costs of different actions, aiming to minimise deviation from target
(given e.g. predicted consequences of actions)

GMSE: methods

Basic structure (3)



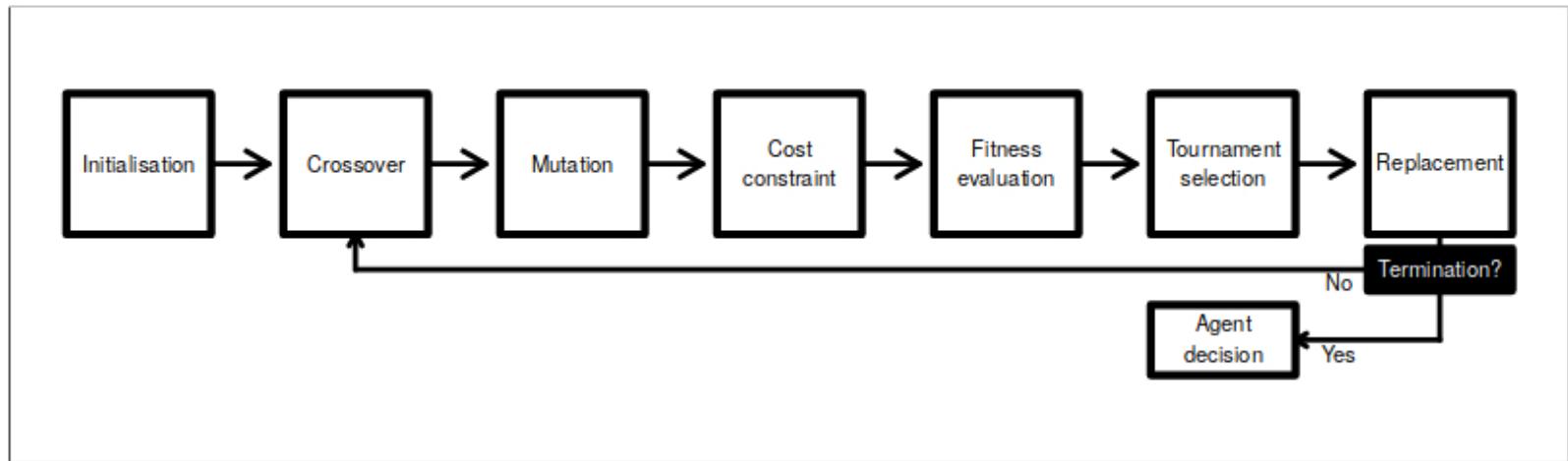
Duthie et al. 2018

4. Users

- Within constraints ("budget")...
- Choose action that maximises "utility"
(e.g. landscape yield, resource use)
- Current actions: cull resource, scare resource, castrate resource, feed resource, help resource offspring

GMSE: methods

Selecting actions: genetic algorithm

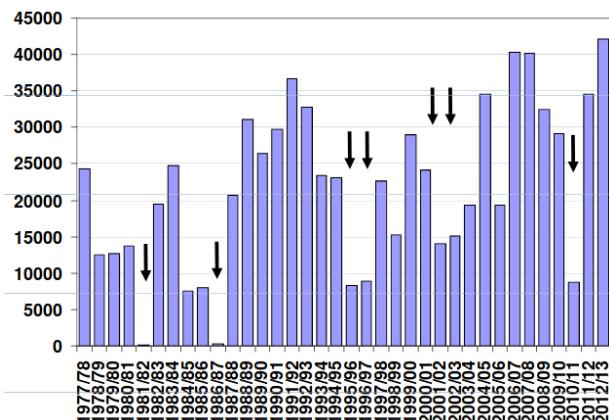
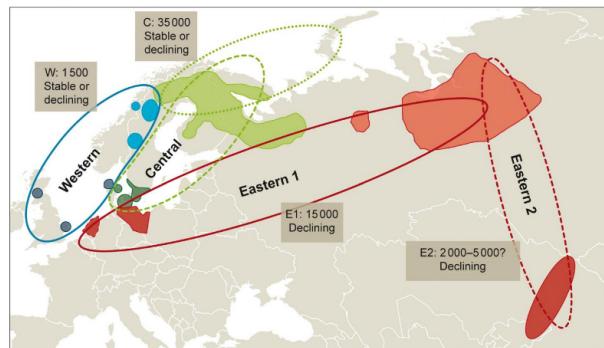


Each time step:

1. Run genetic algorithm (GA) for each agent (manager and each user)
2. GA simulates "evolution by natural selection" of "population" of agent decisions
3. Highest fitness strategy chosen as agent's decision

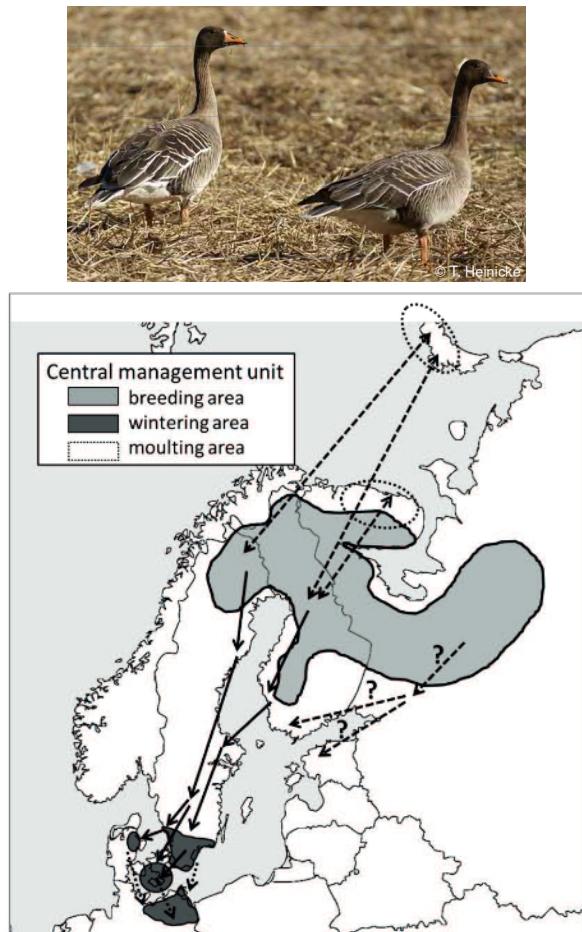
Example use of GMSE: Taiga bean goose (1)

Anser fabalis



T. Heinecke, AEWA Single Species Action Planning Workshop

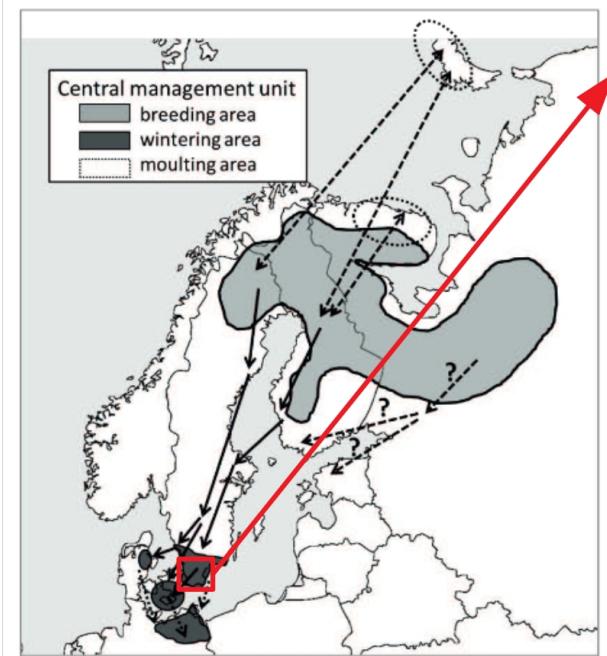
Example use of GMSE: Taiga bean goose (2)



Population parameters based on Johnson et al. (2018) and AEWA (2016)

- Central population = 35000 individuals
- Mean reproductive rate $\sim 0.55 = 0.275 = \lambda$ (half of pop'n = female)
- Goose survival = 0.878, i.e. prob. of death = $1 - 0.878 = 0.122$
- AEWA target for population = 70000

Example use of GMSE: Taiga bean goose (3)

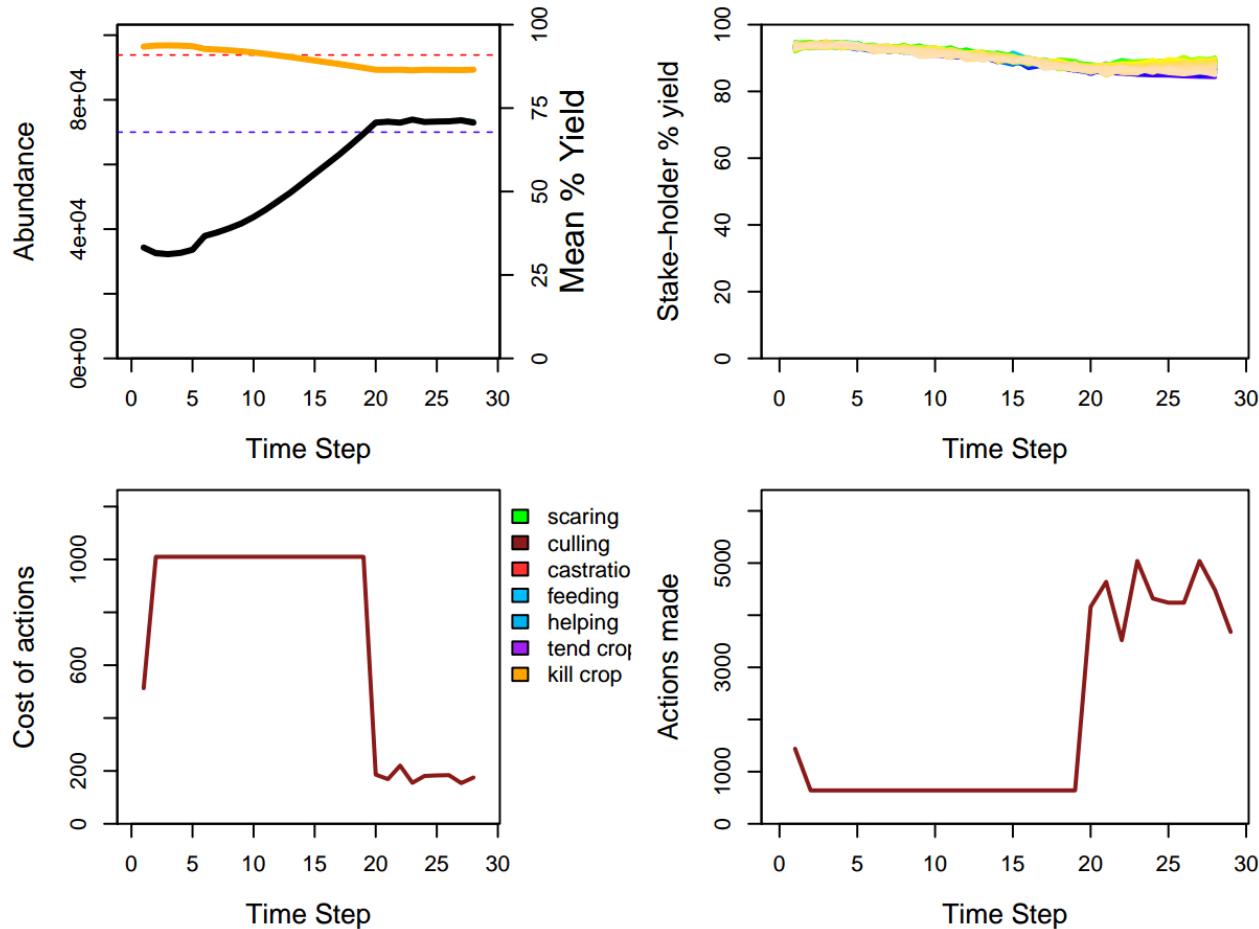


Hypothetical management unit

- 60% private (farm) land, 40% public land
- 80 individual farmers
- 100x100 unit landscape, so each farmer = 75 units
- Single goose reduces yield by 0.02% per time step

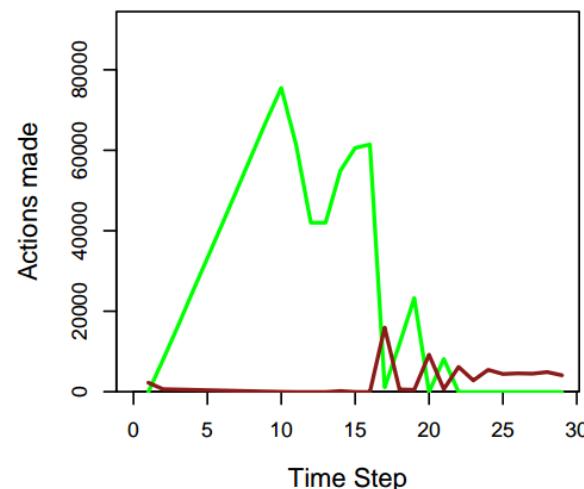
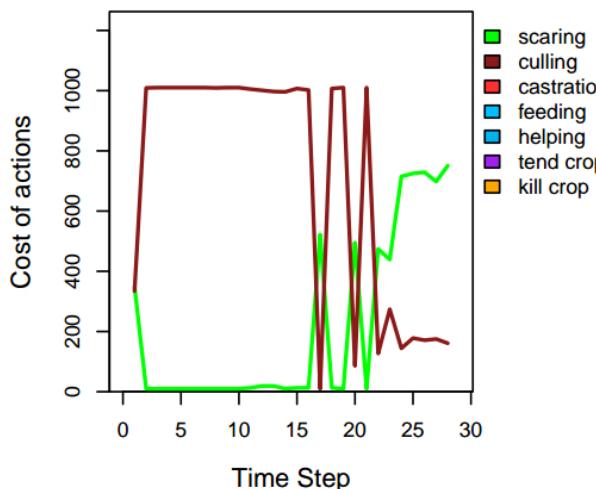
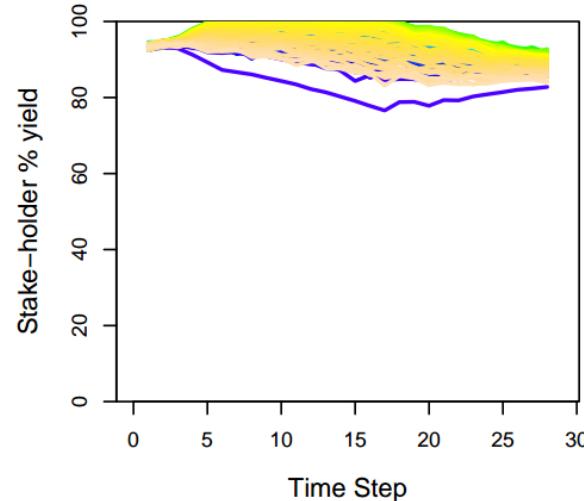
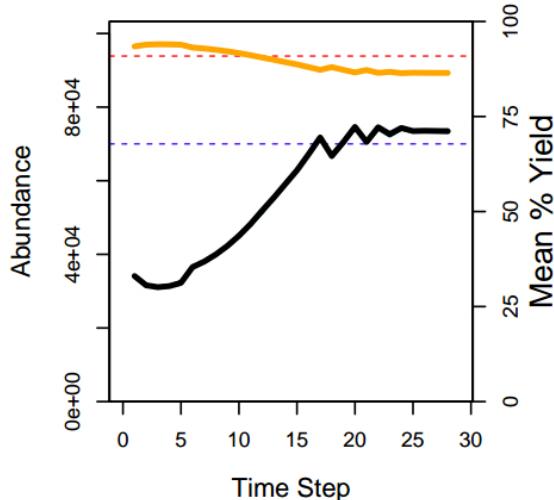
Example use of GMSE: Taiga bean goose (4)

Simulations with **culling** as only option

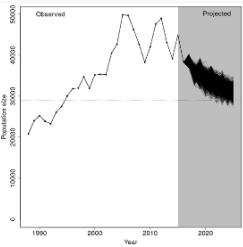
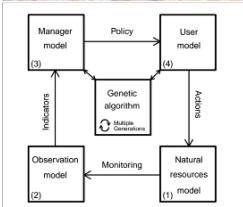


Example use of GMSE: Taiga bean goose (5)

Simulations with both **culling** and **scaring** as options



Summary



- Effective management of natural resources needs consideration of variation in..
 - .. resource behaviour
 - .. stakeholder behaviour
- MSE allows integration of uncertainty
 - Process, observation, structural, implementation
- GMSE is a flexible implementation of MSE, allowing specification of population, observation, management and user models.