MODELLING POPULATION DYNAMICS: DENSITY STRUCTURED MODELS

Rob Freckleton
University of Sheffield

CHALLENGES FOR APPLIED ECOLOGY

- Climate change

- Sustainable harvest

- Invasives

- Pest management

Average of all IPCC Models: Temperature Change in 2070
IPCC SRES Scenarios a2 (left) und b2 (right)

-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 [Deg.C]
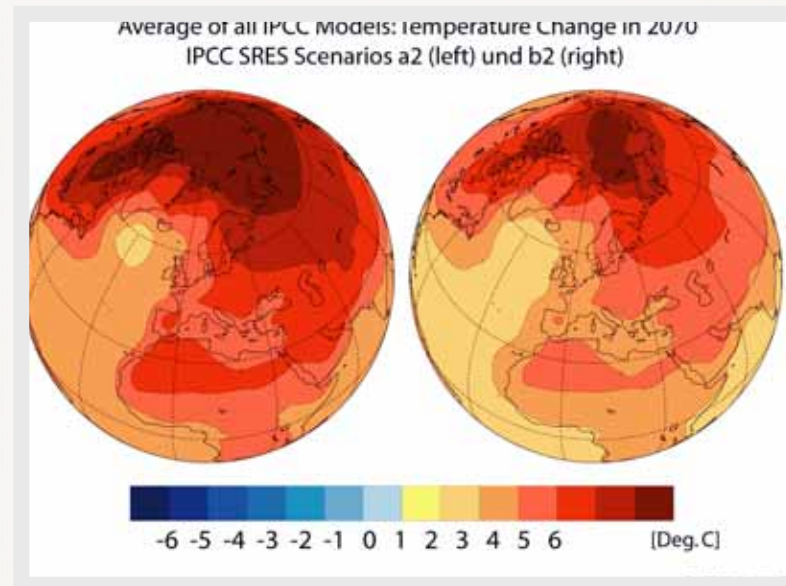
POPULATION MODELLING

- Biodiversity & GM crops

- Infectious diseases

- Single population management

TALK OUTLINE

- **Modelling Population Dynamics for Applications**

  - Problems with data

  - Problems with models

  - Density-structured models

    - Formulation

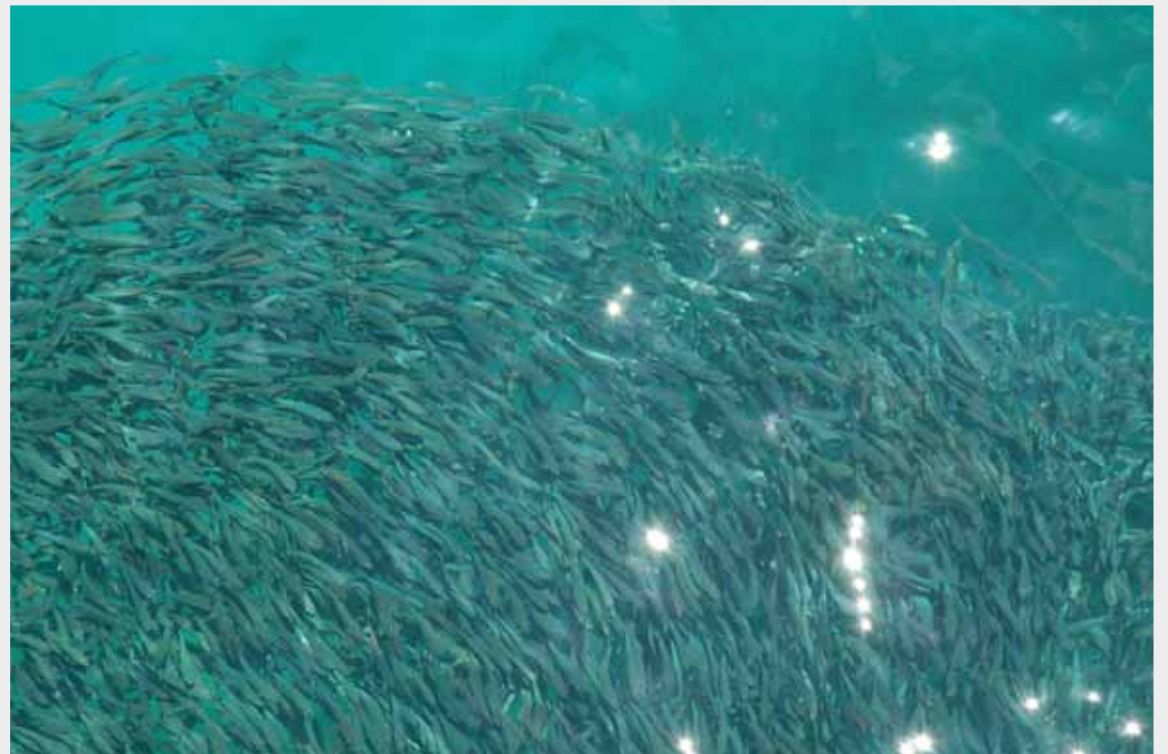   - Application

DEMOGRAPHIC MODELS

- State variable is N(t)

- $f(N)$ measures competition, density-dependence etc.

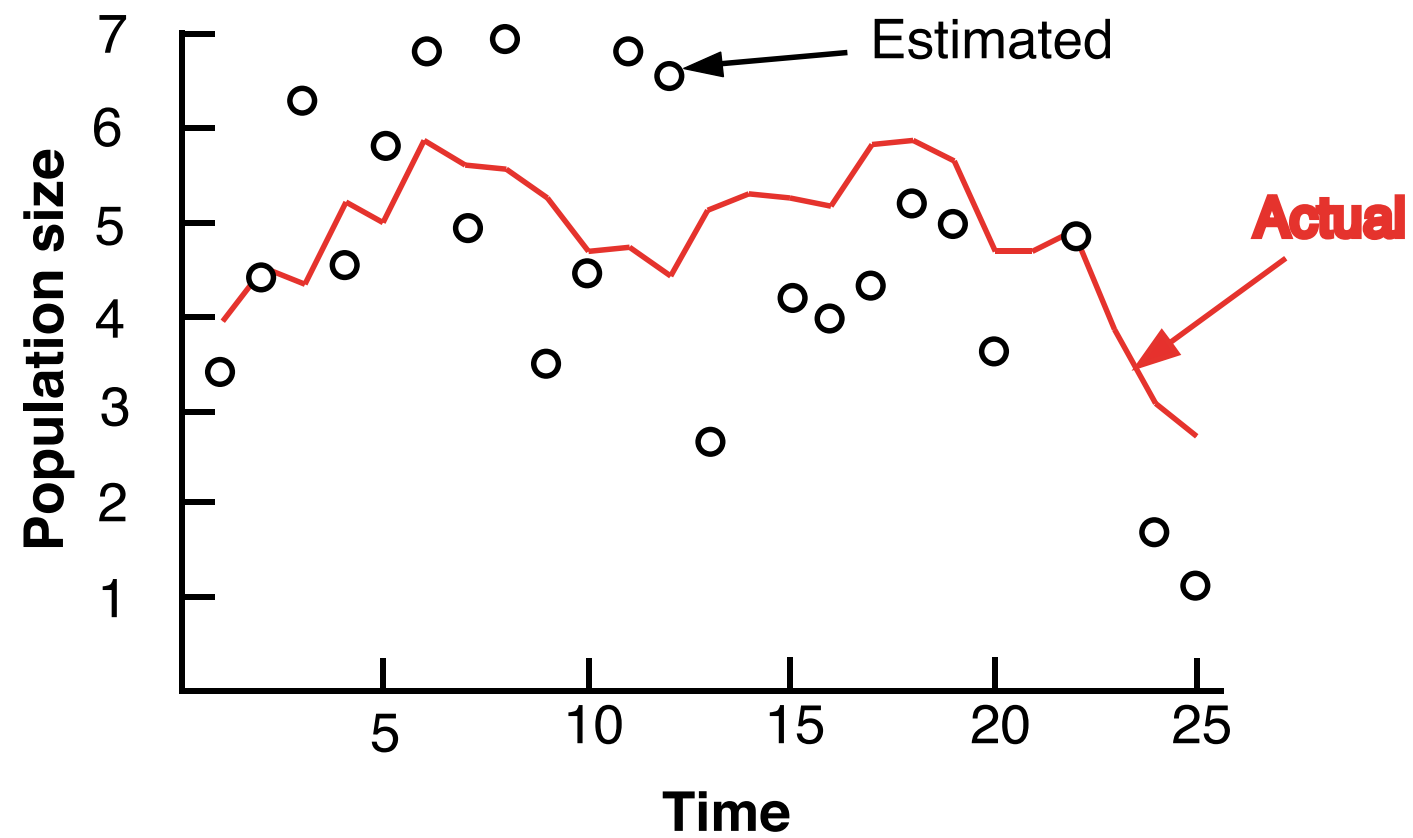- λ is low density population growth rate

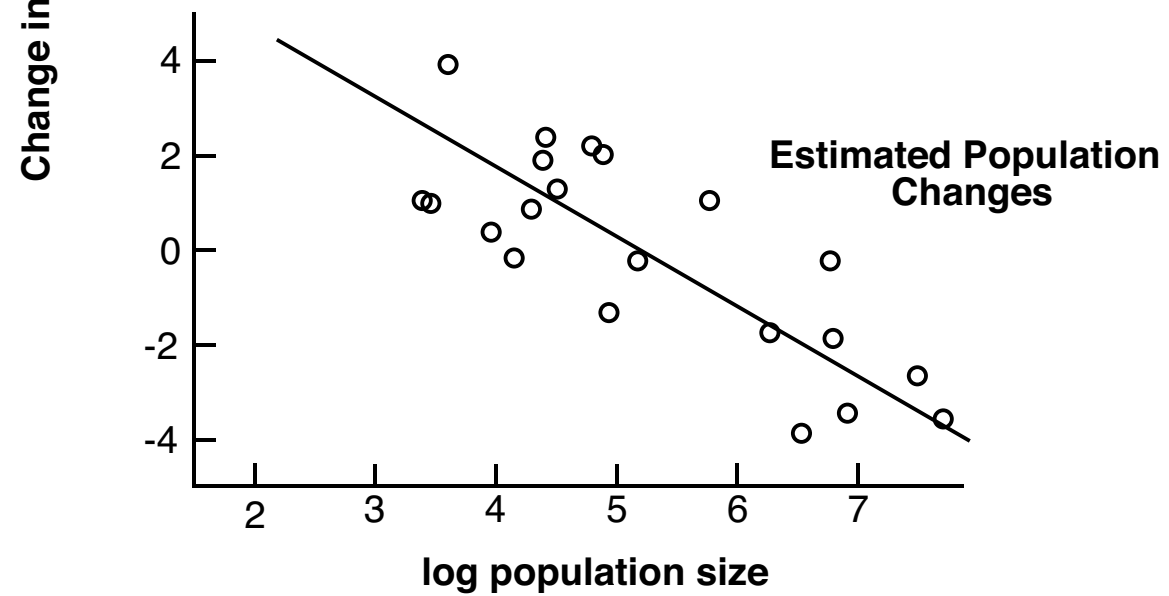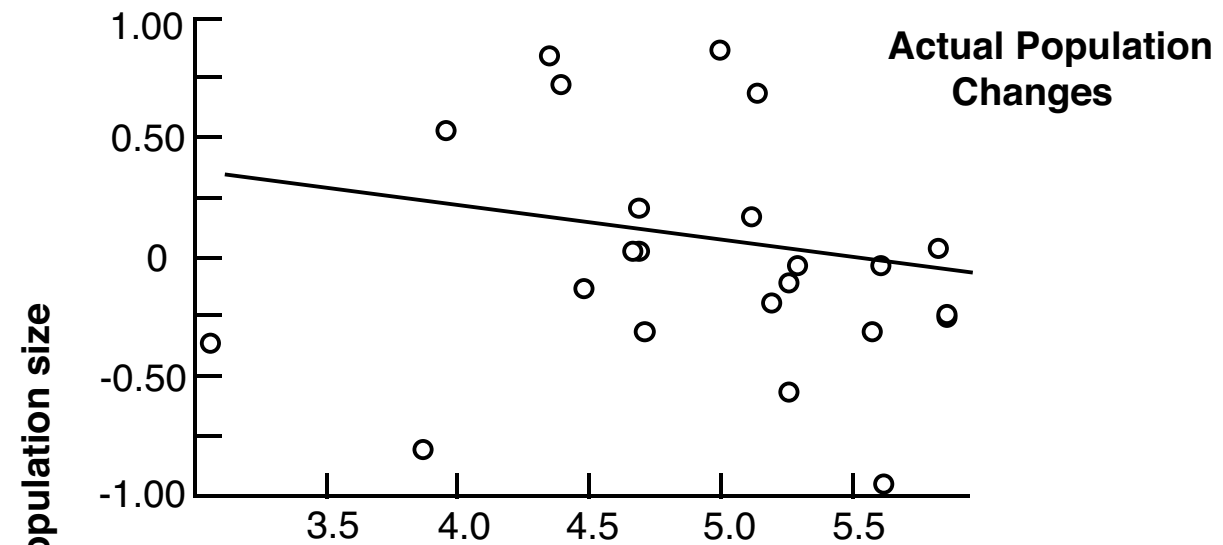$$N(t+1) = \lambda N(t) f[N(t)]$$

PROBLEMS WITH DATA

MEASURMENT ERROR

- Ecological data contain error

- Errors of measurement

- Estimation error

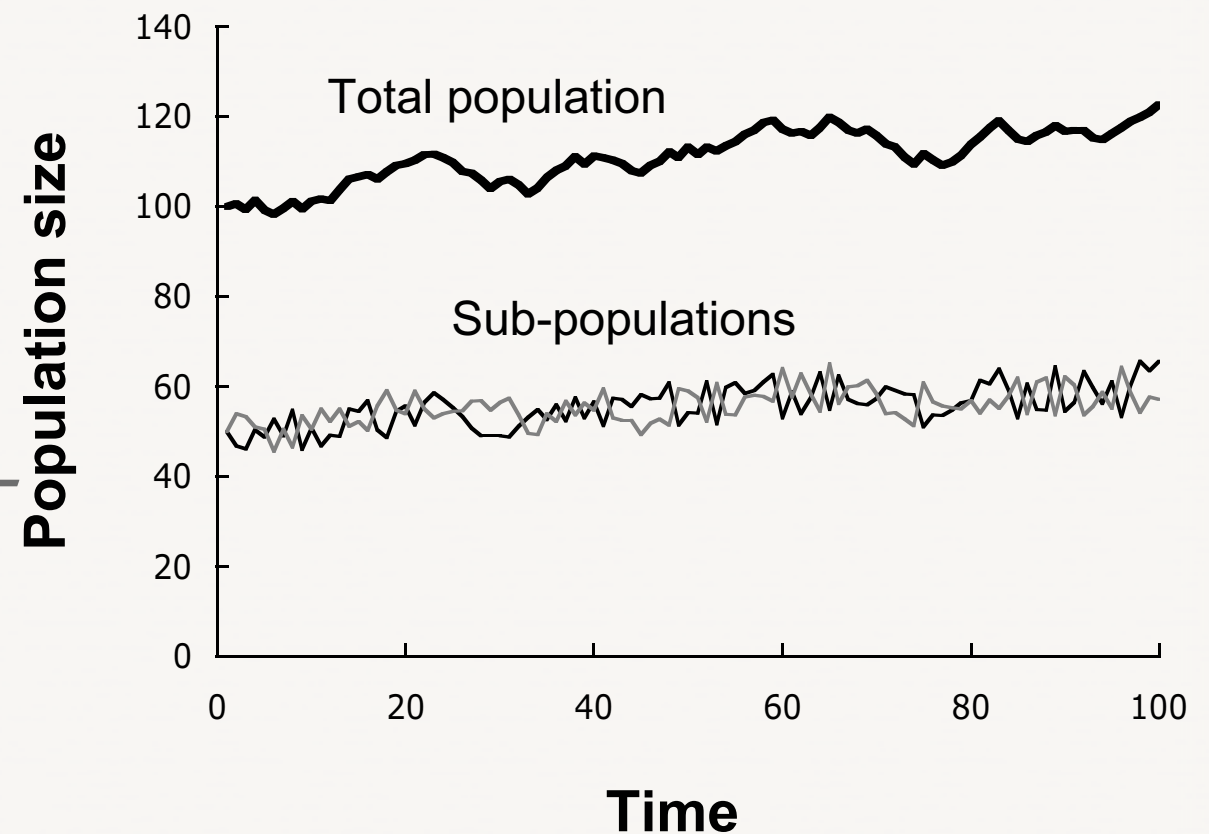# SPURIOUS DENSITY-DEPENDENCE

SPURIOUS DENSITY-DEPENDENCE

CLOSED POPULATIONS

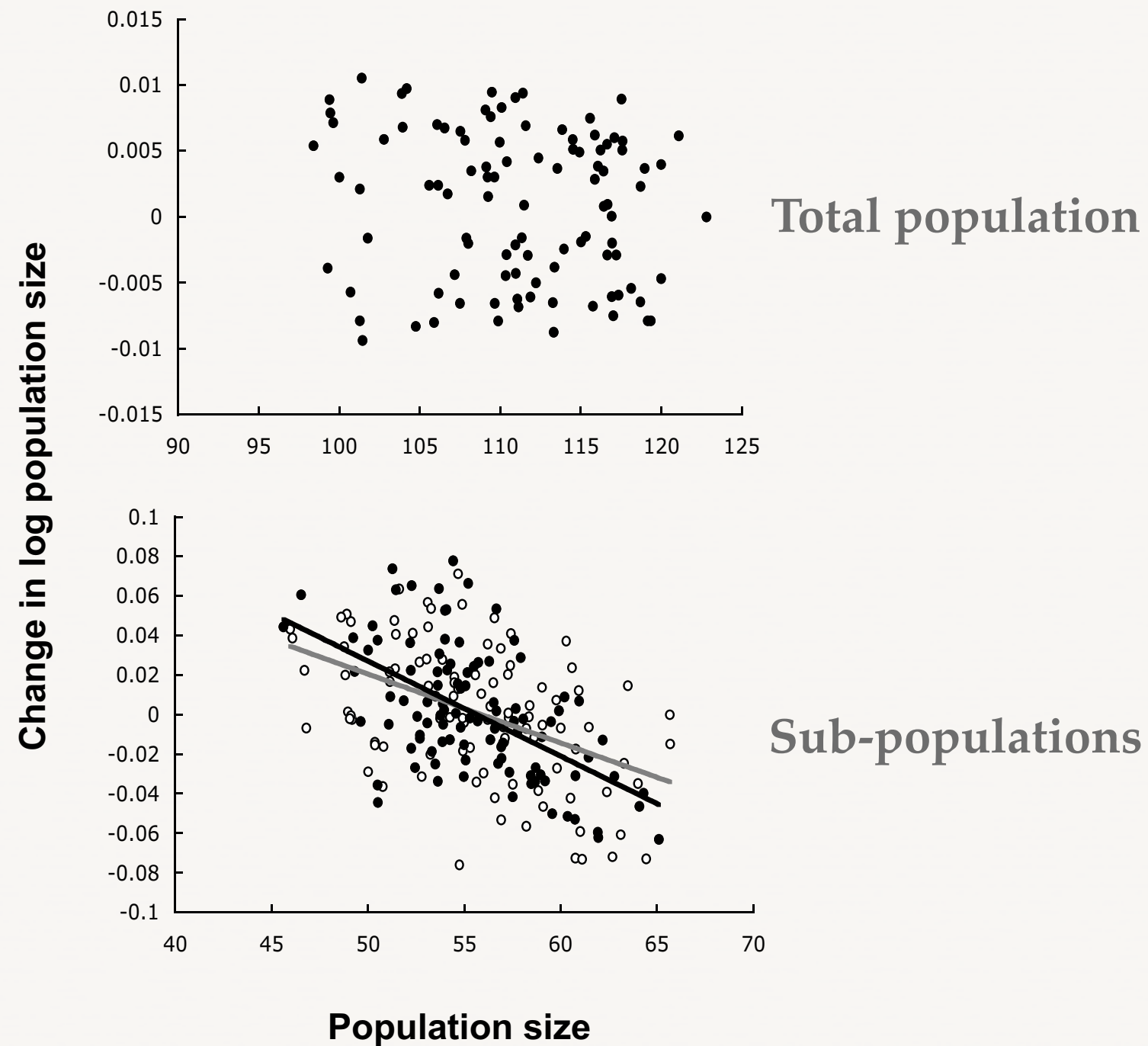- Populations are not discrete

- Movement into and out of populations is common

DYNAMICS OF UNCLOSED POPULATIONS

- Total population composed of two sub-populations

- Small amount of movement between sub-populations

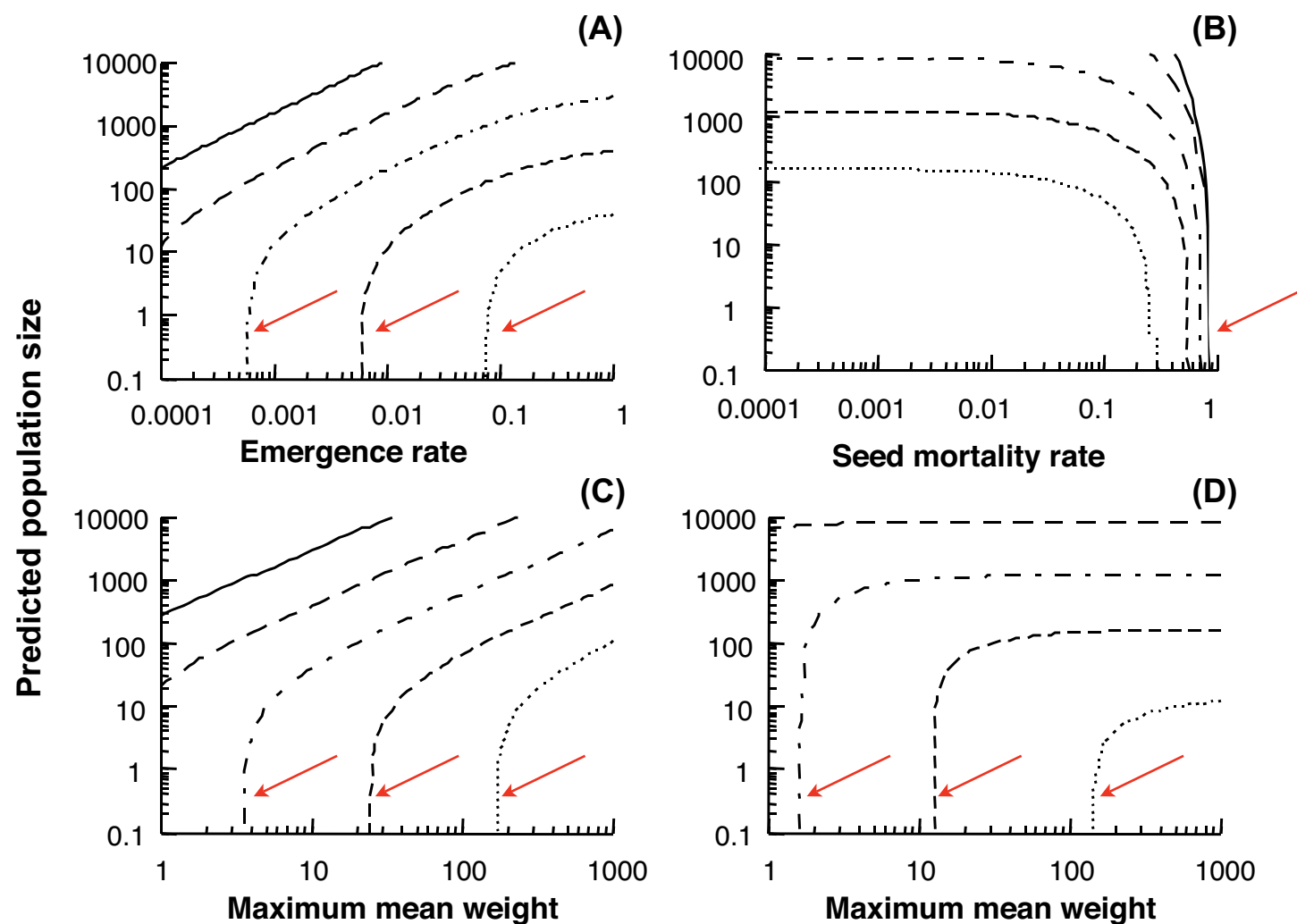- No density-dependence in total population

SPURIOUS DENSITY DEPENDENCE

SOLUTIONS

- Randomisations

- Likelihood

- Simex

- State-space models

All require census error to be estimated

PROBLEMS WITH DEMOGRAPHIC MODELS

NUMERICAL INSTABILITY

Models are frequently numerically unstable near to extinction boundaries

CONSEQUENCES

- Model may be wrong?

- Quantify parameter error

- Alternative model formulation?

DENSITY-STRUCTURED MODELS

DENSITY-STRUCTURED MODELS

- State variable is **N**(t)

- **N** is a set of ordered density states

- **T** models transitions between states

- Model is empirical

$$\mathbf{N}(t + 1) = \mathbf{T}.\mathbf{N}(t)$$

Continuous Density Stochastic Model:
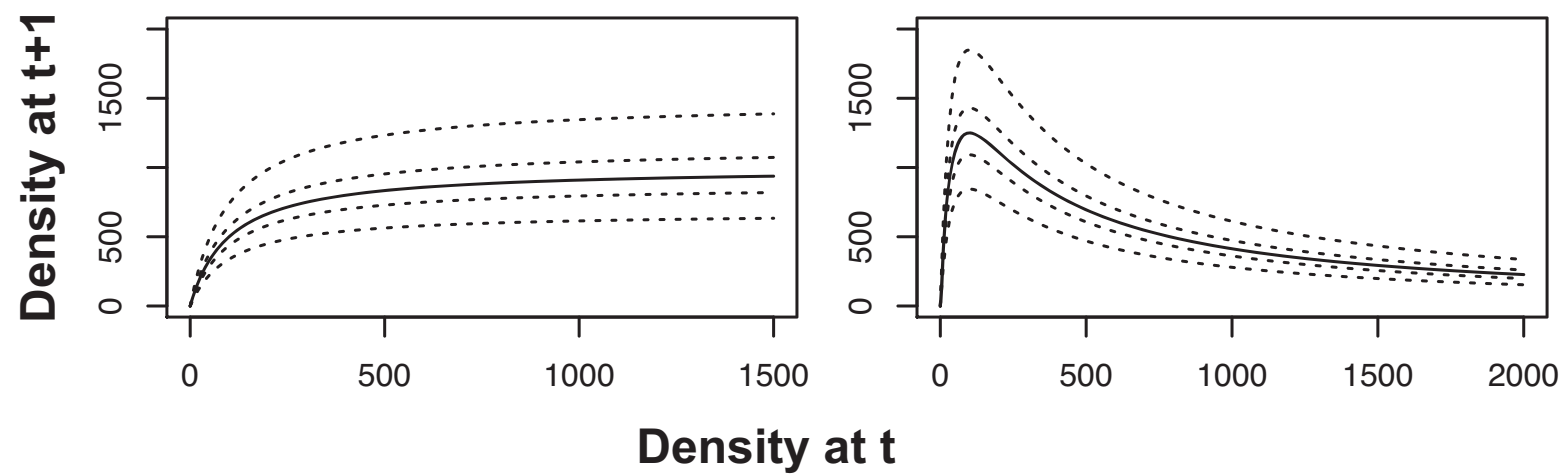
50 State Model:
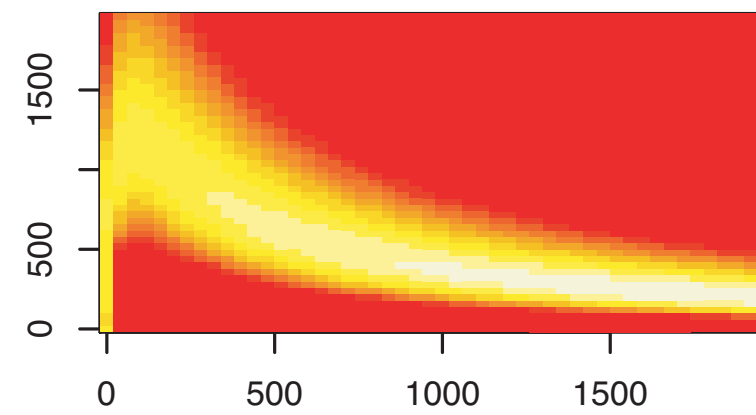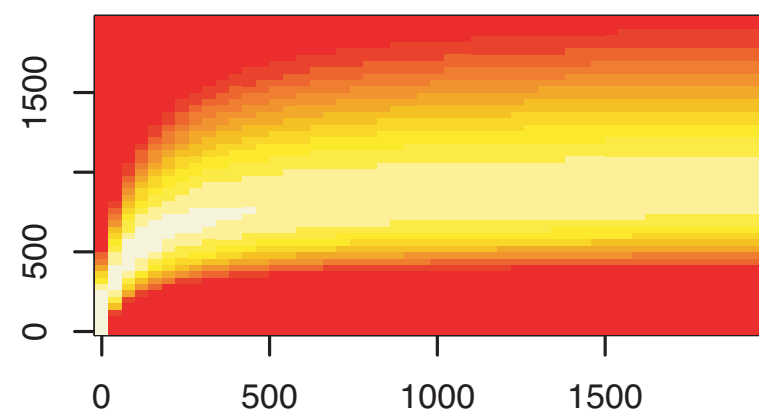
5 State Model:
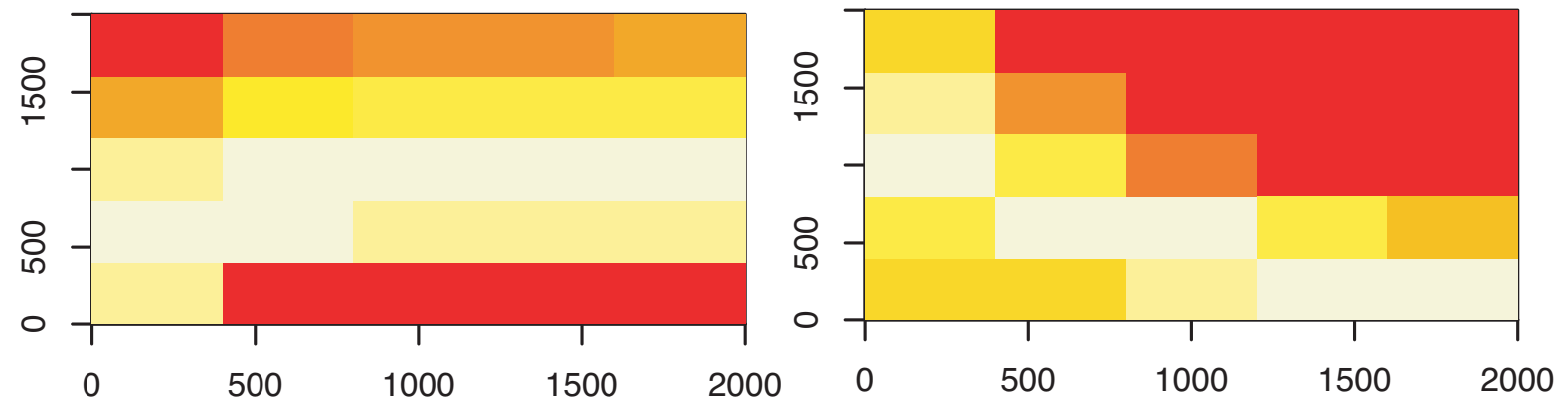
3 State Model:
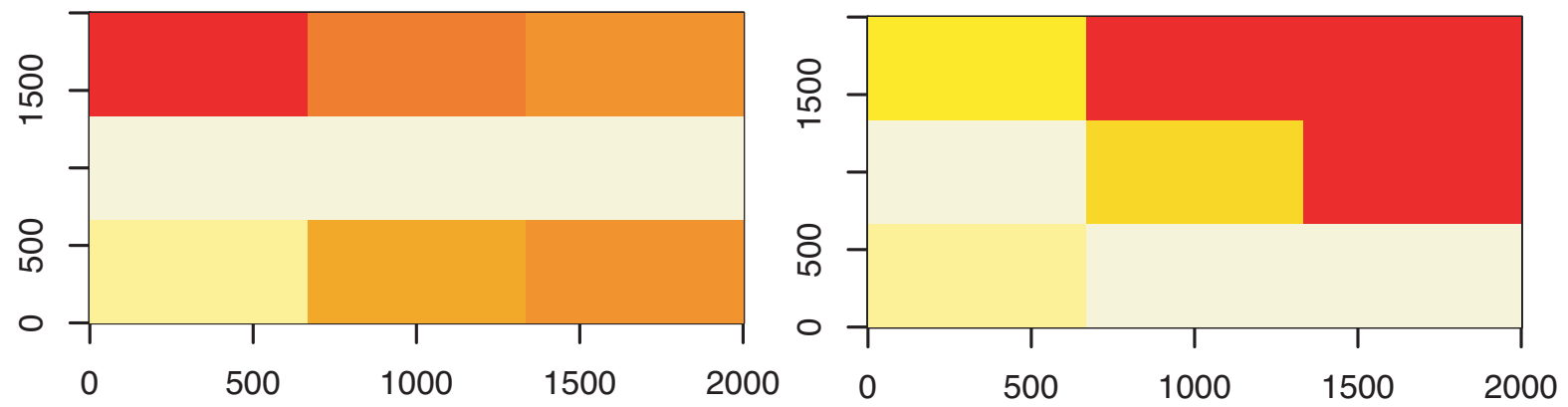
DENSITY-STRUCTURED MODELS

- DS models capture stochastic population dynamics

- Explicitly empirical focus
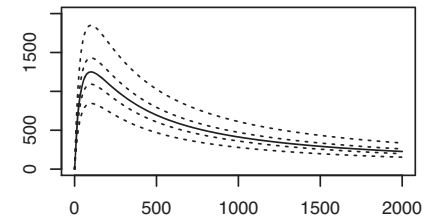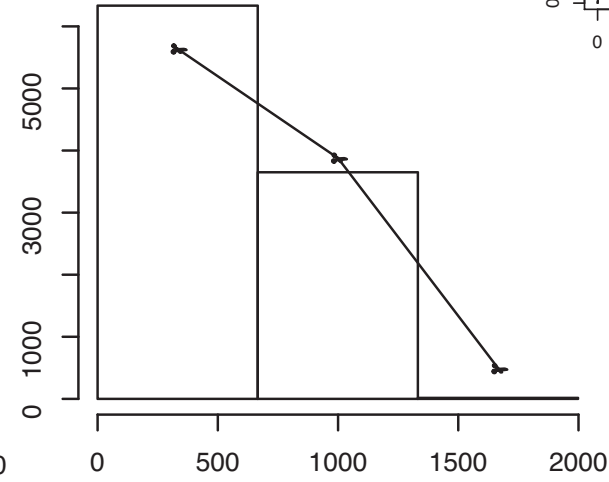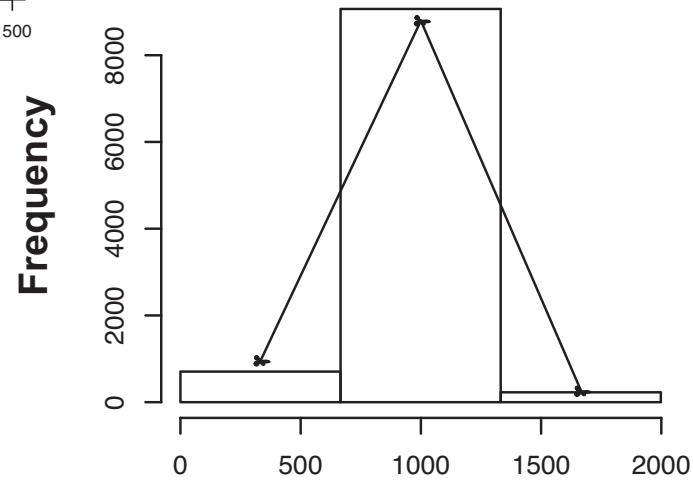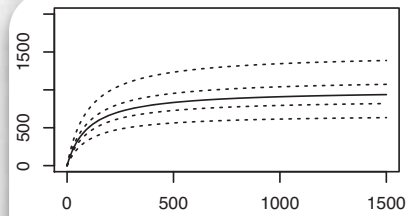
- Readily parameterised
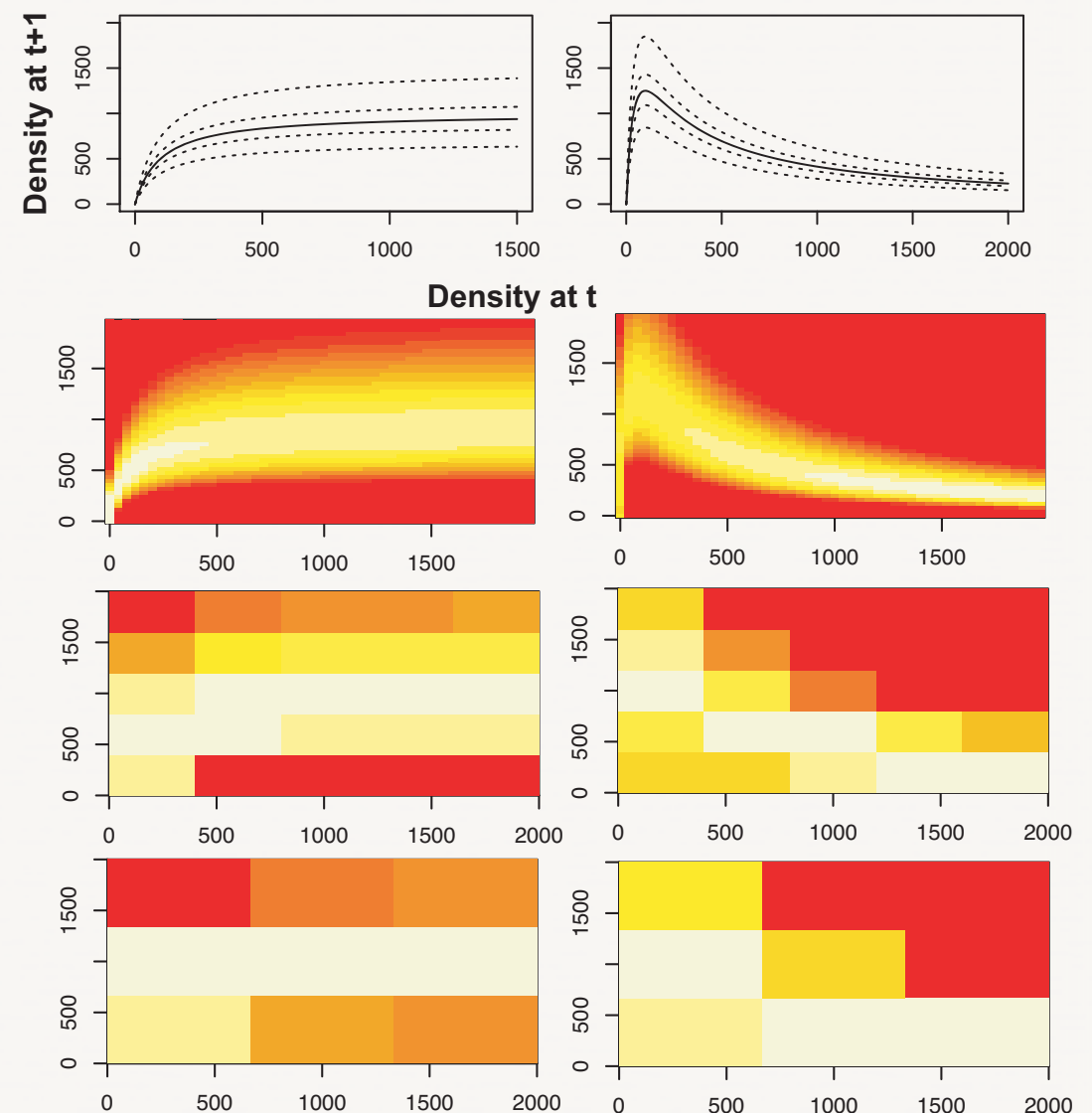
50 State Model:
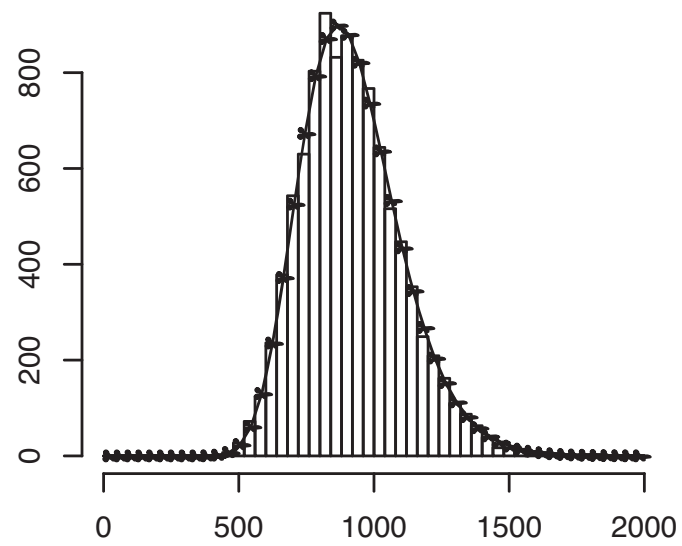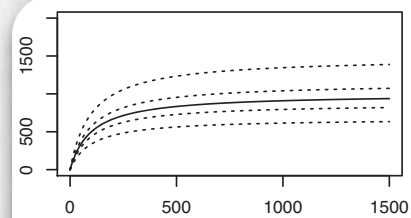
Density (50 states)
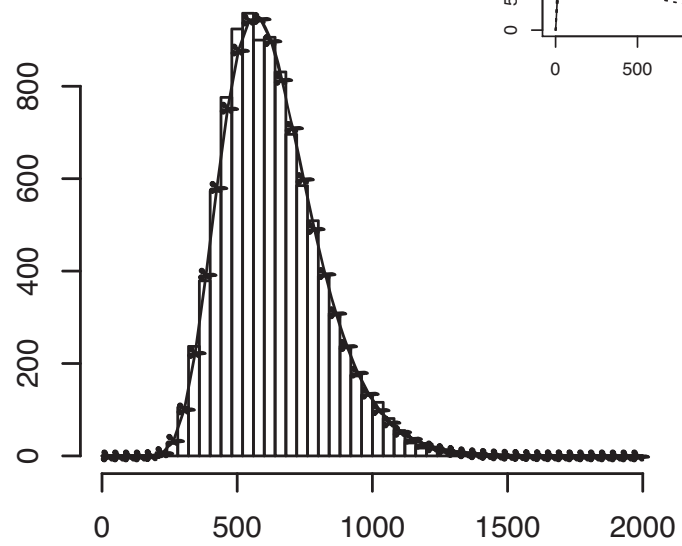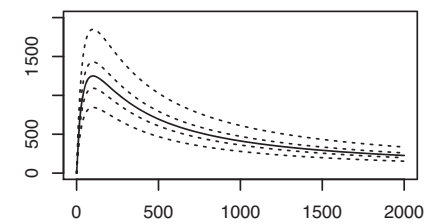
5 State Model:
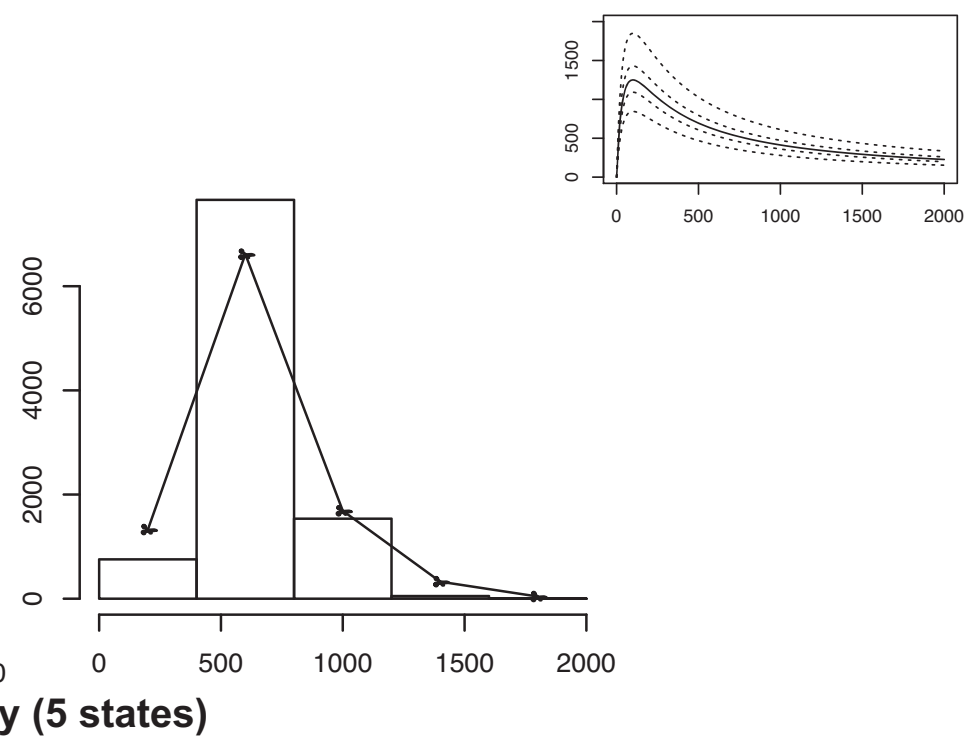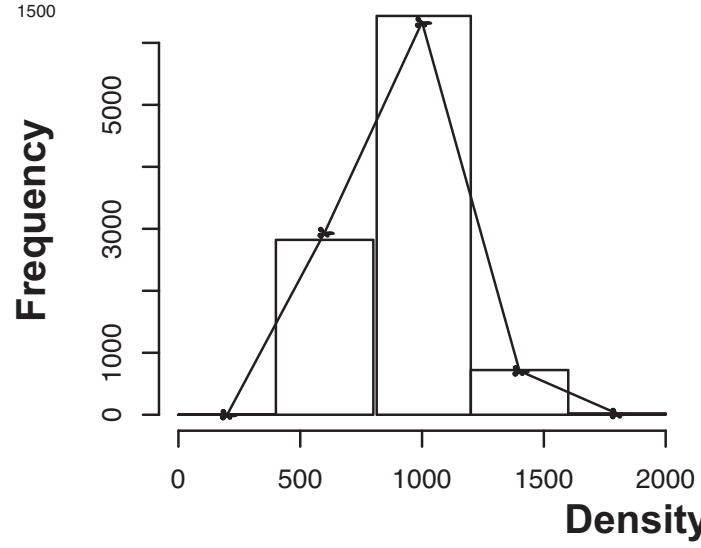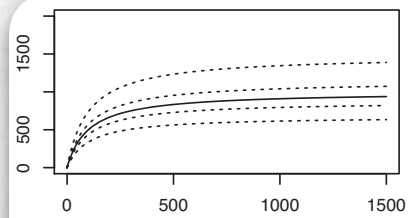
3 State Model:

ANALYTICAL ADVANTAGES

- Do not need to specify functions

- Relatively simple to analyse

- Census error easy to analyse

- Model output is numerically stable

PRACTICAL ADVANTAGES

- Data are rapid to collect

- Allows multiple field sites to be studied

- Even with few personnel

- Lots of data available

APPLICATION
1. ARABLE WEEDS

ARABLE WEEDS

- Annual plants in arable crops

- Reduce yields

- Often have positive effects on biodiversity

RESEARCH QUESTIONS

- How do weeds respond to management?

- How does management influence biodiversity?

- What are the economic and social drivers of management and biodiversity?

ISSUES

- Huge variation in density

- Between farms

- Between fields on a farm

- Between years

MODELLING ARABLE WEEDS

- Hierarchical survey

- 45 arable farms (Beds, Lincs & Nofolk)

- 10 fields per farm

- Fields monitored down to 20m x 20m scale

- 900 ha surveyed in total

45 x Farms
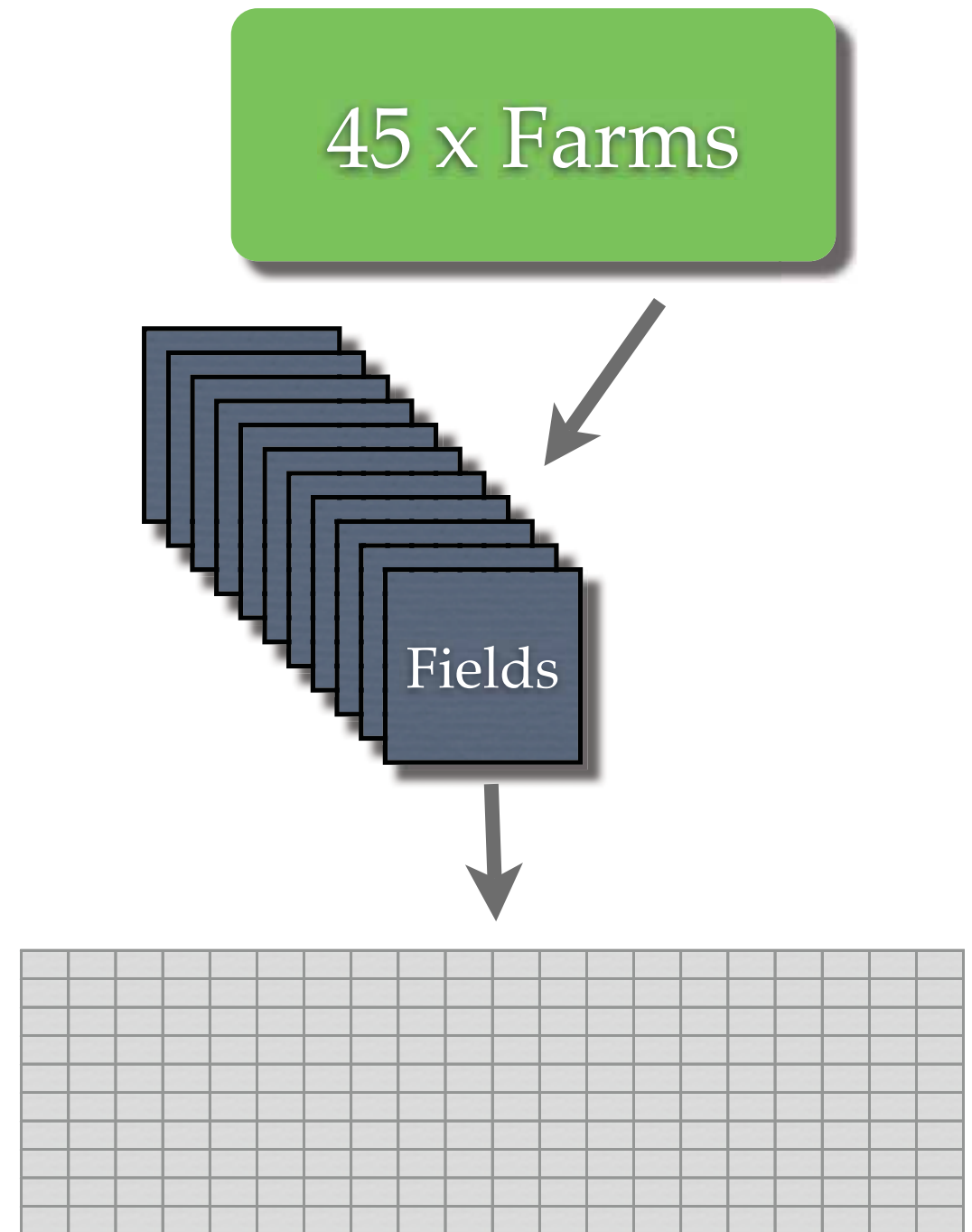
Fields

EXAMPLE DATA - GRASS WEEDS
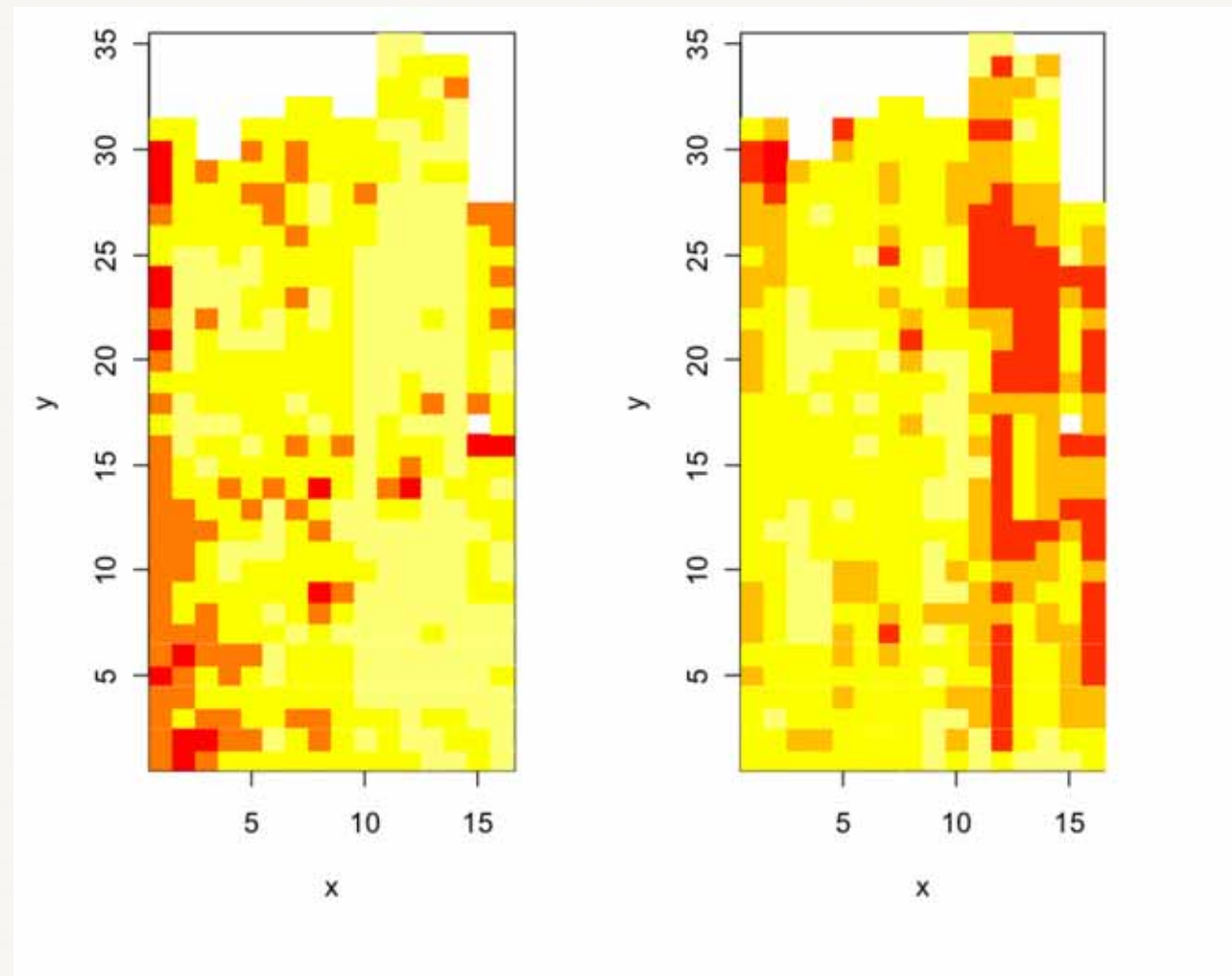
BROAD-LEAVED
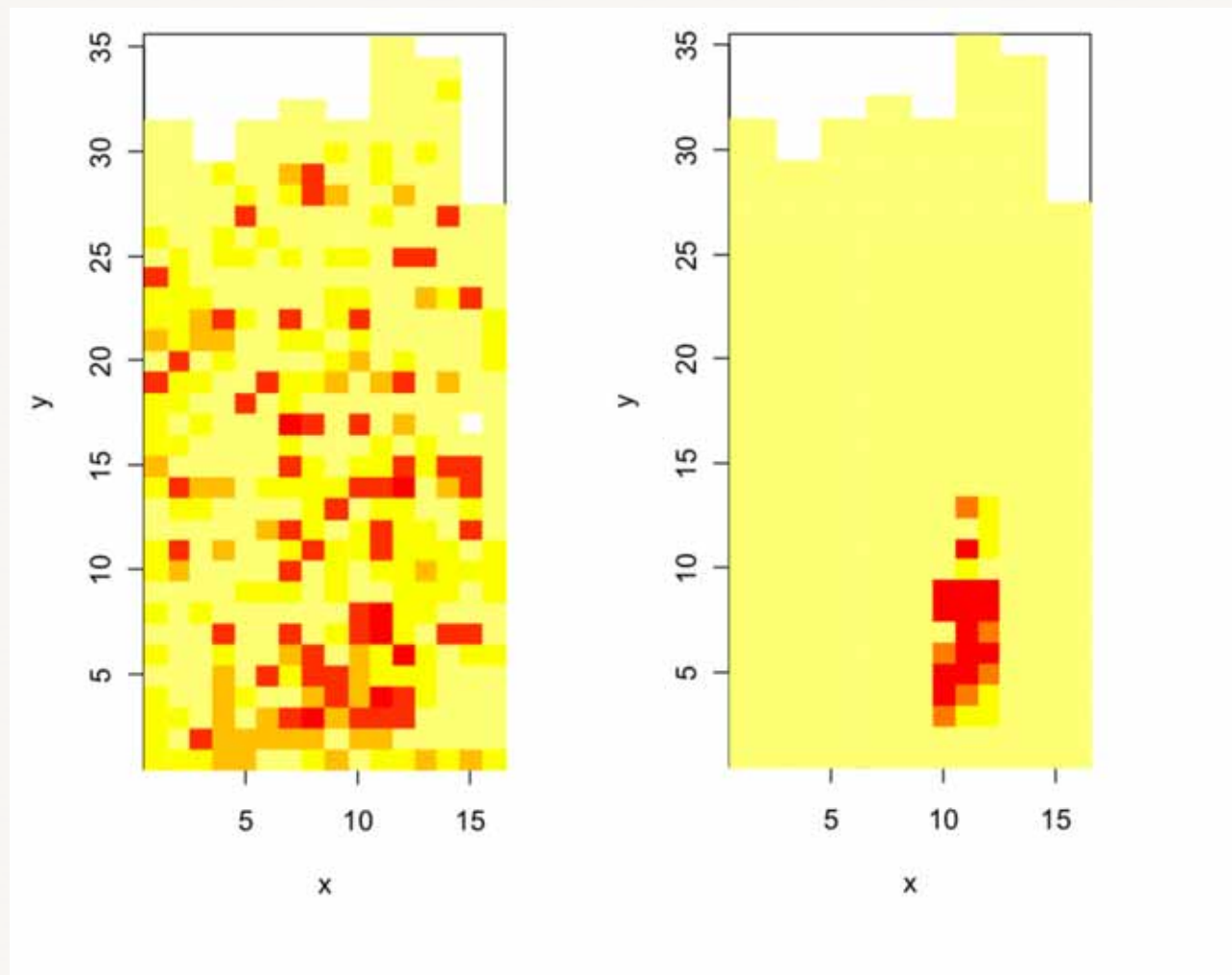
SCARCE / PATCHY WEEDS
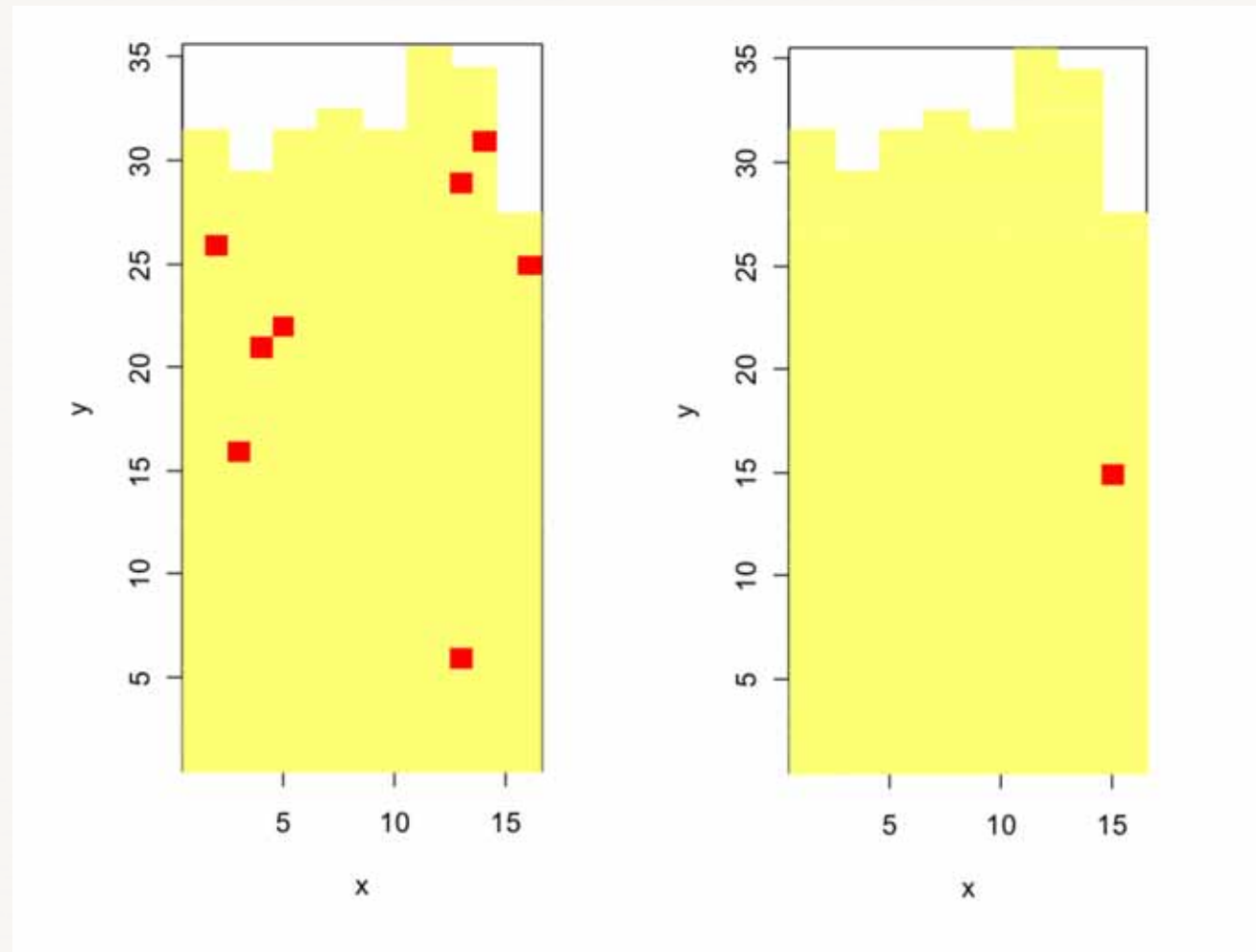
EXAMPLE DATA - BLACKGRASS
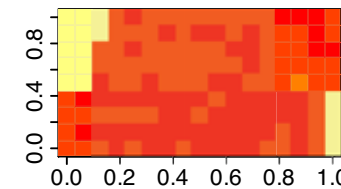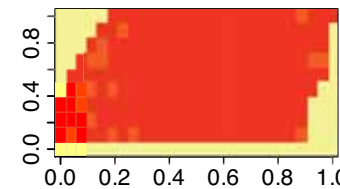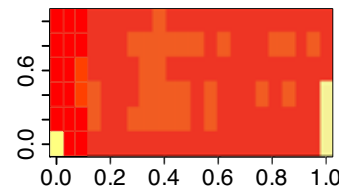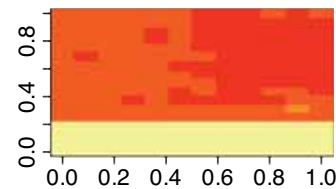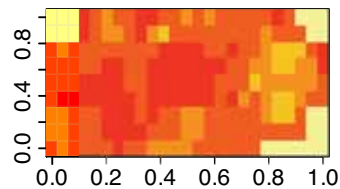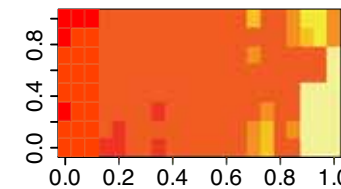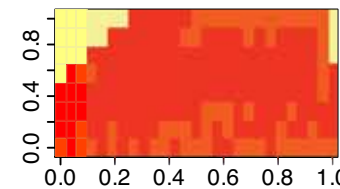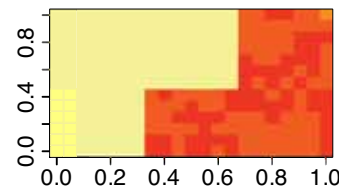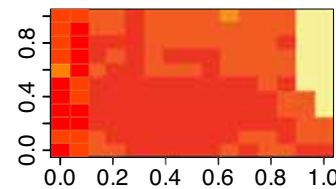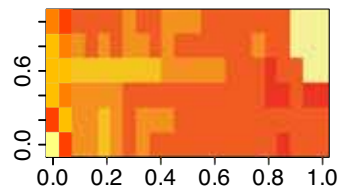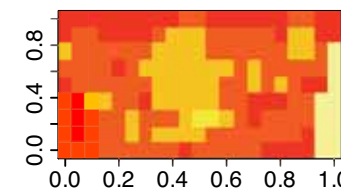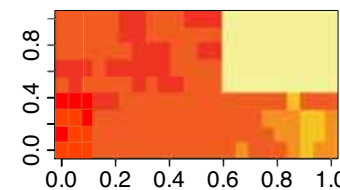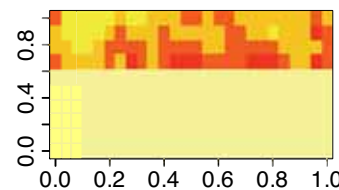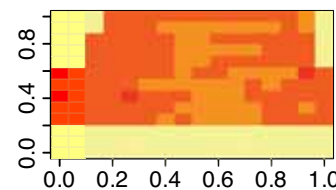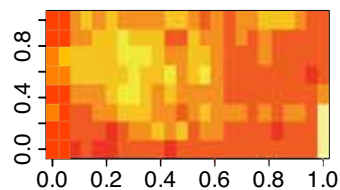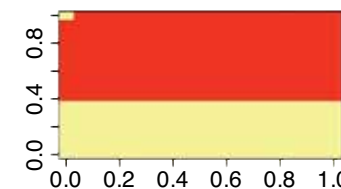
ON-GOING

- Continue monitoring for 2 more years
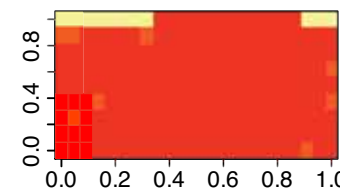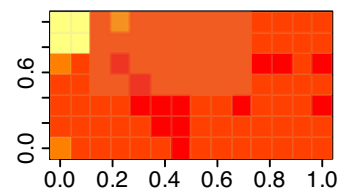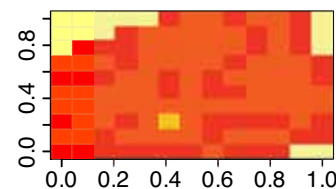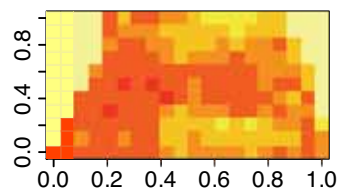
- Interview farmers

- Classification errors

- 'Ground-truthing'

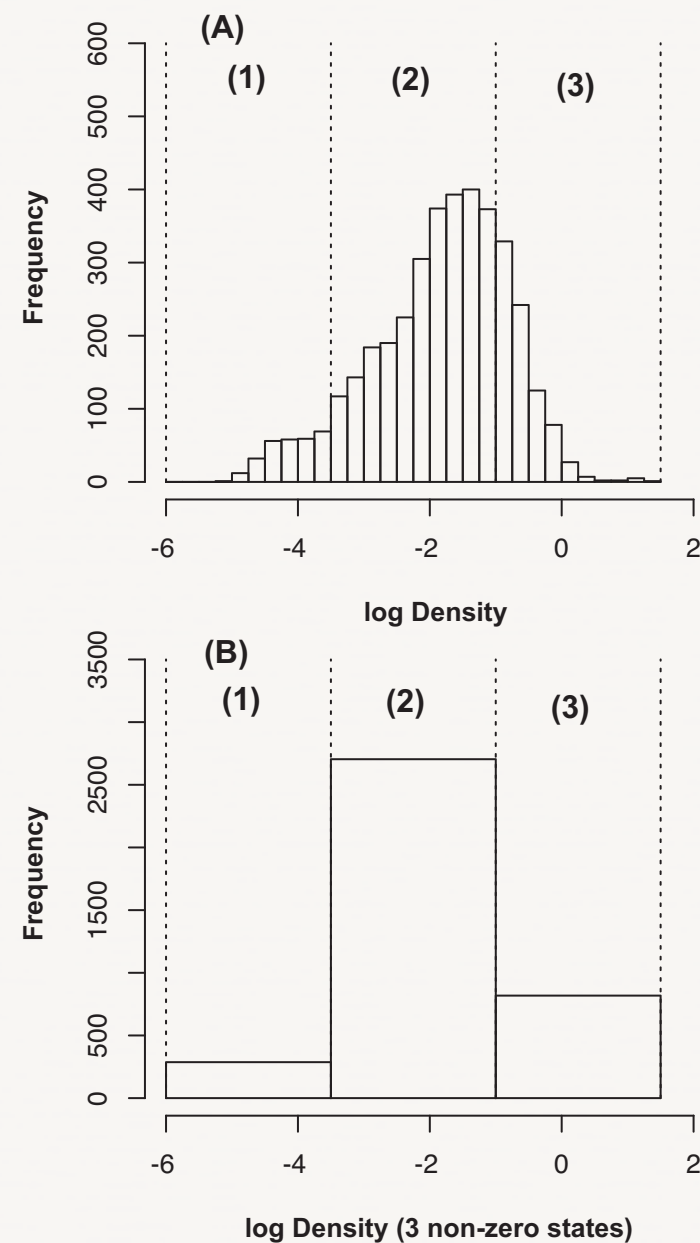# APPLICATION
2. WREN POPULATIONS

COMMON BIRD CENSUS

- Standardised estimate of breeding birds

- 1964 - 2000

- c. 200 sites per year throughout UK

- Number of breeding pairs recorded
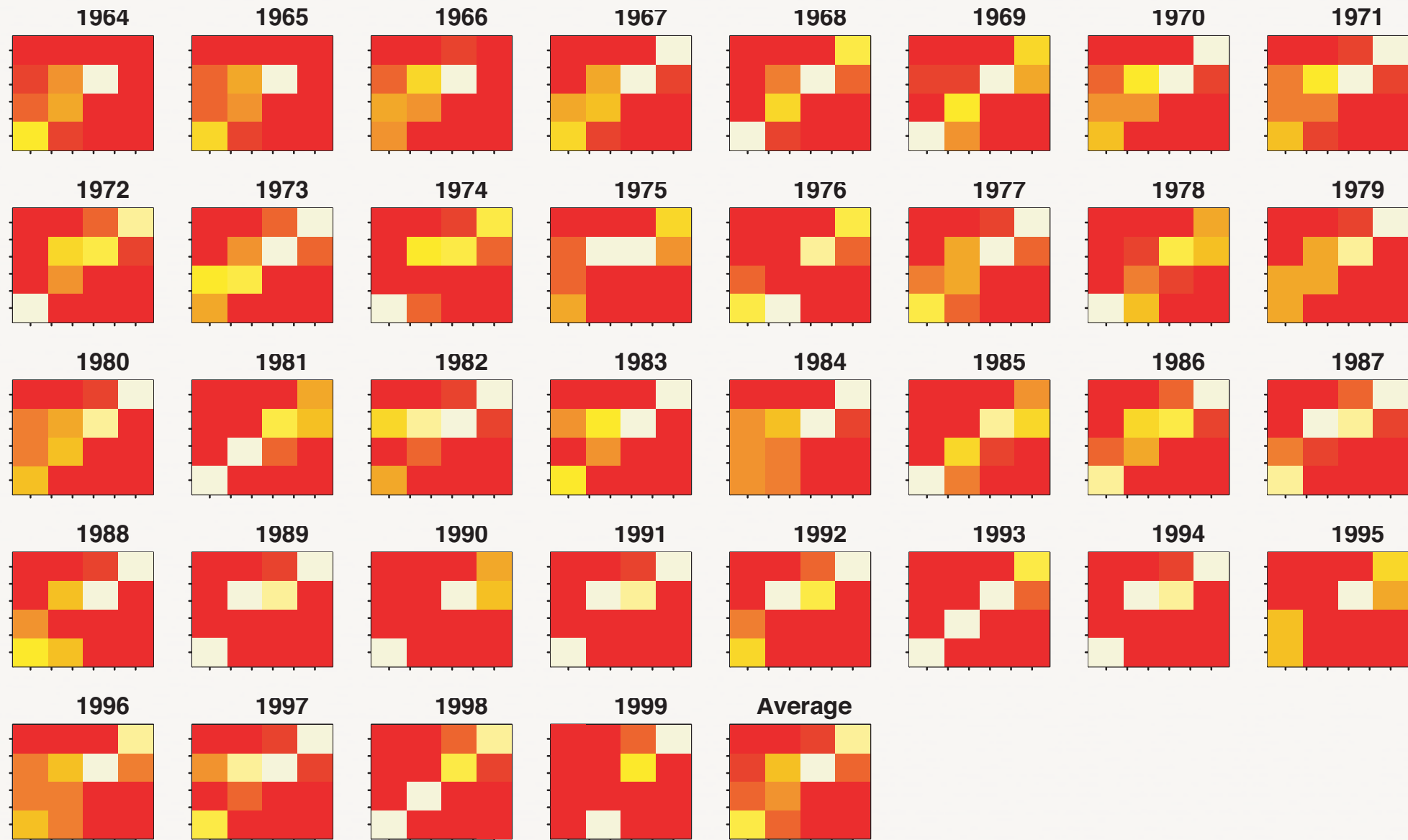
- No estimate of census error

4-STATE MODEL

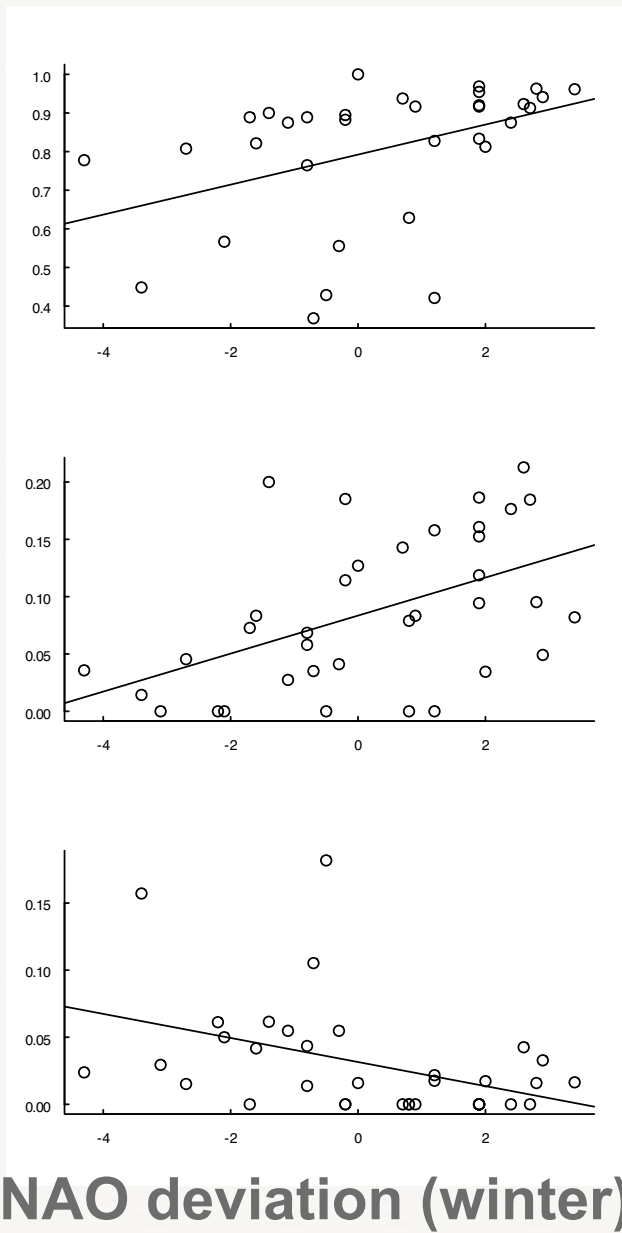- Divide data into 3 non-zero states & zero state
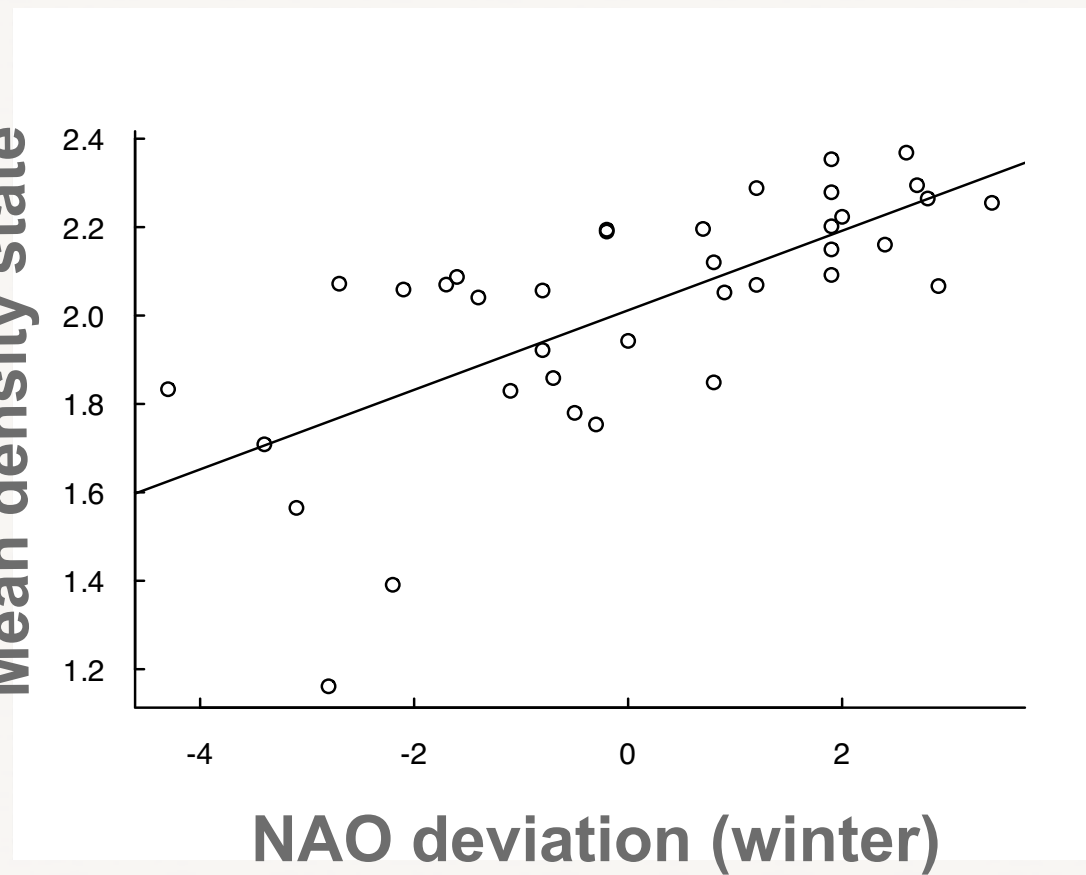
- Analyse as DS model

4-STATE MODEL FOR WRENS

CORRELATION WITH NAO INDEX

CONCLUSION

SUMMING UP

- Empirical models useful for developing models

- Linked closely to data collection

- Analysis reveals determinants of change

- Development of statistical methodology

ACKNOWLEDGMENTS

- Bill Sutherland

- Andrew Watkinson

- Rhys Green

- Phil Stephens

- Simon Queenborough

- David Noble