TESS
Transactional Environmental Support System

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A Transactional Environmental Support System for Europe:

Modelling theory: from problem to model

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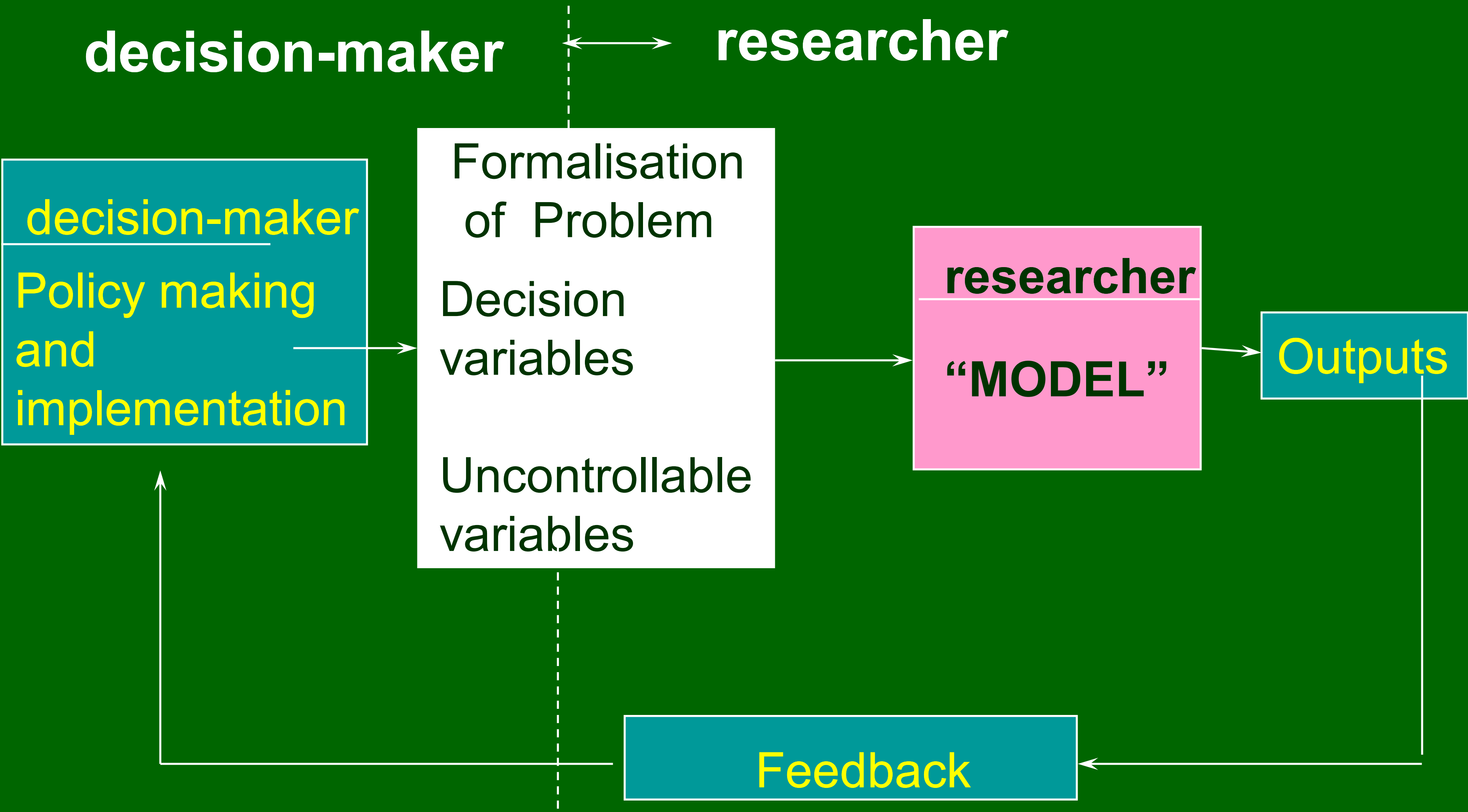
Rationale for presentation

- How do you model ?
- How do you integrate models from different disciplines ?
- How do you test complex models ?

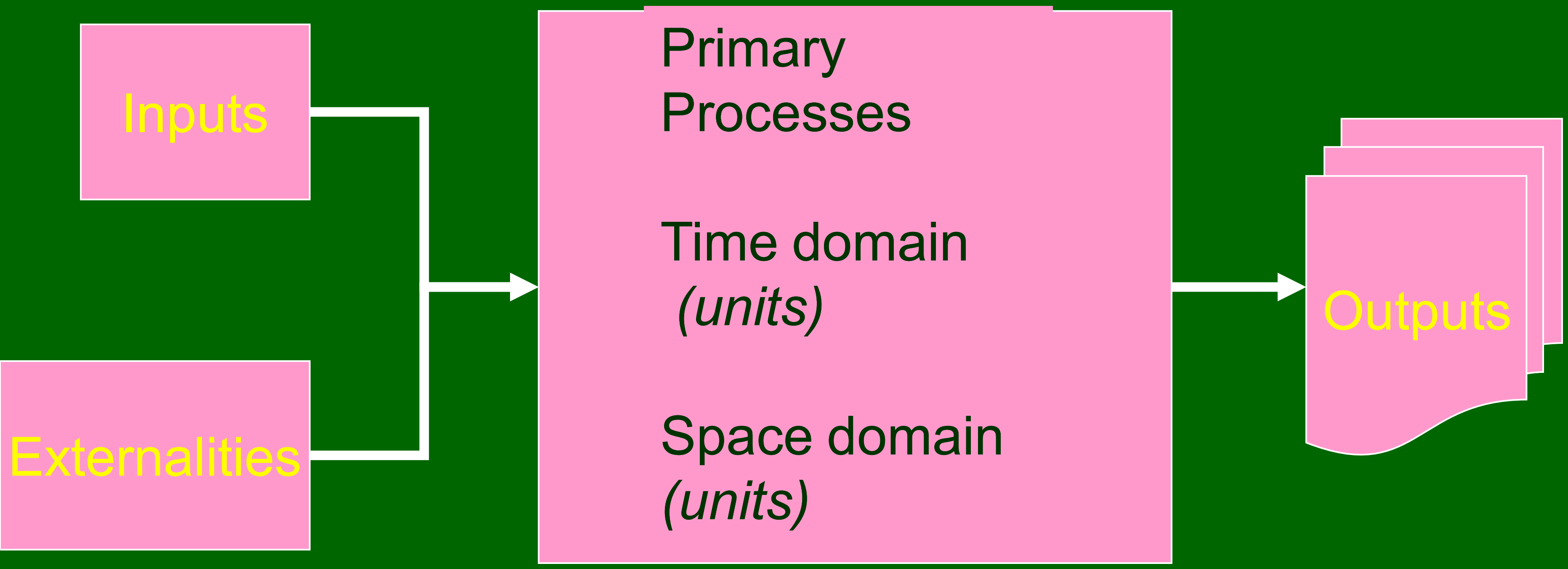
What is modelling ?

- Simplification of reality that encapsulates key components of systems
- It needs to capture key components in order to predict how a system will behave
- Models and modelling are what differentiate science from natural history and anecdote

Modelling in land use: decision-makers and researchers

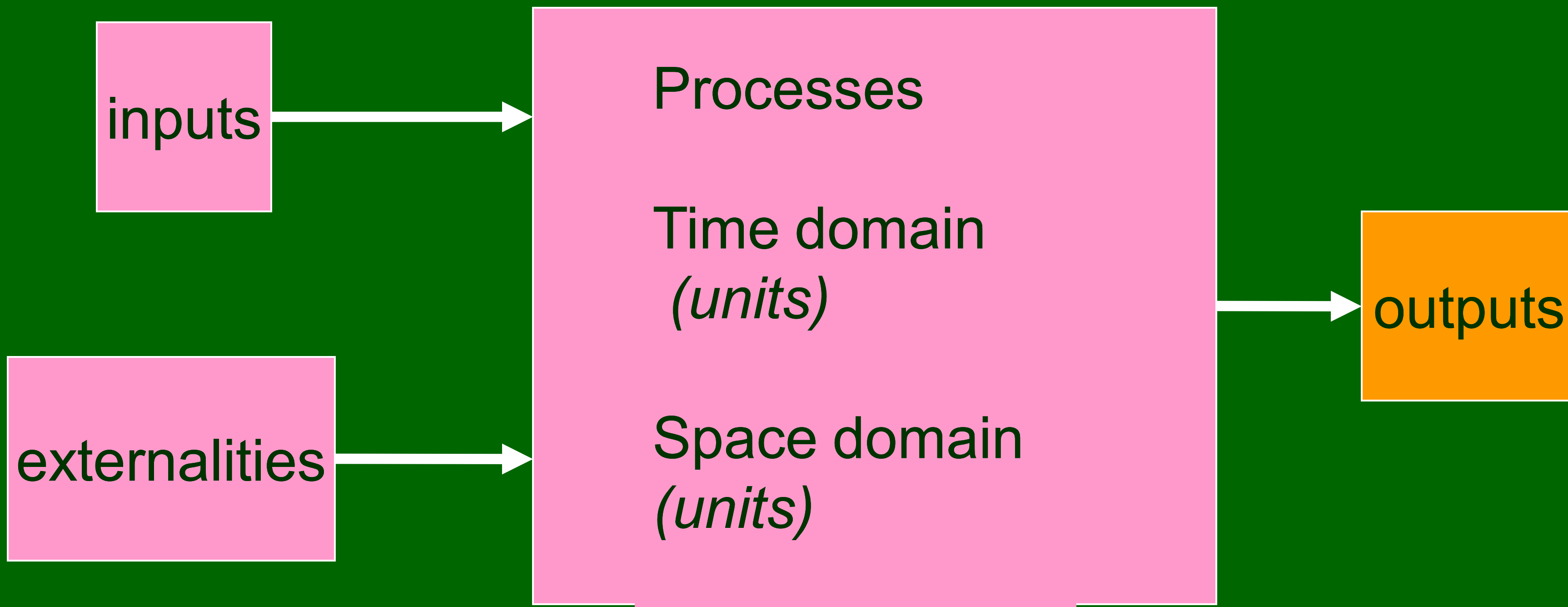


Model Schematic



Spatio-temporal scales of three main components in relation to land use?

Expanding on the model bit…

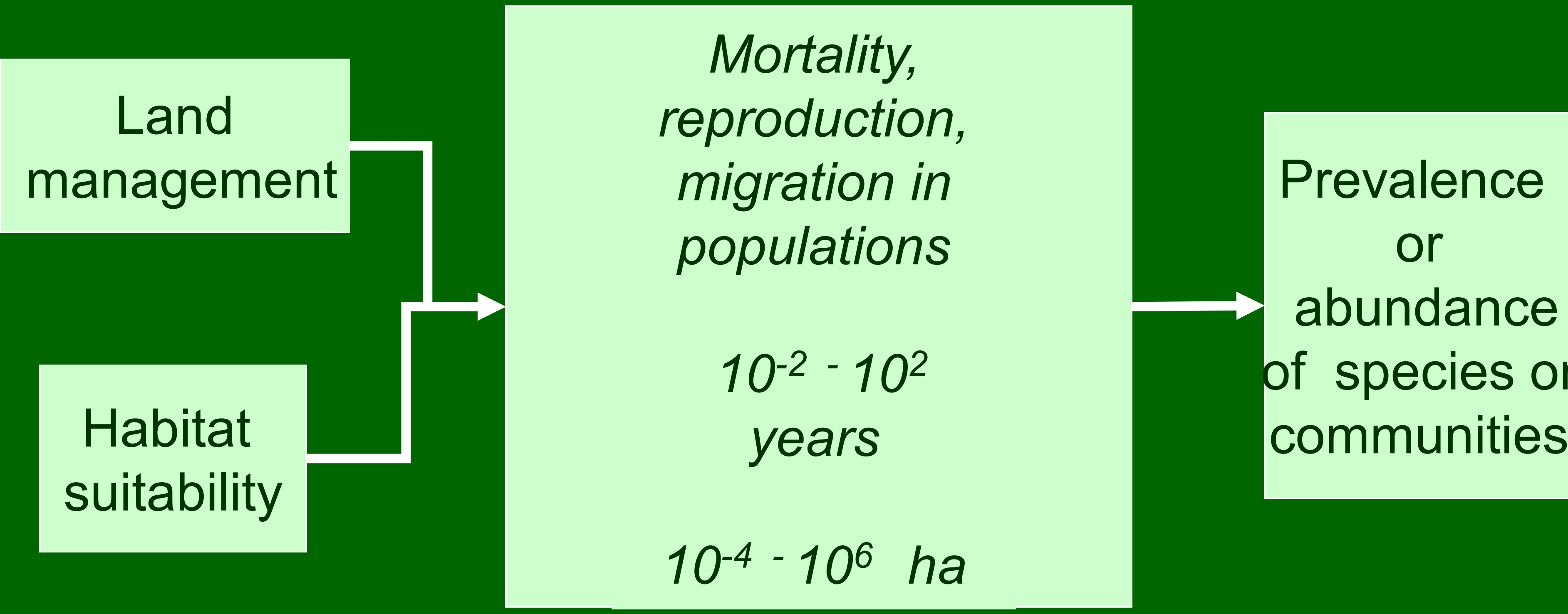


However, this is too simplistic, there are other constraints……

Conflict of spatio-temporal scales

- Problem: ecological, hydrological and economic models operating at different spatial and temporal scales
- Hydrological models - small to whole catchment scale, dynamic
- Ecological models - landscape scale, long-term changes
- Economic - short term, farm-based

Land use change and Ecology



Land use change and hydrology

Land management

Soil, climate vegetation topography

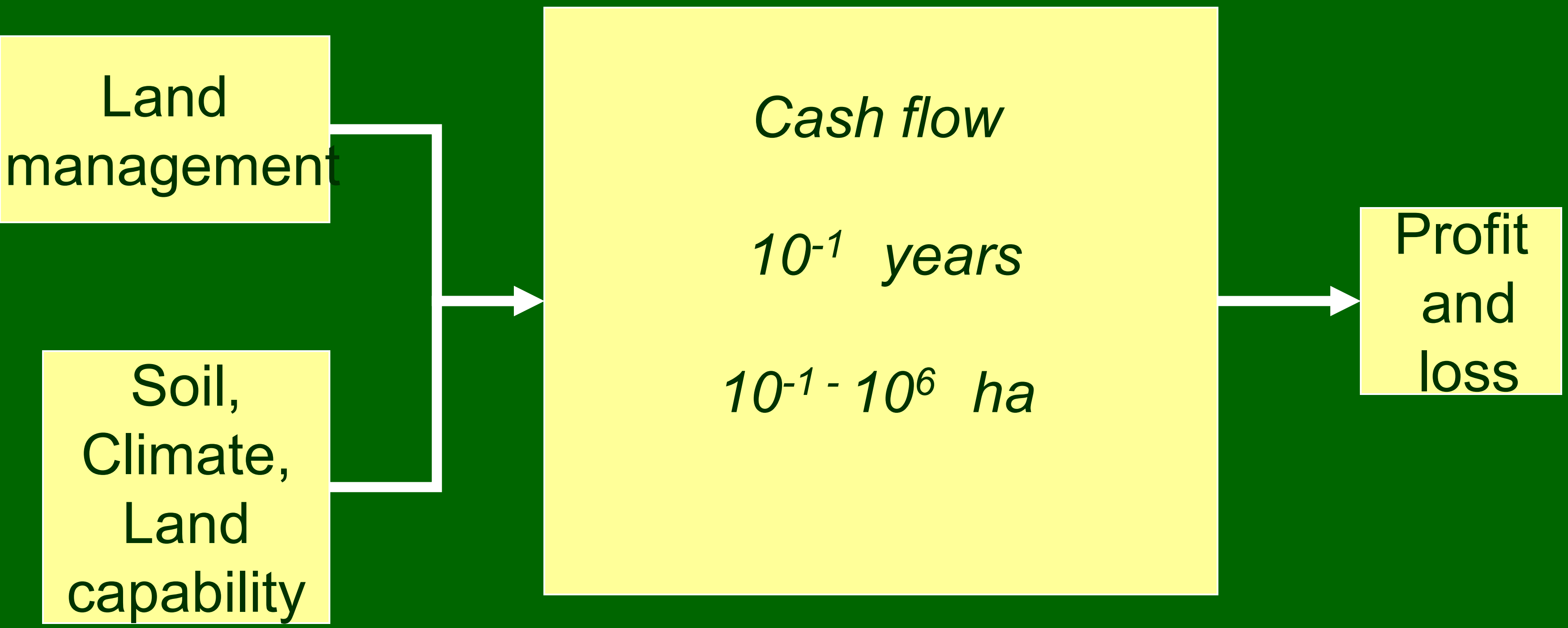
Water flow, evaporation

10^{-5} - 10^{2} years

10^{-4} - 10^{6} ha

Water dynamics

Land use change and economics



Conflicting domains?? … furthermore…

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Modelling constraints: numbers of entities

Entities	Process/system	Analysis/prediction
Large number	Behaviour of gases	Statistical (averages)
	Environmental and ecological systems	?
small number	Movement of planets	Newtonian maths

Environmental systems and complexity

- ***Hierarchies*** of interacting sub-systems comprising:
- Environmental drivers
- Human drivers
- Ecological drivers

All operating at different spatial and temporal scales

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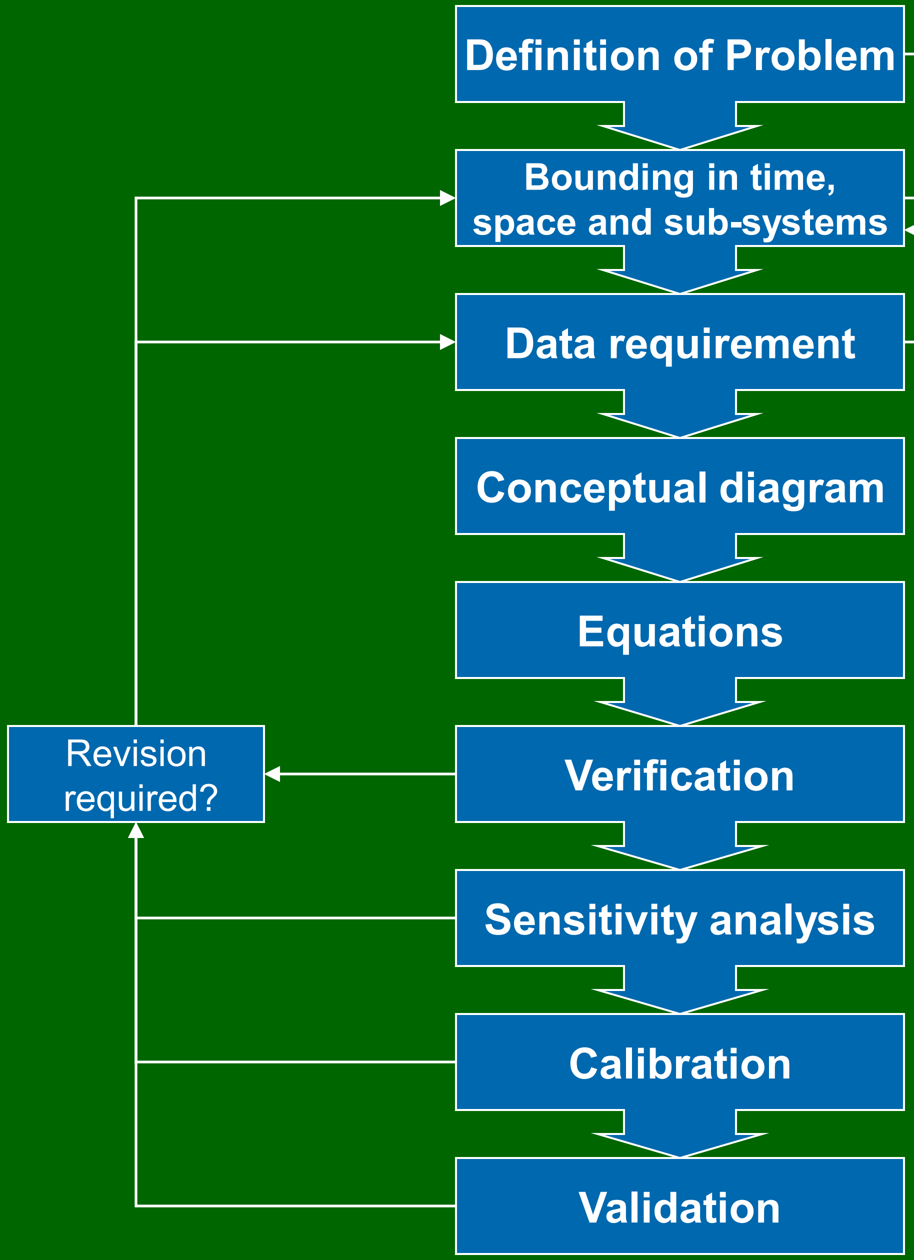
So, how do you model these systems ?

You start with a model of how to model !



A tentative modelling procedure

Doing it for real with the 'framework'

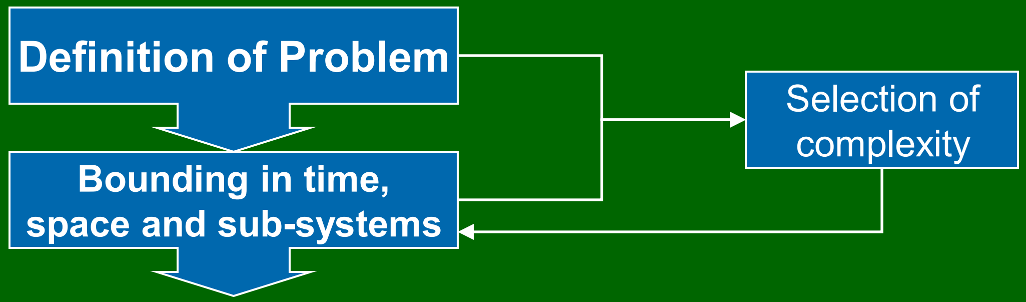
- An example problem:

Predicting impacts of land use and other species on animal populations

Definition of Problem

Grey squirrel introduced to UK 1876; considered forest pest and threat to native red squirrel, a broadleaf specialist

Large conifer forests in the North considered possible sanctuaries in early 1990s


Definition of Problem
Bounding in time, space and sub-systems
Selection of complexity

Bounding in time, space and sub-systems

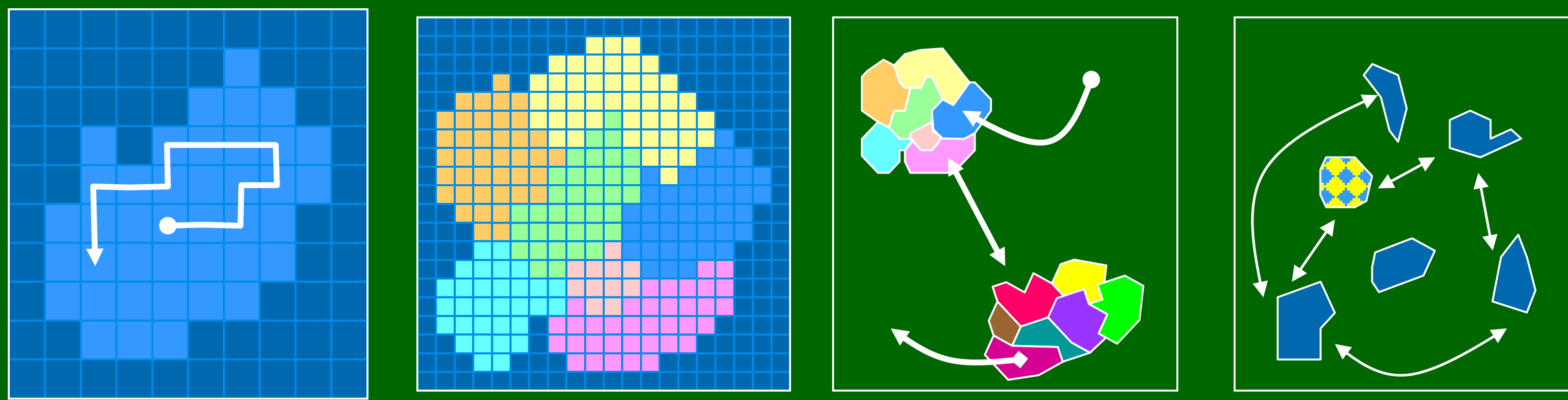
- Most difficult part of the modelling process
- Need to select scales appropriate for processes considered
- The model has a scale at least one level lower than the scale of the response (the response then ‘emerges’ from model)

Bounding in space

- how do animals use space and at what time scale ?

Decreasing spatial scale

hectares **SPACE** **continents**

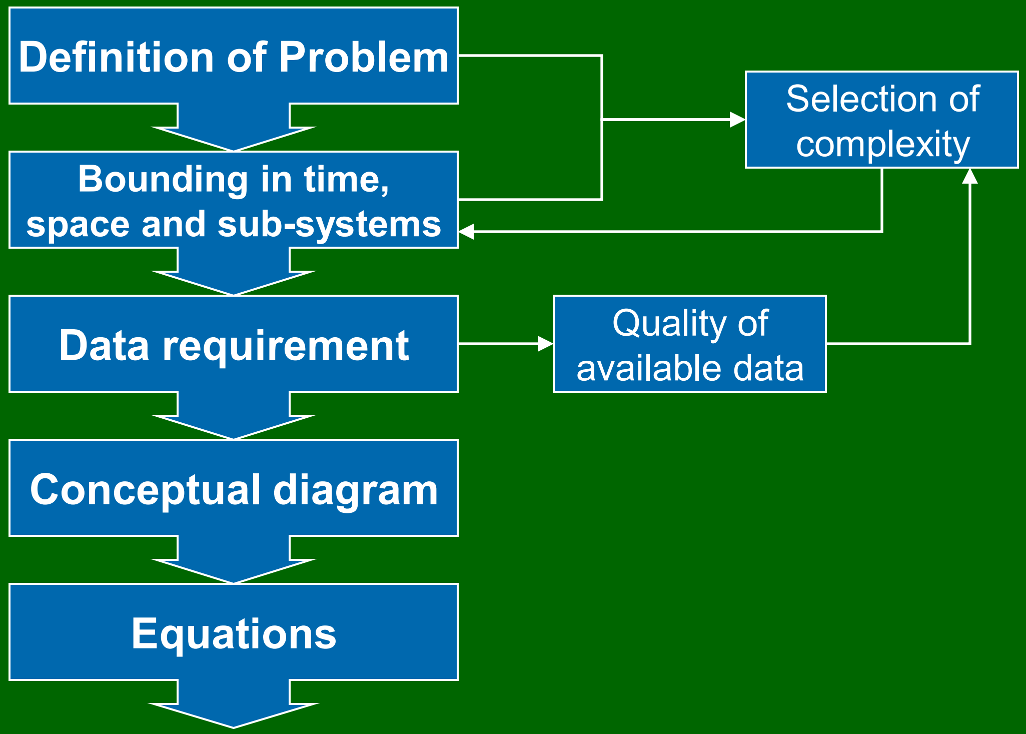


hours **TIME** **centuries**

Increasing time scale

processes

Bioenergetics & behaviour	Ranges & individual life histories	Population persistence	Metapopulations & evolution


Definition of Problem
Bounding in time,
space and sub-systems
Data requirement
Conceptual diagram
Equations
Selection of
complexity
Quality of
available data

Defining landscape-animal interactions

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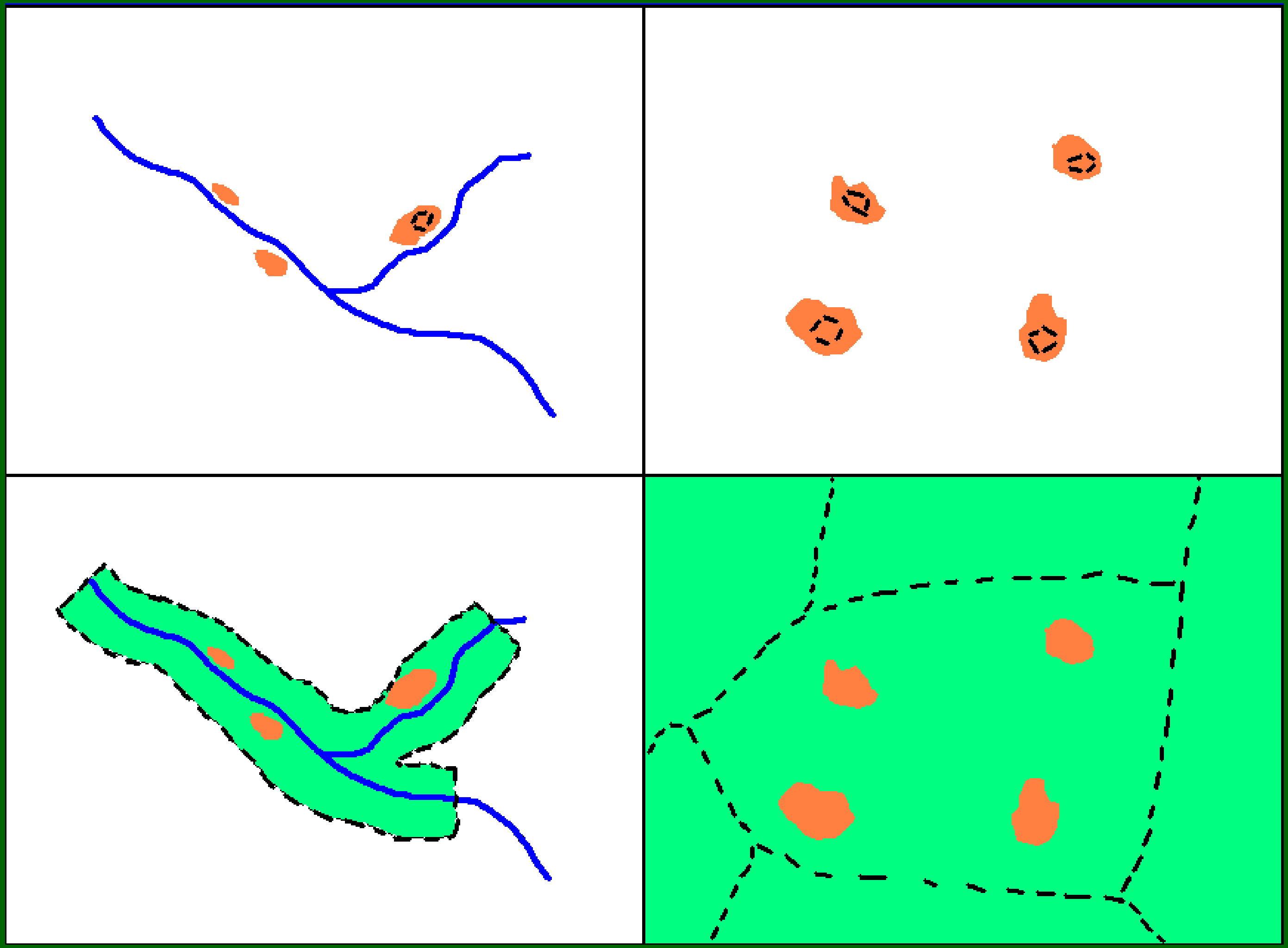
	Riparian	Non-riparian
Within habitat		
Across habitats		



Modelling individuals in landscapes

- as populations of individuals within blocks of habitat
- as individual ranges within blocks of habitat
- as individuals creating ranges across habitats

- So, what equations (=modelling approach) should we use ?

Selecting the modelling approach

- There are as many techniques as modellers
- Need to consider:

    type of state variables and

    are these discrete, continuous or categorical responses ?

    are they dynamic or static ?

    is system stochastic or deterministic ?

- The model selected determines the data requirements and the ‘equations’

What they do

- Broadly divided into:

    a) descriptive/static

    b) dynamic

Goals of descriptive models

- Generating hypotheses from observed phenomena
- Testing hypotheses concerning observed phenomena
- Survey of complex observed systems
- Simplification of observed systems
- Commonest are statistical

Static: statistical models

All based on quantifying variation in terms of :

RESPONSE = PREDICTOR(S) + ERROR

Collectively these are Generalised Linear Models

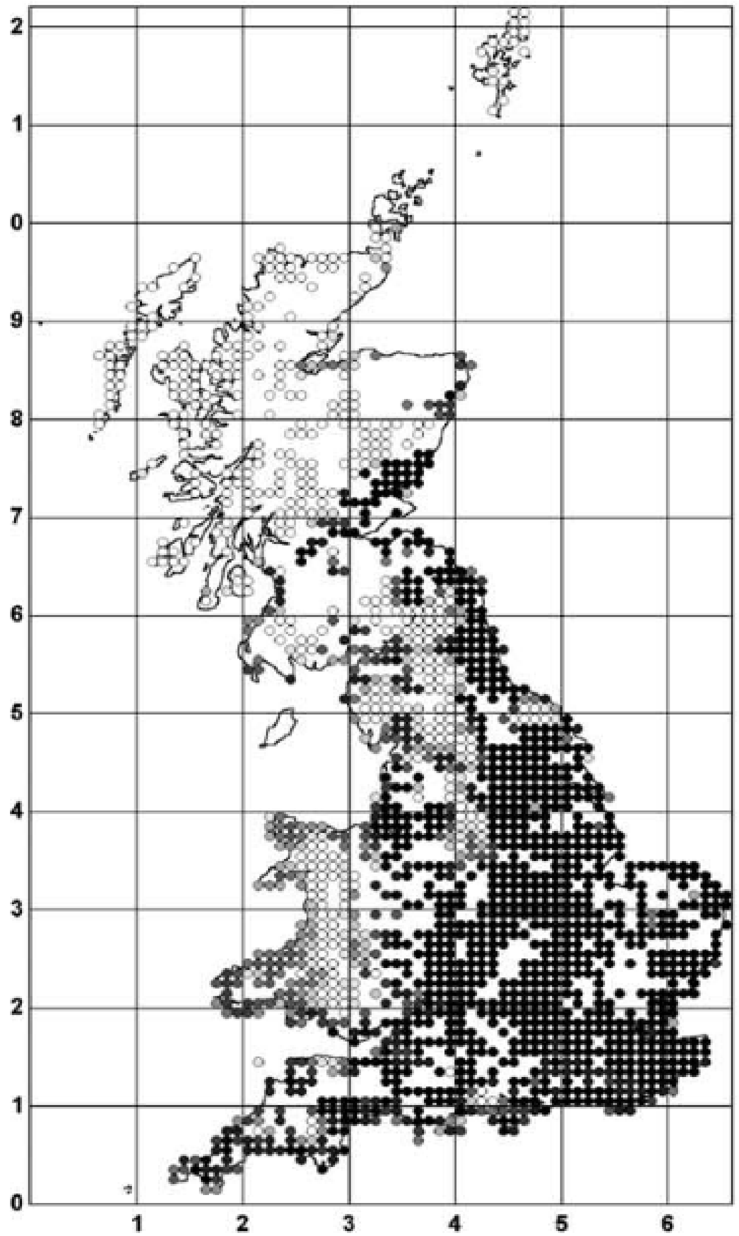
Modelling with GLMs

- identify suitable response and predictor variables
- identify suitable distribution for the error component of the model
- assess whether this model is appropriate

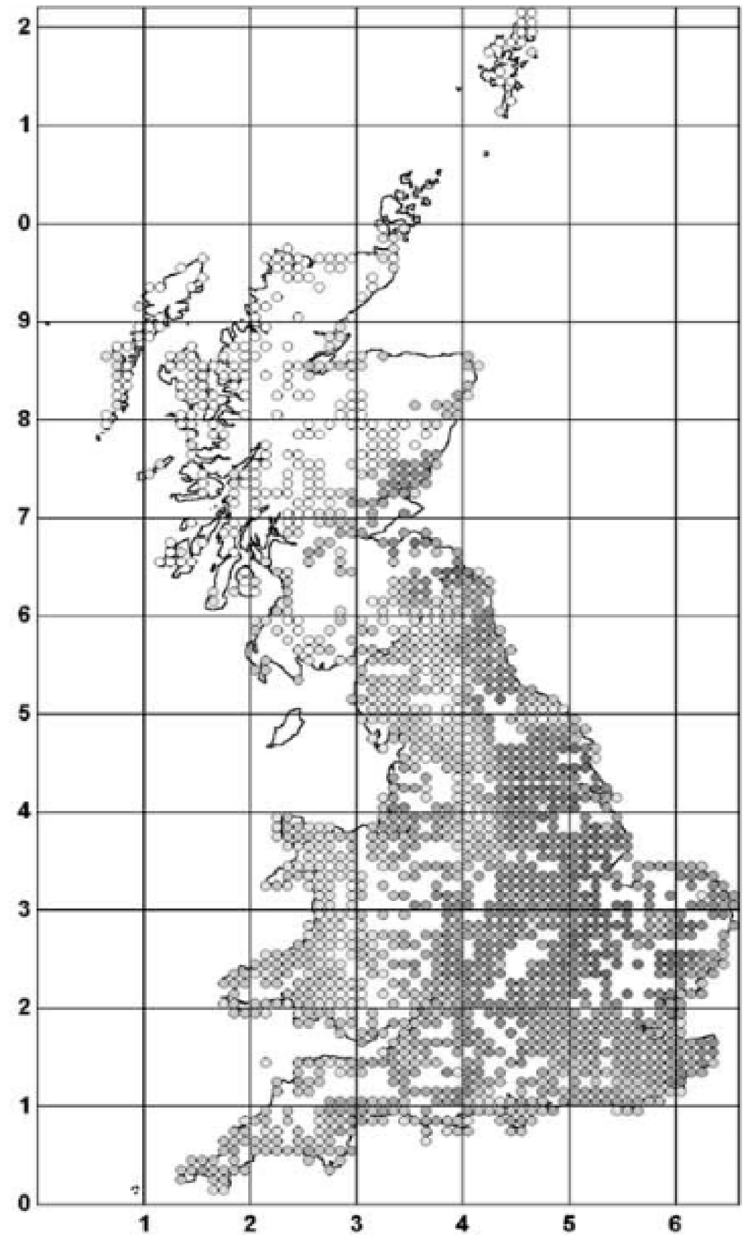
Land use variables and beetles

- Use recording Biological Recording information as response
- Land use and land cover as predictors
- Binomial error model
- Predict over whole of UK

Acupalpus dubius



Carabus nemoralis



Land Use GLMs

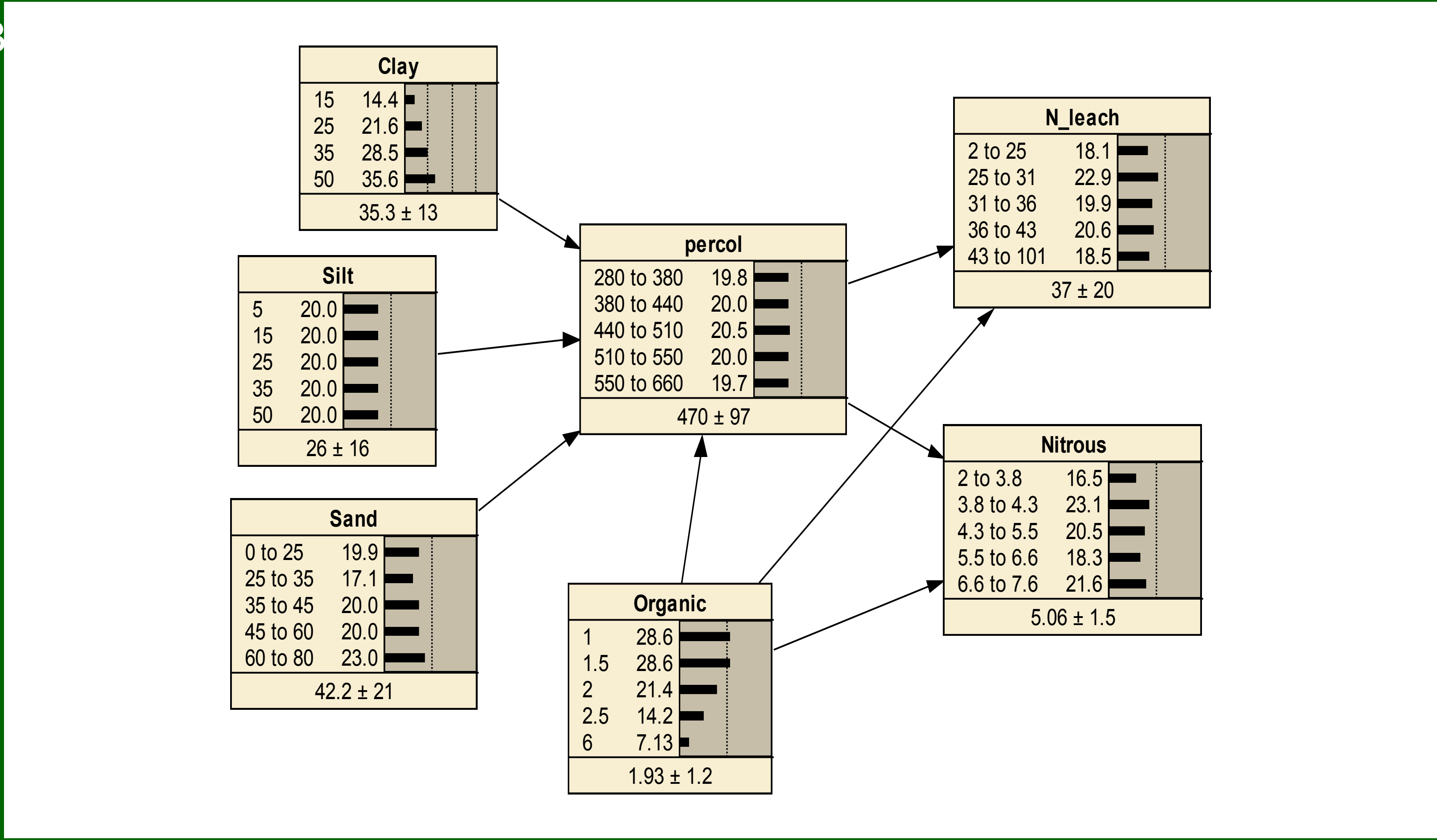
- They assume steady state conditions
- They assume you include all of the covariates of interest

- Whilst you can include time (eg harmonic regression) biological systems are adaptable, so covariates may change

They can be extended to Bayesian approaches…

- These can integrate ‘non formal’ knowledge into a quantitative framework
- Here we link agricultural management to ecosystem service provision

B


Clay
15 14.4
25 21.6
35 28.5
50 35.6
35.3 ± 13
Silt
5 20.0
15 20.0
25 20.0
35 20.0
50 20.0
26 ± 16
Sand
0 to 25 19.9
25 to 35 17.1
35 to 45 20.0
45 to 60 20.0
60 to 80 23.0
42.2 ± 21
percol
280 to 380 19.8
380 to 440 20.0
440 to 510 20.5
510 to 550 20.0
550 to 660 19.7
470 ± 97
Organic
1 28.6
1.5 28.6
2 21.4
2.5 14.2
6 7.13
1.93 ± 1.2
N_leach
2 to 25 18.1
25 to 31 22.9
31 to 36 19.9
36 to 43 20.6
43 to 101 18.5
37 ± 20
Nitrous
2 to 3.8 16.5
3.8 to 4.3 23.1
4.3 to 5.5 20.5
5.5 to 6.6 18.3
6.6 to 7.6 21.6
5.06 ± 1.5

E.g. linking agricultural management to ecosystem service provision

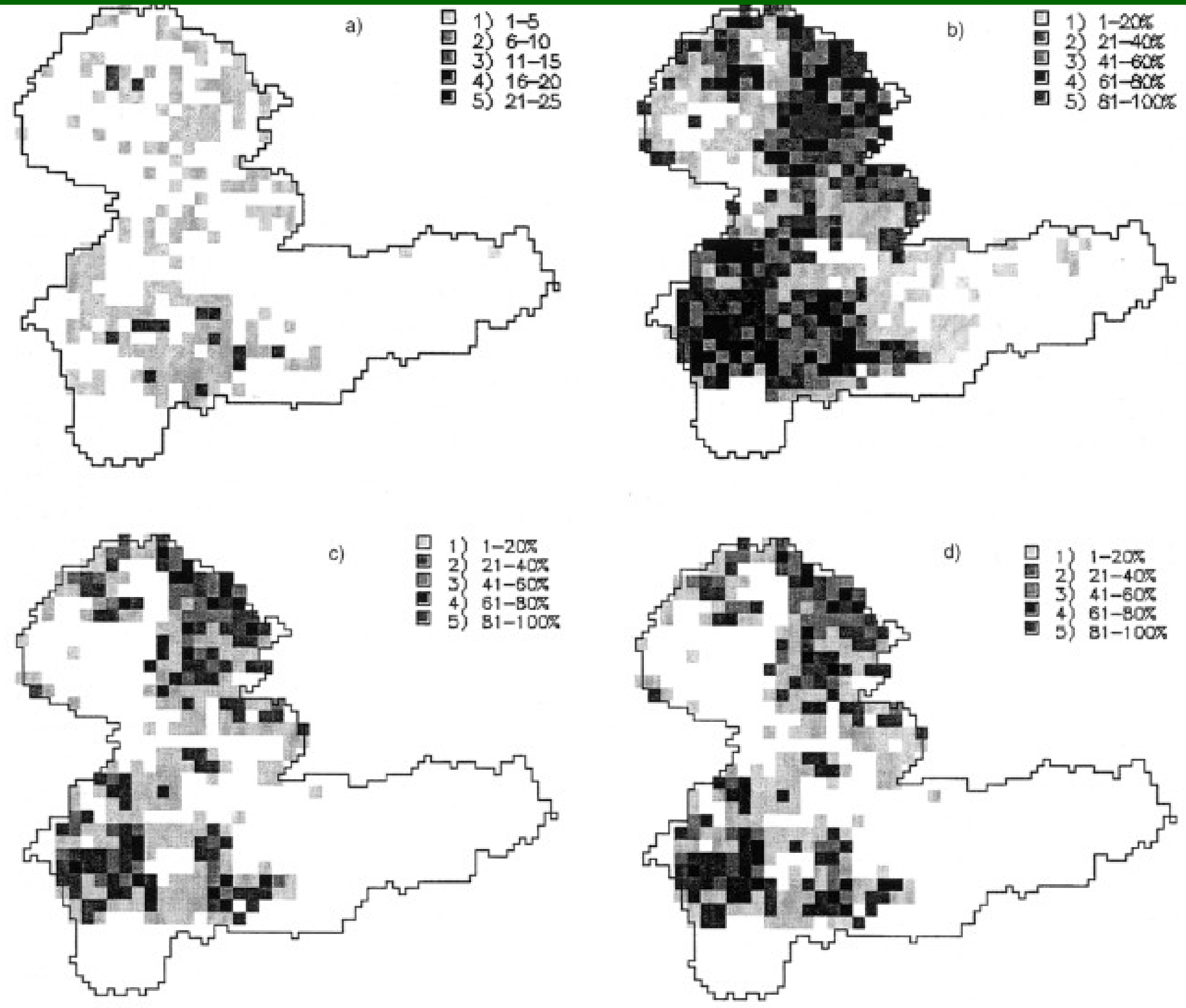


Fig. 5. Distribution of the snipe in the Tyne Catchment. Each square is 2 km × 2 km. a) observed number of pairs. b) predicted distribution with standard model, c) predicted distribution first set of altered conditional probabilities, d) predicted distribution with second set of altered conditional probabilities. Figures in b) to d) are probabilities (%).

Dynamic models

- simulate changes through time in discrete time (difference equations) or continuous time (differential equations)
- E.g. epidemiological and population models

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Our modelling example:

- Needs to be dynamic ~ we are dealing with human induced changes and a dynamic environment
- Needs to consider spatial and temporal heterogeneity

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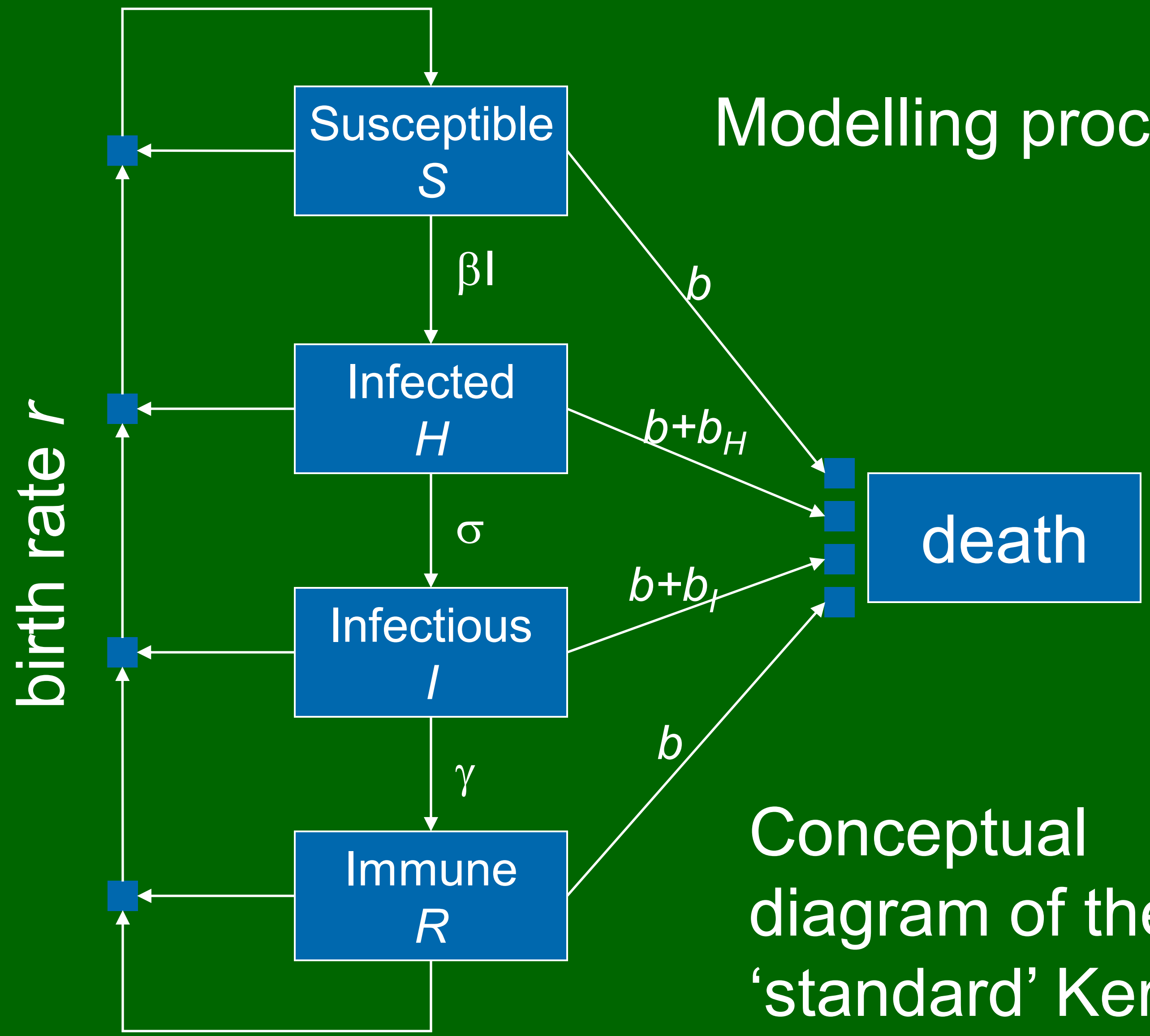
Differential versus Difference

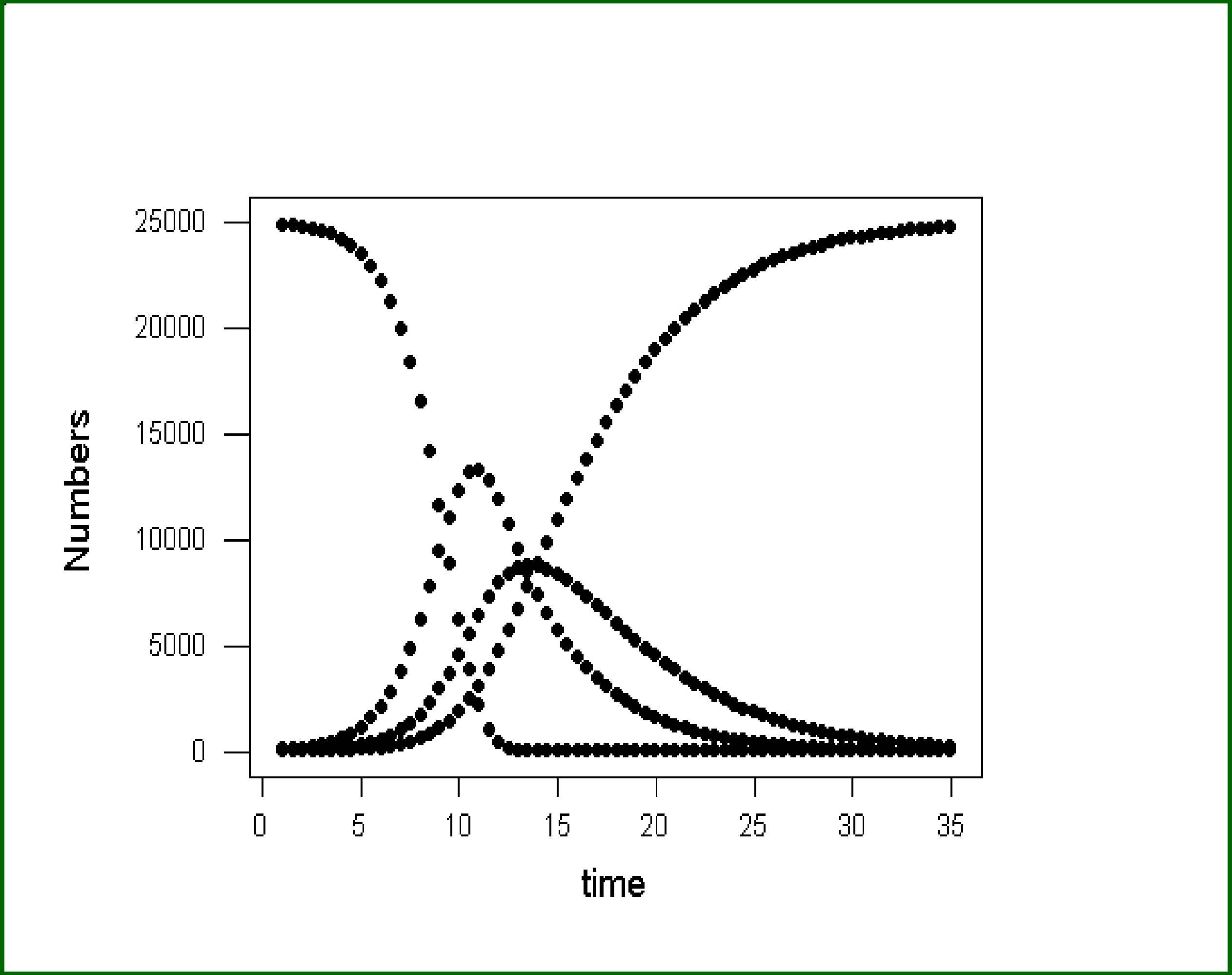
- Differential: models processes as rates
- Difference: models processes as discrete events

Modelling process



Conceptual diagram of the 'standard' Kermack-McKendrick model for disease

Plot of the solution of the Kermack – McKendrick model using data for measles

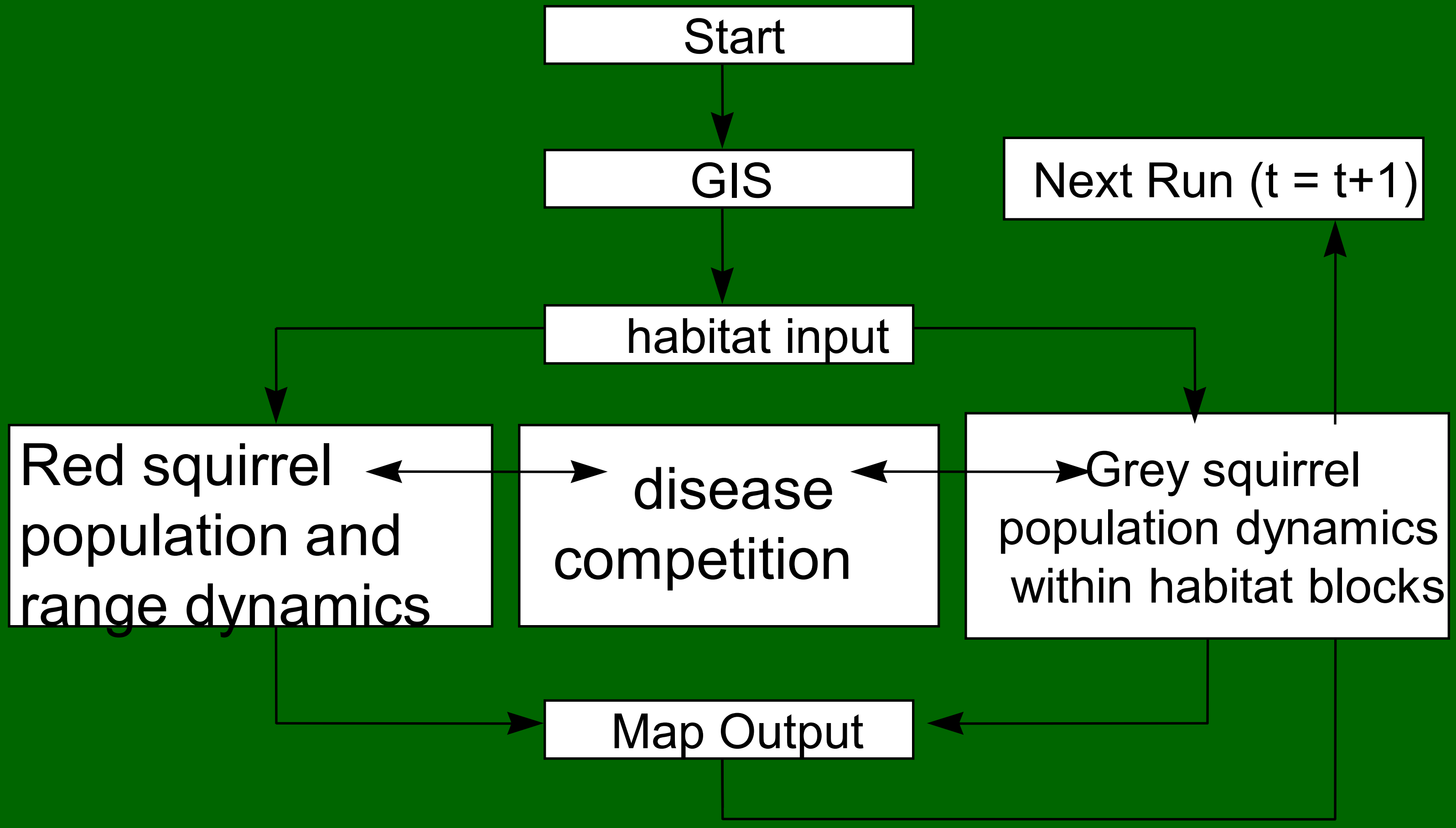


A **realisation** of the model for measles

Difference models

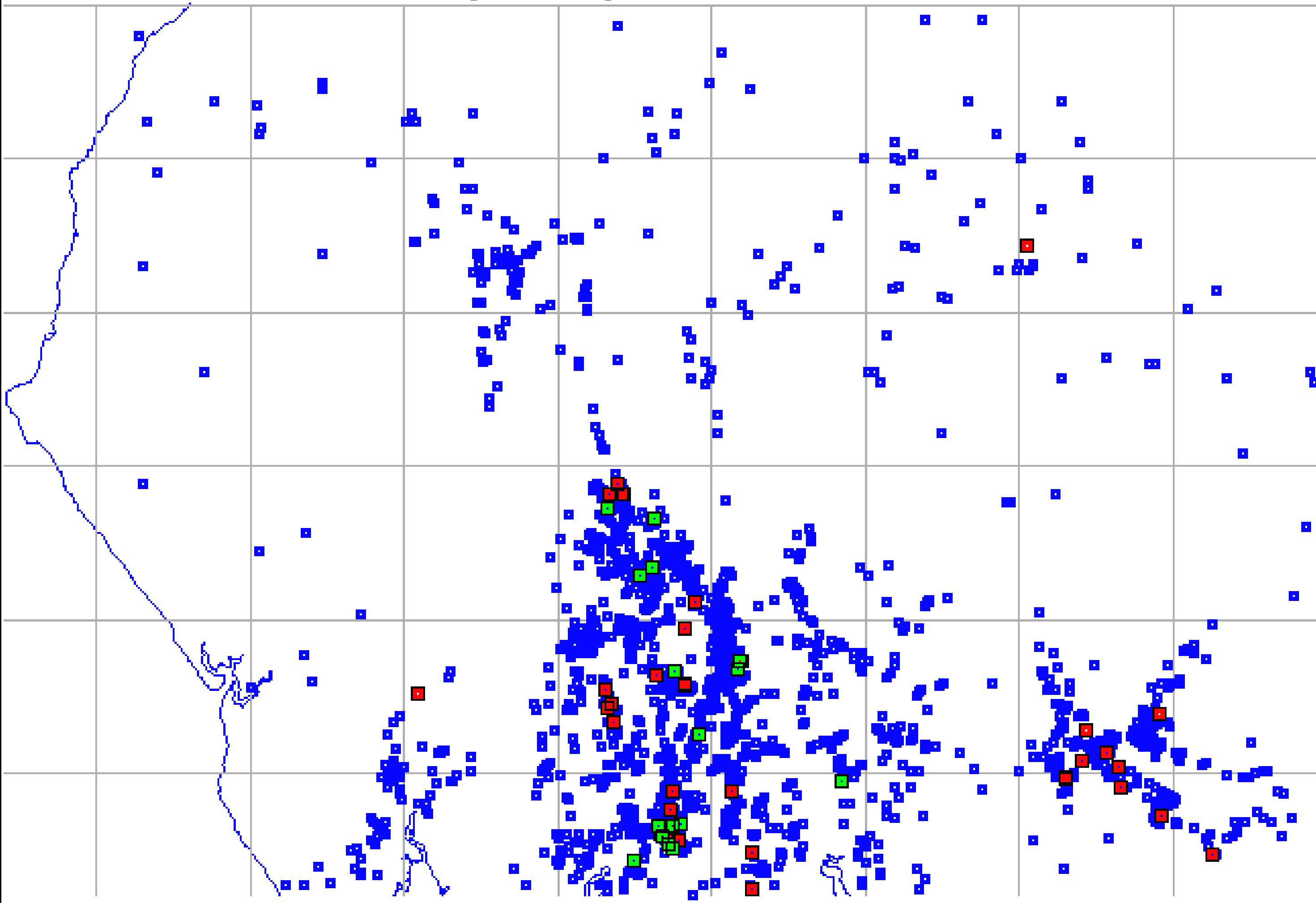
- Discrete event, more tractable computationally
- Cope with spatial and temporal heterogeneity (eg landscape and landuse)
- Cope with stochasticity in system components

Conceptual model of a spatially explicit simulation model for analysis of interactions between red and grey squirrels



GRASS 4.3 - Monitor: x1

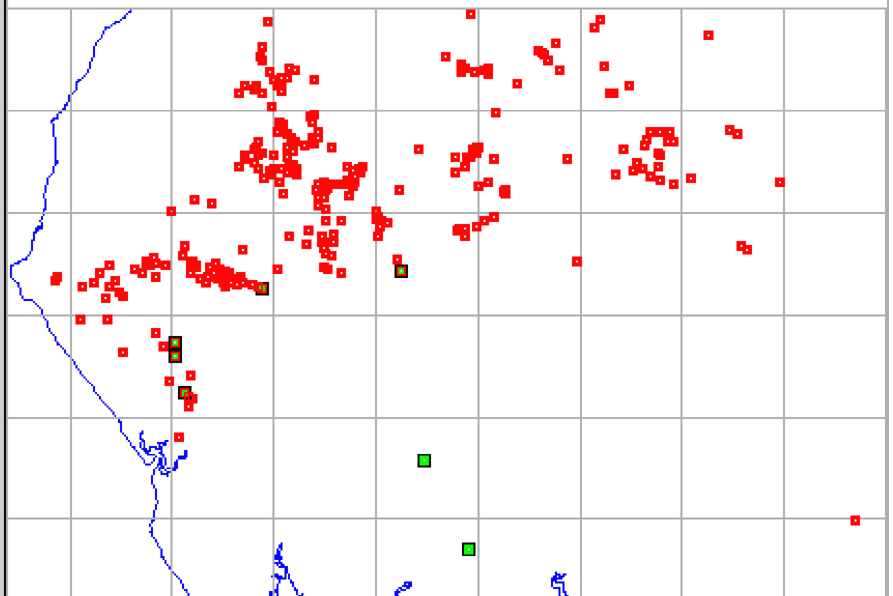
Observed grey squirrel expansion and incidence of parapoxvirus in Cumbria

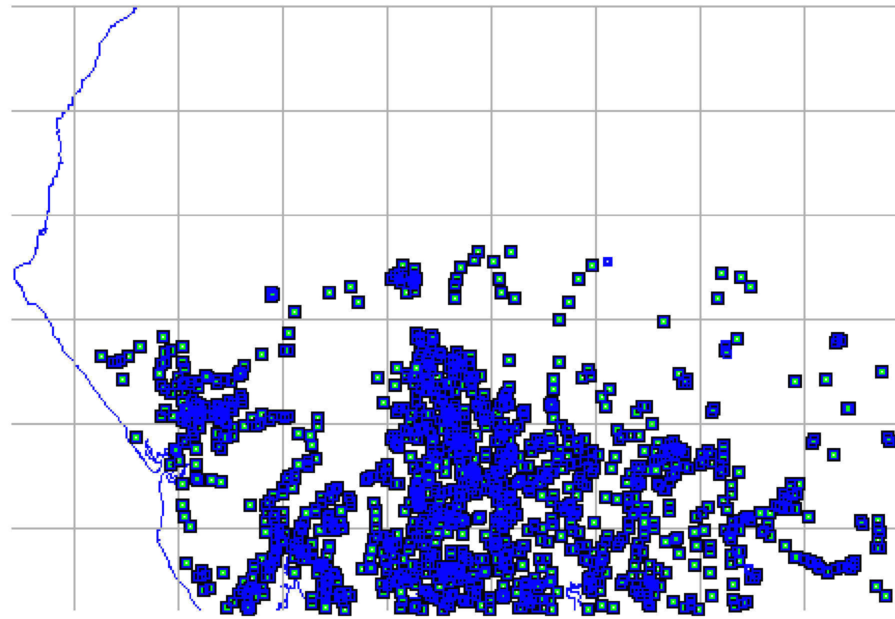


Grey **Grey with parapox** **Red with parapox**

GRASS 4.3 - Monitor: x1

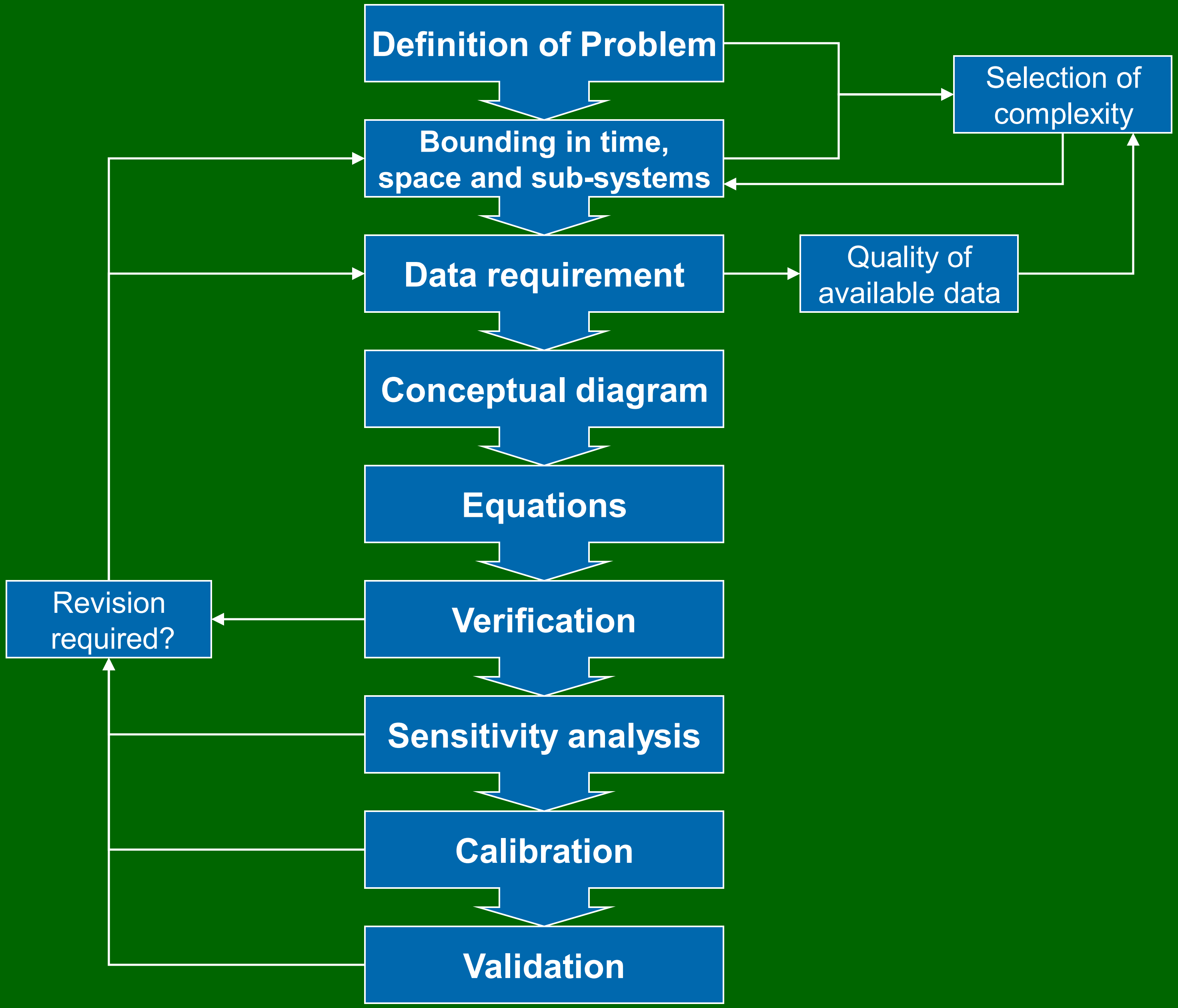
Simulation of incidence of parapoxvirus in red and grey squirrel populations in Cumbria





Red   Red with parapox

Grey   Grey with parapox


Definition of Problem
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Data requirement
Conceptual diagram
Equations
Verification
Sensitivity analysis
Calibration
Validation
Selection of complexity
Quality of available data
Revision required?

Verification, sensitivity analysis and validation

- Verification -- checks that the model is running within sensible bounds
- Sensitivity Analysis -- quantifies the impact of input parameters on the model output
- Validation -- compares model output with data not used to create model

Verification

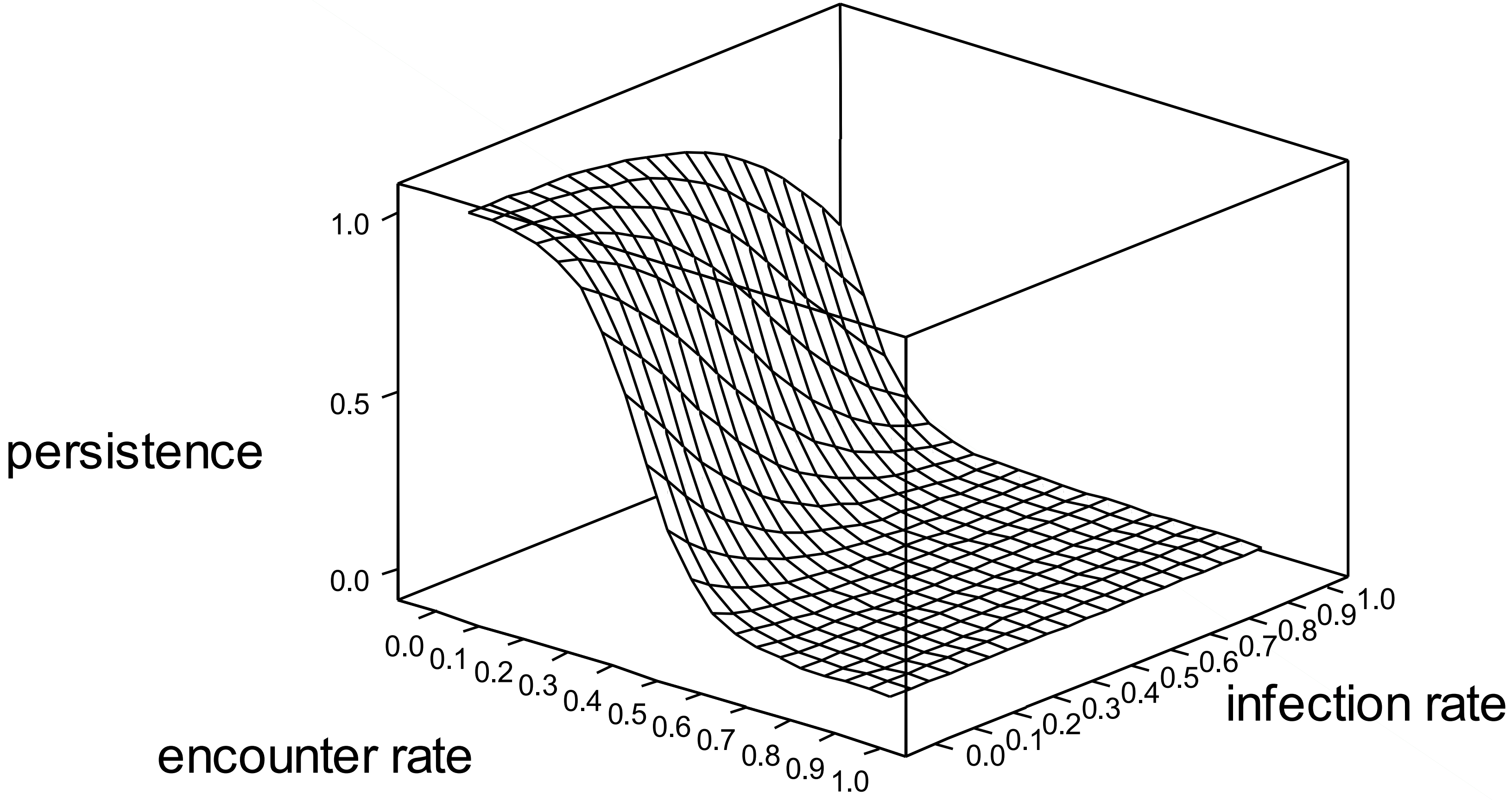
- Is the model generating garbage (e.g. more squirrels per ha than stars in the Milky Way, or negative squirrels)?
- Many errors here will arise from syntax as much as errors in model logic

Sensitivity Analysis

- Quantifying impacts of inputs on outputs
- Useful to know which variables are key in the model
- Guides us in identifying those variables for which we need accurate measures

Sensitivity Analysis

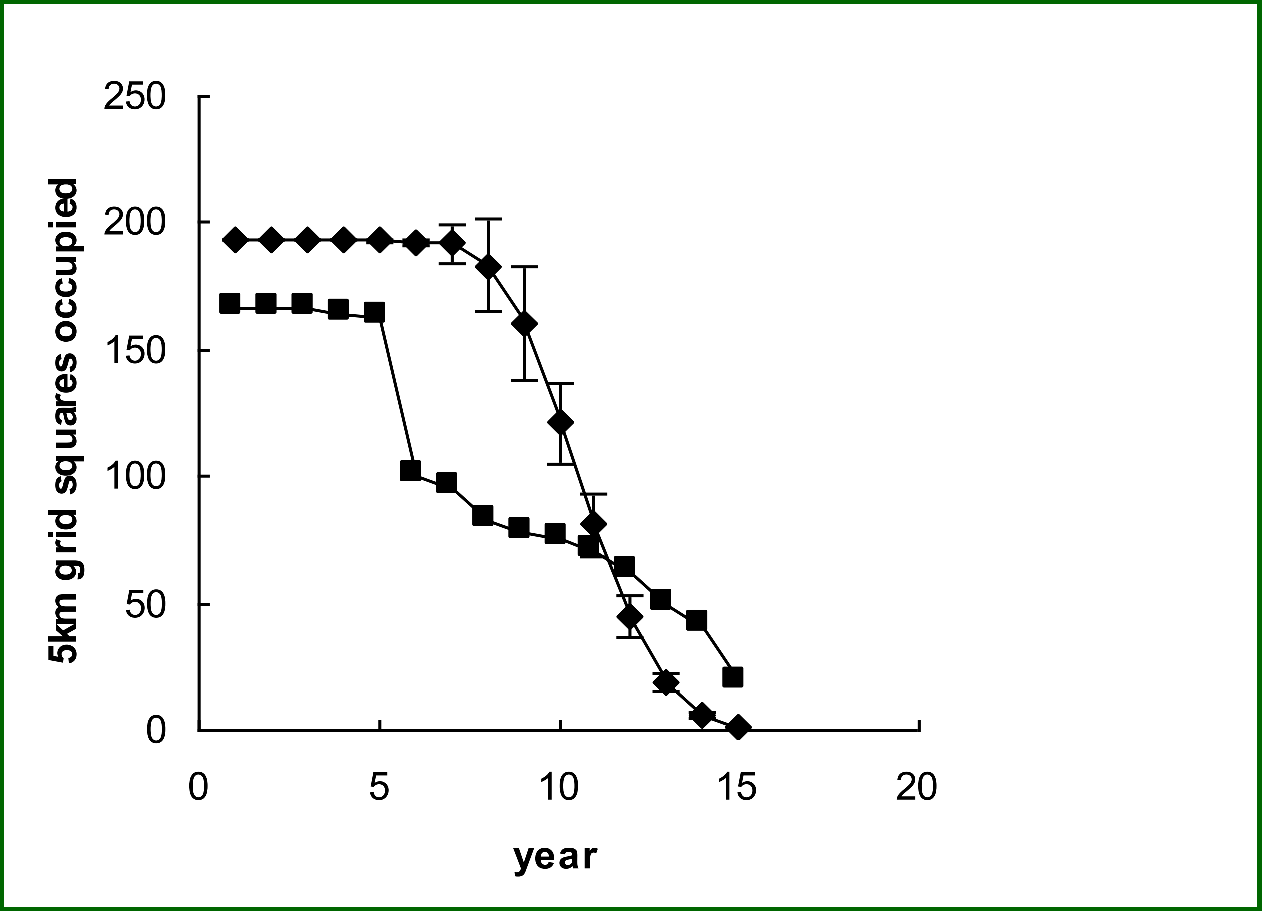
The impact of encounter rate and infection probability on red squirrel persistence in Norfolk



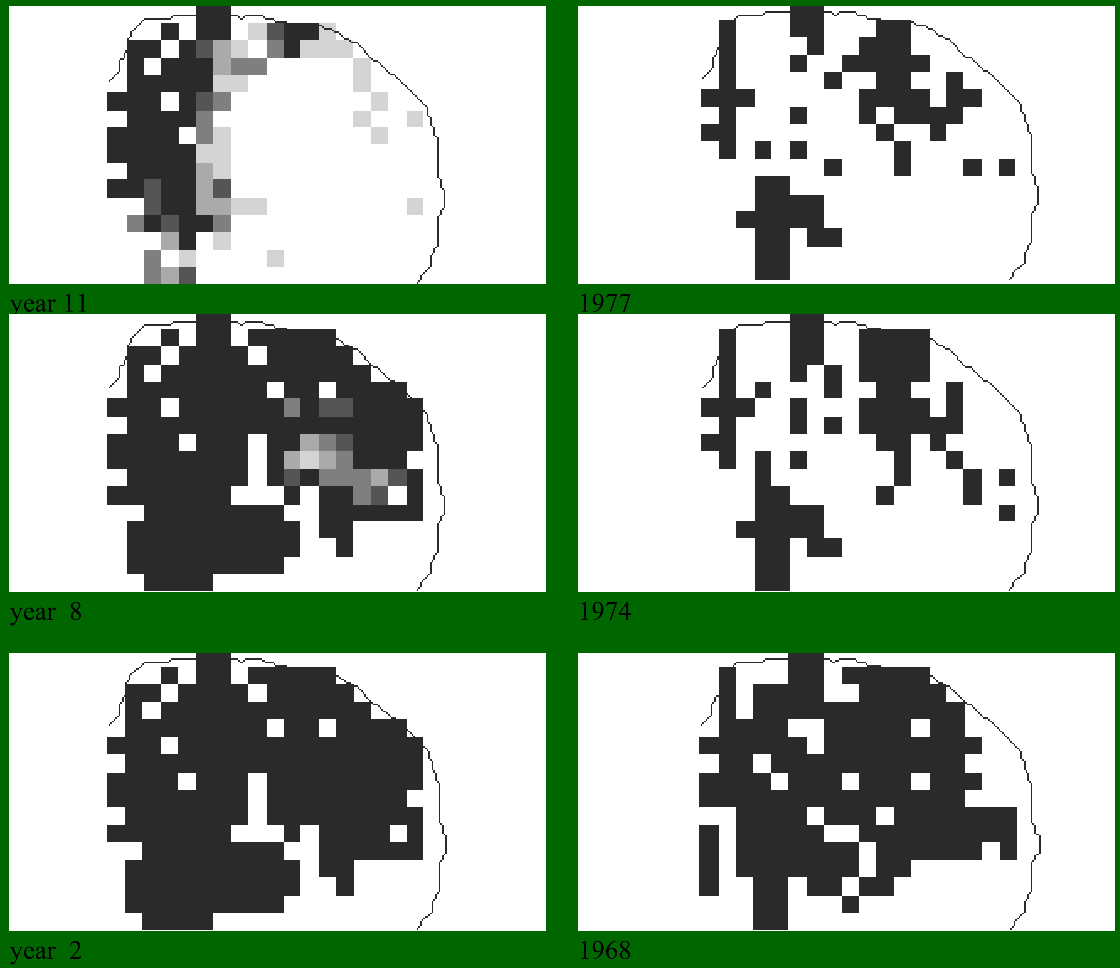
Validation

- Formal comparison of how the model performs in the context of data not used to create it
- Usually undertaken with a statistical method – although this can be problematic with spatial models
- Some argue a model is always wrong and cannot be validated.

Validation: decline in red squirrels in Norfolk as predicted by disease model and as observed



Validation: predicted and observed decline of red squirrels in Norfolk



We now have a model

- Take home messages before moving onto considering modelling land use systems.

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Messages for designing modelling approaches to investigate land use

- horses for courses
- all assume environmental systems can be bent to suit the mathematics used (a defect)
- care needed in selection of modelling approach (don't listen to mathematicians)
- care needed in selection temporal and spatial scales (use environmental and biological knowledge)

Interdisciplinary Decision Support

Definition, implementation & some lessons learned

- Evaluation of the social, economic and environmental consequences of policies associated with land use through the use of numerical modelling approaches

1. **Large scale** (catchment level); multi-disciplinary end-users
2. **Small scale** (field level); farm-managers and environmental consultants target end-users

Large-scale

- NERC-ESRC Land Use Programme ("NELUP")
- Was applied to range of issues proposed by ESRC/NERC
- 1989 -1995 £1.2 million (ca 60 man-years)
- Catchments of Rivers Tyne (mixed) and Cam (intensive arable)
- to develop a Decision Support System (DSS) that integrated models for evaluating the ecological, economic and hydrological consequences of land use change

Issues in integration

- Speaking the same language
- Reconciling numerical and qualitative approaches across disciplines
- Reconciling spatial and temporal processes across disciplines
- Minimising the impacts of compromise between disciplines

Optimal modelling approaches

- disciplines adopt approaches that address their system processes best but may be difficult to integrate:

i) water: continuous, process, analytical models (eg finite difference methods)

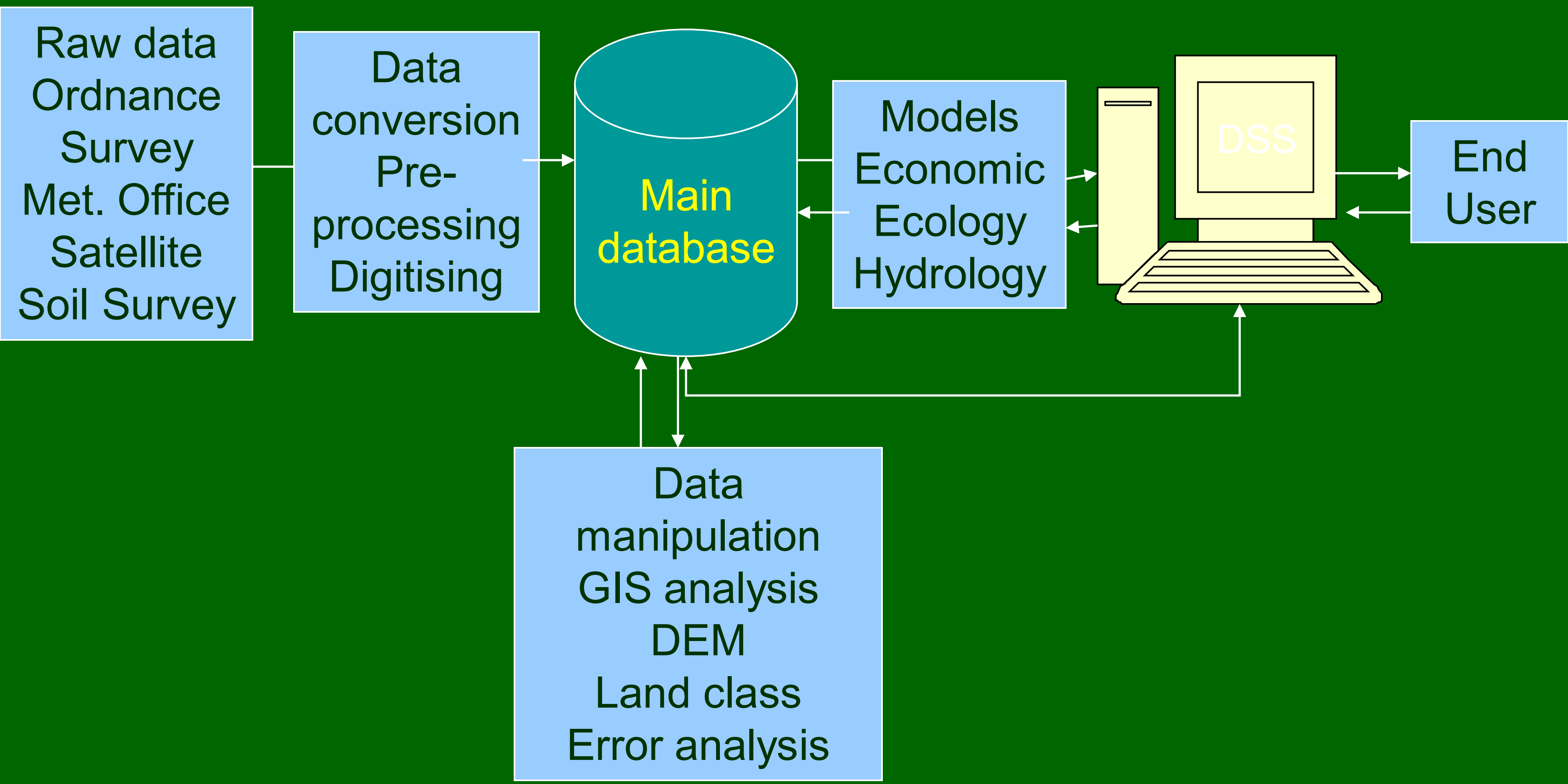
ii) ecology: pseudo-continuous population dynamic models (eg IB models)

iii) economics: optimisation (eg linear programming)

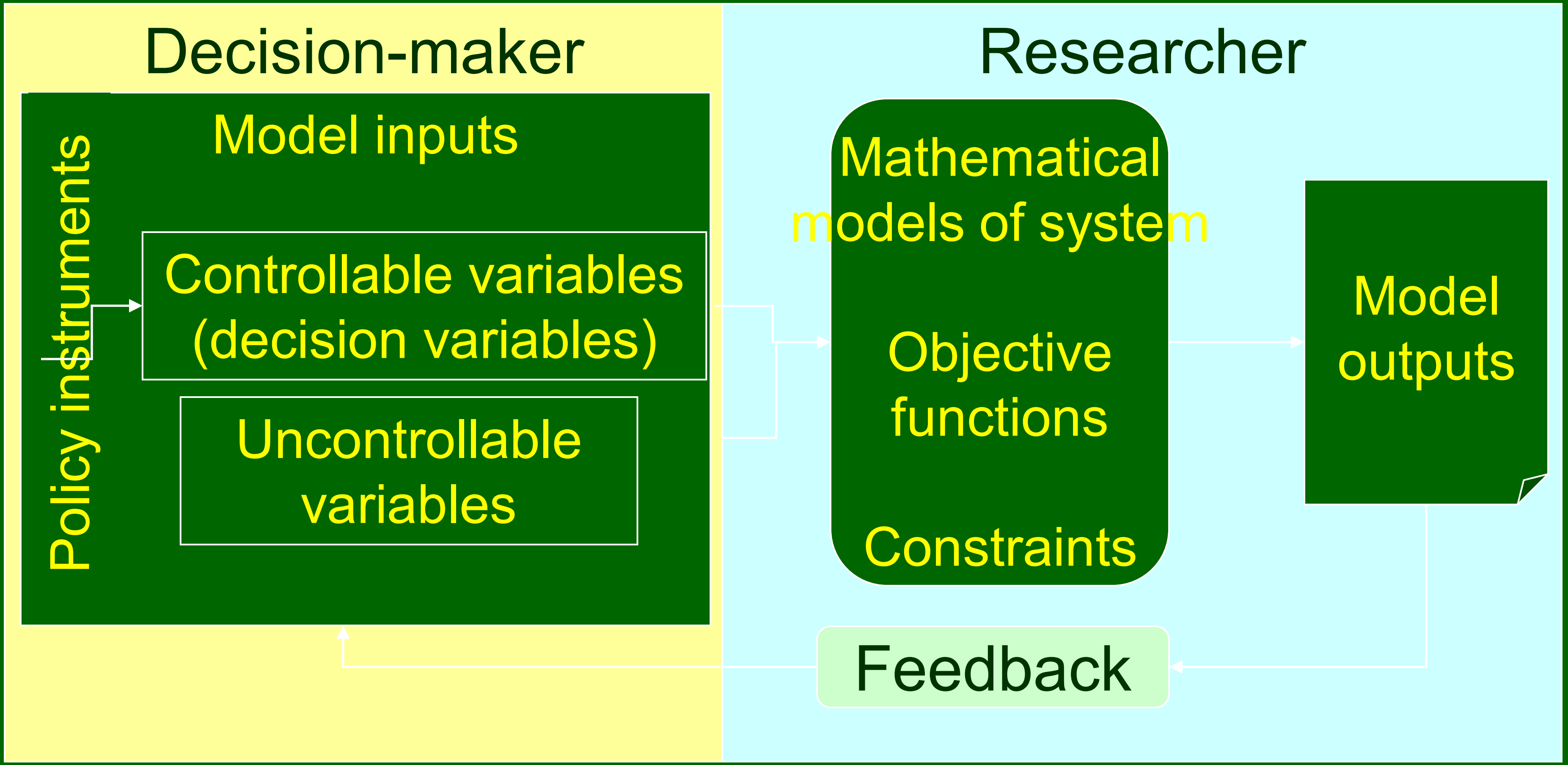
Issues of reconciliation

- Development/use of models to allow communication across disciplines (eg EPIC for linkages between economics and hydrology)
- Choice of sub-optimal models (ecology with economics; use of associative models in ecology)

Data flows within NELUP DSS



NELUP Decision Support System



Decision-maker to researcher (and back again?)

Some NELUP examples

- Integrated models meant changes in inputs for one component affected other two
- Decision-makers assumed to primarily alter economics: subsidies, farm costs, farm prices etc.
  - Knock-on effects on grazing regimes, fertiliser inputs
  - Vegetation patterns, associated wild animals
  - Changes to hydrological patterns, water and contaminant flows
- e.g. Reduced agri-economics leads to reduced sheep grazing in uplands: impact on vegetation and birds…

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Project-specific use of DSS

- Proposed river corridor scheme near Cambridge: intensively managed River Cam catchment
- Scenarios with river 'buffer zones' of different sizes; taking land out of intensive agriculture
  - Protection of in-stream water quality, reduction in sediment run-off, fertiliser contamination etc.
  - Buffer strip beneficial, but impacts depend on local denitrification rates as well as width of buffer strip
  - Ecological benefits, especially vegetation and birds
  - Economic impacts; reduction in profits for farmers due to less land, lower intensity production

What was wrong with it ?

- NELUP used steady state ecological models - reconciling economic time and ecological time was not possible
- Ecological models were associative - (did not simulate processes)
- Ecologically spatially inarticulate; a compromise driven by the economics
- Hydrological models data-hungry and CPU consuming (batch mode; separate server)
- Individual models tested (‘validated’) in isolation; how reliable were predicted overall scenarios when models integrated?

Stakeholder/end-user issues

- Management via a fairly remote Executive Committee \ Review Board during most of project
- End-users were only included NELUP at late stage
- End users should be involved from the beginning - they should be integral to the development and design

Lessons from NELUP & other systems

- providing integration across disciplines is a key to success with compromise inevitable (especially on spatial / temporal scales)
- time must be spent learning the ‘language’ of each others’ disciplines in order to undertake effective dialogue
- try to avoid compromises that lead to sub-optimal modelling strategies
- ensure effective and regular communication between modellers
- identifying users/stakeholder is critical (most models developed in NELUP were never used); and involve them formally throughout the project life-cycle

Suggested modelling agenda

- develop systems that model at fine scale
- increased computing power allows greater use of dynamic, individual-based \ agent-based models rather than associative methods
- develop meta-models to synthesise output from fine scale models for different types of end-user
- use qualified software developers if major programming tasks likely to be needed (especially for GUI implementation)