University of Kent NERC Innovation Workshop

New developments in the statistical modelling of presence/absence data

Rachel McCrea, Byron Morgan and Martin Ridout

NERC SCIENCE OF THE ENVIRONMENT

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ncse
National Centre for Statistical Ecology

University of Kent

Outline of the workshop

- Introductory Tutorial (Rachel)
- Covariates: Examples involving butterflies and newts (Byron)
- Break
- Abundance estimation using presence/absence data (Martin)
- Models for spatial replication (Martin)
- Occupancy as a hidden Markov model (Byron)

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New developments in the statistical modelling of presence/absence data

An Introductory Tutorial

Rachel McCrea

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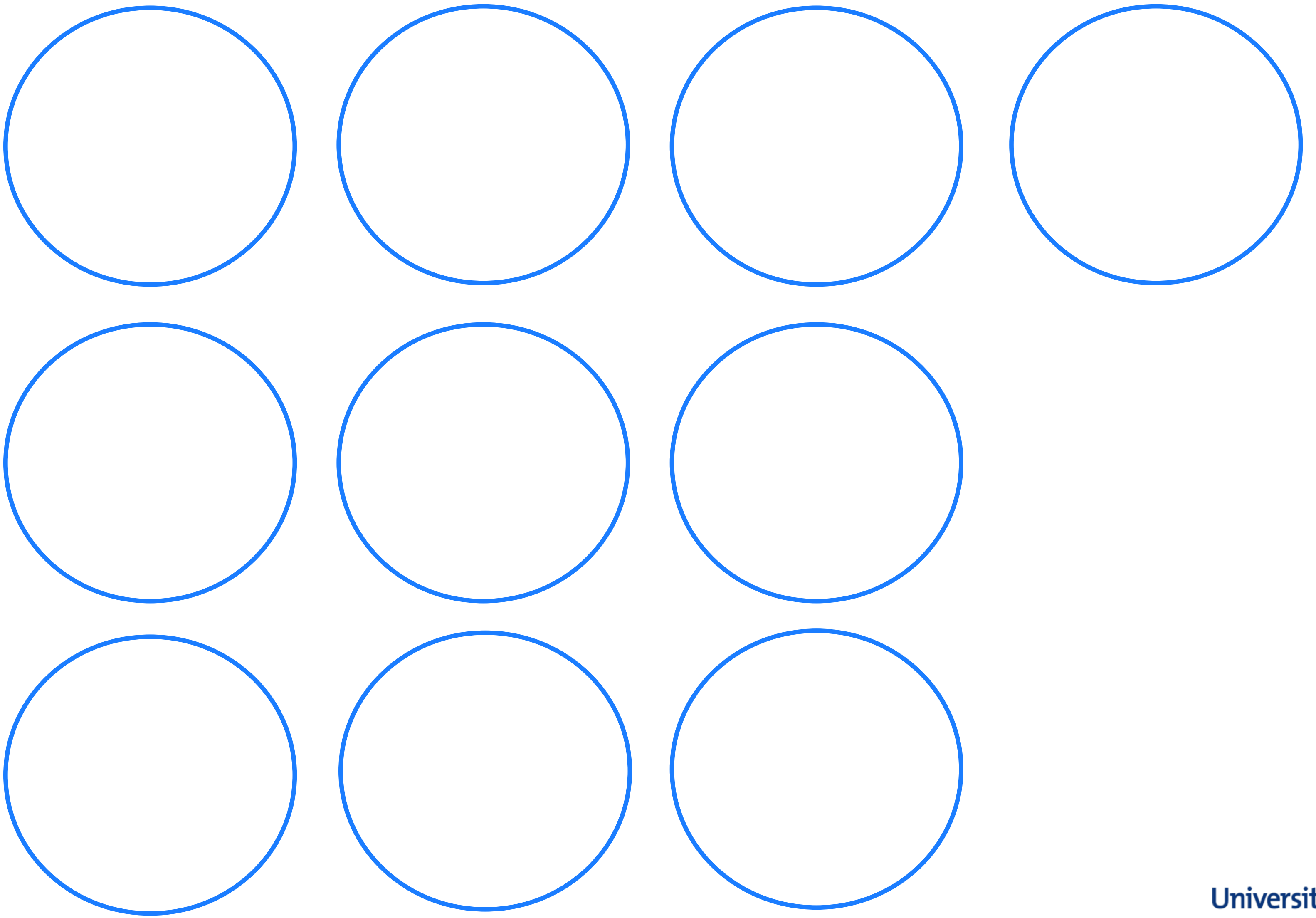
Overview

- Introduction
- Aside: likelihood theory
- Simple occupancy models
- Model selection
- Advanced occupancy models
- Computer software

- Further resources

Do we need to account for detectability?



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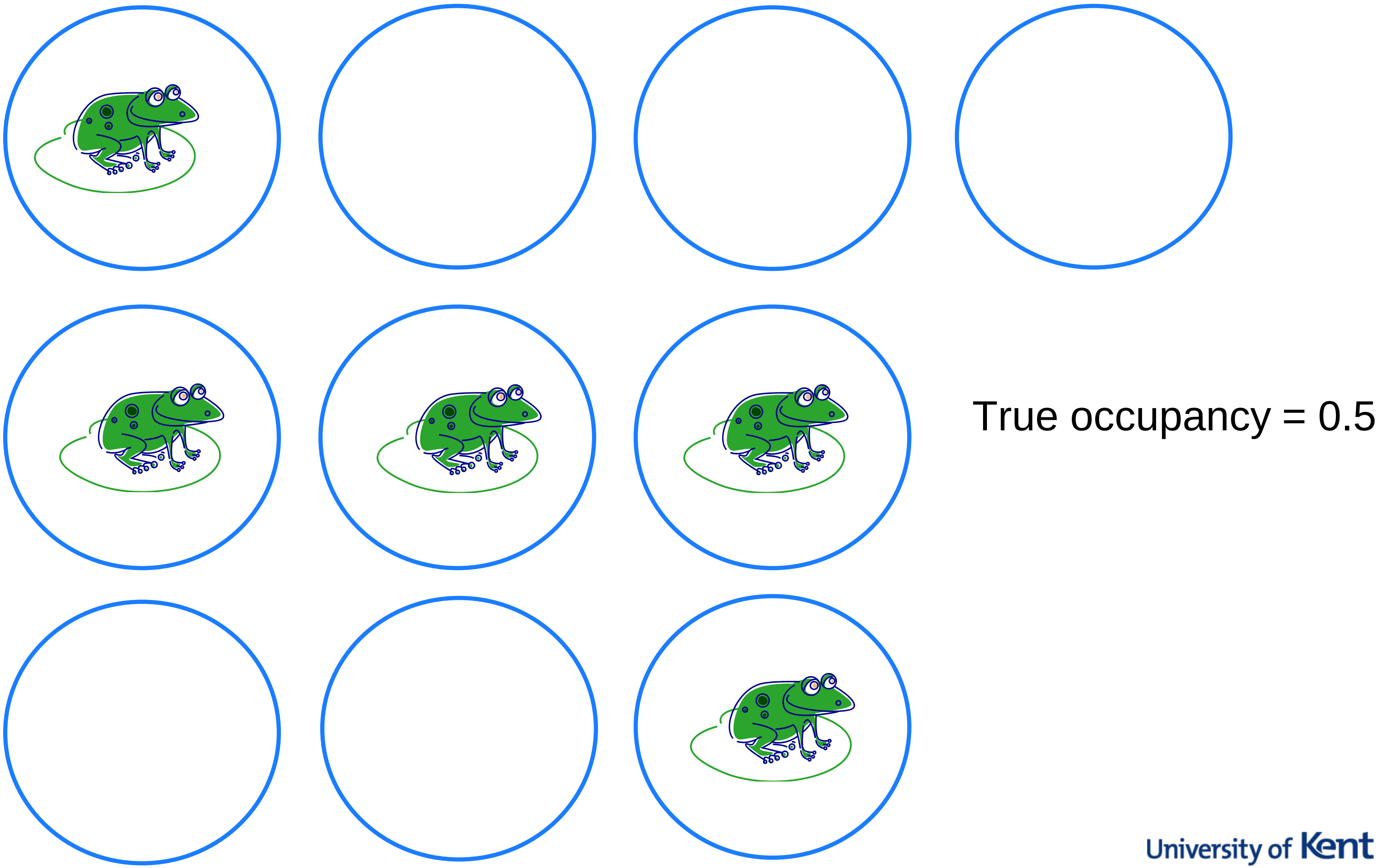

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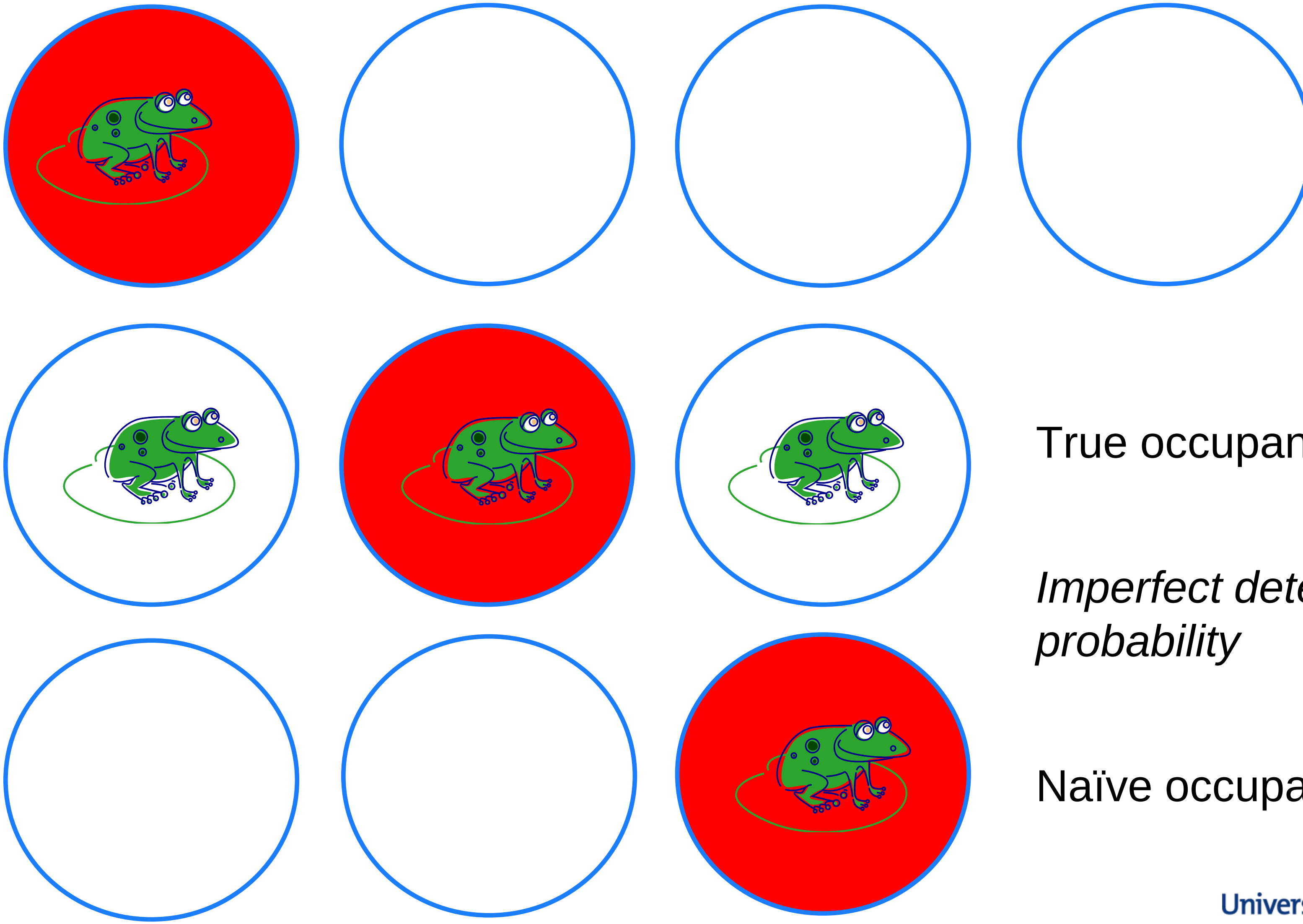

True occupancy = 0.5

Imperfect detection probability

Naïve occupancy = 0.3

Multinomial probabilities

- Suppose we have three buckets labelled A, B and C



- We try and throw N balls into the buckets.

Multinomial probabilities

- There are 4 possible outcomes for each of the throws:
  - Ball goes into bucket A
  - Ball goes into bucket B
  - Ball goes into bucket C
  - Ball doesn’t go into any of the buckets

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n_A n_B n_C

$$N - n_A - n_B - n_C$$

Multinomial likelihood

- Suppose the probability of getting the ball in bucket i is p_i
- We want to find the values of the parameters p_A, p_B, p_C which ***maximises the likelihood*** that we would observe the data that we did (n_A,n_B,n_C).

$$\mathcal{L}(p_A, p_B, p_C | N, n_A, n_B, n_C)$$
$$\propto {p_A}^{n_A} {p_B}^{n_B}\ {p_C}^{n_C} \times (1 - p_A - p_B - p_C)^{N - n_A - n_B - n_C}$$

- Note here we assume N is known.

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- Note here we assume N is known.

Simple occupancy model

- Visit sites i = 1, …, S
- Multiple surveys j = 1, …, K
  - Can be temporal, or may be different teams conducting surveys
- Observed data: h_i
  - Detection history for each site
- Examples:
  - `0101`
  - `1110`
  - `0000`
  - …

Simple occupancy model

- Conceptual model:
  - A site may be occupied or not
  - If the site is occupied, there is some probability of detecting the species

Formalising the model

- Parameters:
  - ψ: probability the site is occupied
  - p_j: probability species is detected at survey j

- Construct probabilities

$$\Pr(h_i = 0101) = \psi(1-p_1)p_2(1-p_3)p_4$$

$$\Pr(h_i = 0000) = \psi(1-p_1)(1-p_2)(1-p_3)(1-p_4)+(\mathbf{1-}\psi)$$

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Alternative models

- Constant detection probability
- Relate detection to covariate values
- Relate occupancy to covariate values
- Incorporate heterogeneity (finite and infinite mixtures)

- How do we select between these alternative models?

Model selection: AIC

- AIC can be calculated for each of the fitted models.
- AIC is a measure of the relative quality of a statistical model for a given set of data.
- It is a trade-off between how well the model fits the data and the complexity (number of parameters) of the model
- The smaller the AIC, the more support for the model
- Suppose you want to select between T candidate models:
  - $\Delta AIC_i = AIC_i - \min(AIC_1, \ldots, AIC_T)$

Example: Blue-ridge two-lined salamanders

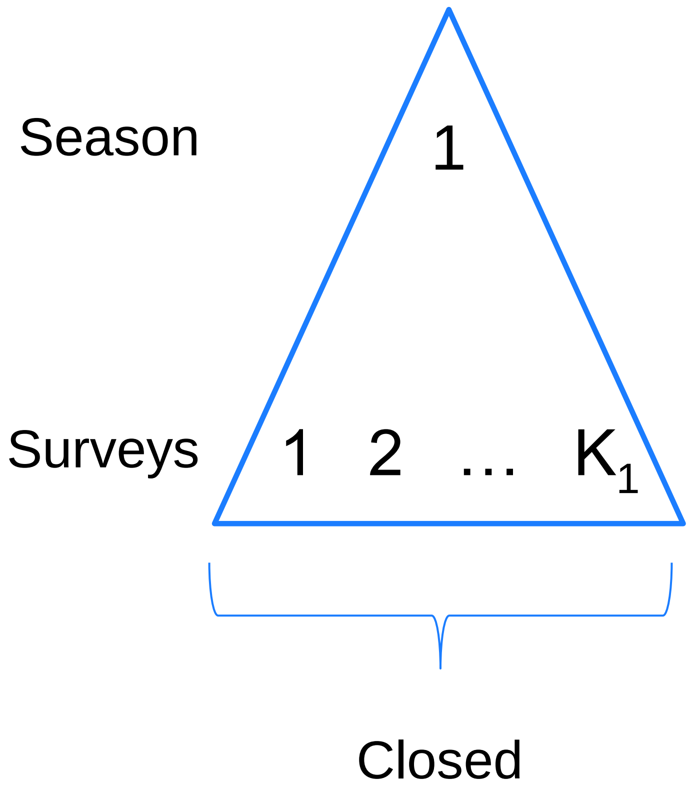
- MacKenzie et al (2006) p. 99
- s = 39 (number of sites)
- K = 5 (number of surveys)
- Two candidate models:
  - Occupancy and detection are constant
  - Constant occupancy, time-dependent detection
- Salamanders were detected at 18 of the 39 sites
  - Naïve occupancy estimate = 18/39 = 0.46

Results

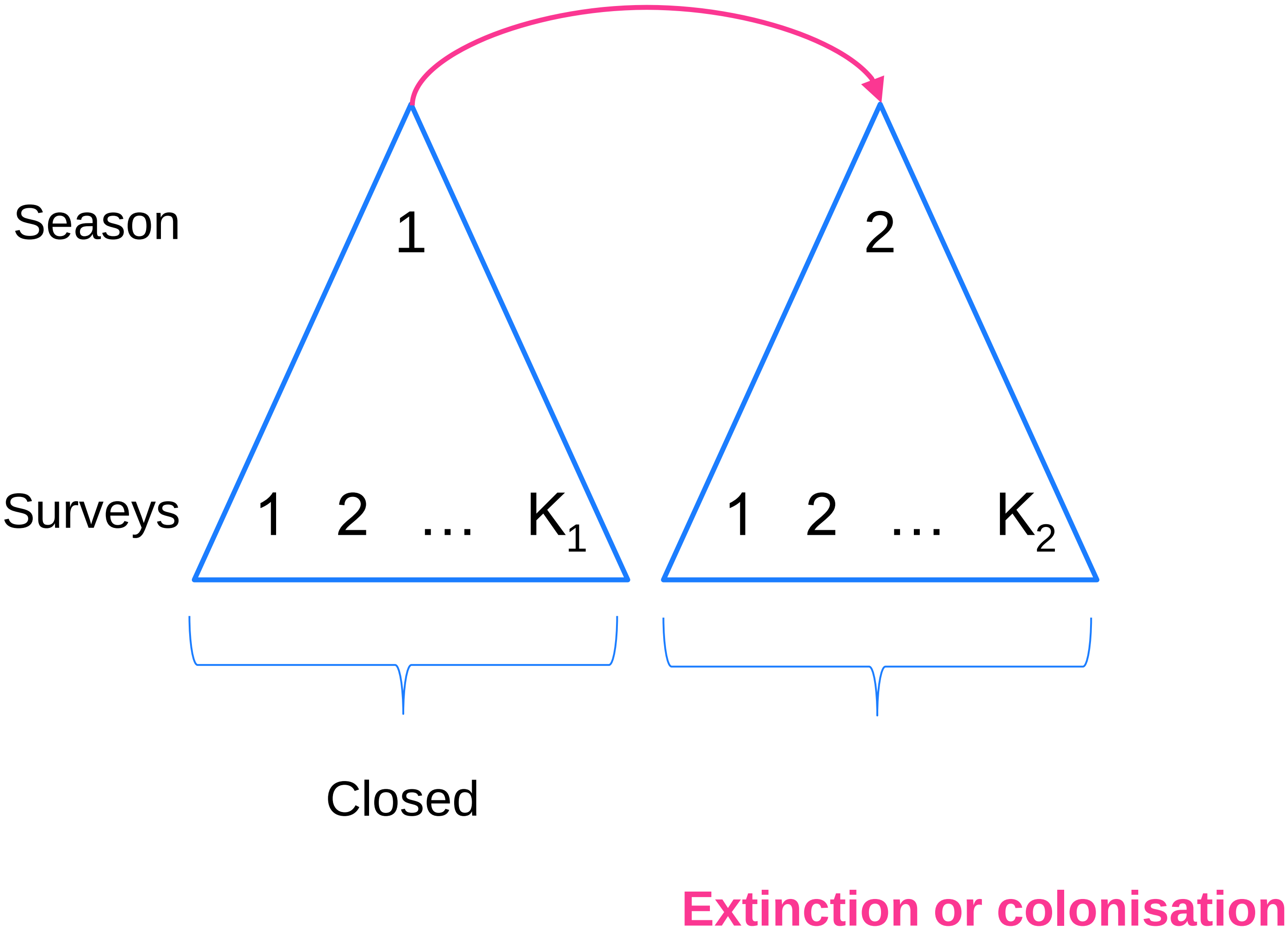
Model	ΔAIC	np	$\widehat{\psi}$	$\widehat{p_1}$	$\widehat{p_2}$	$\widehat{p_3}$	$\widehat{p_4}$	$\widehat{p_5}$
ψ(.),p(.)	0.00	2	0.60	0.26	0.26	0.26	0.26	0.26
ψ(.),p(t)	1.95	6	0.58	0.18	0.13	0.40	0.35	0.27

- Probability of false absence?
- Which model is best?

Advanced models: multiple-season models



Advanced models: multiple-season models



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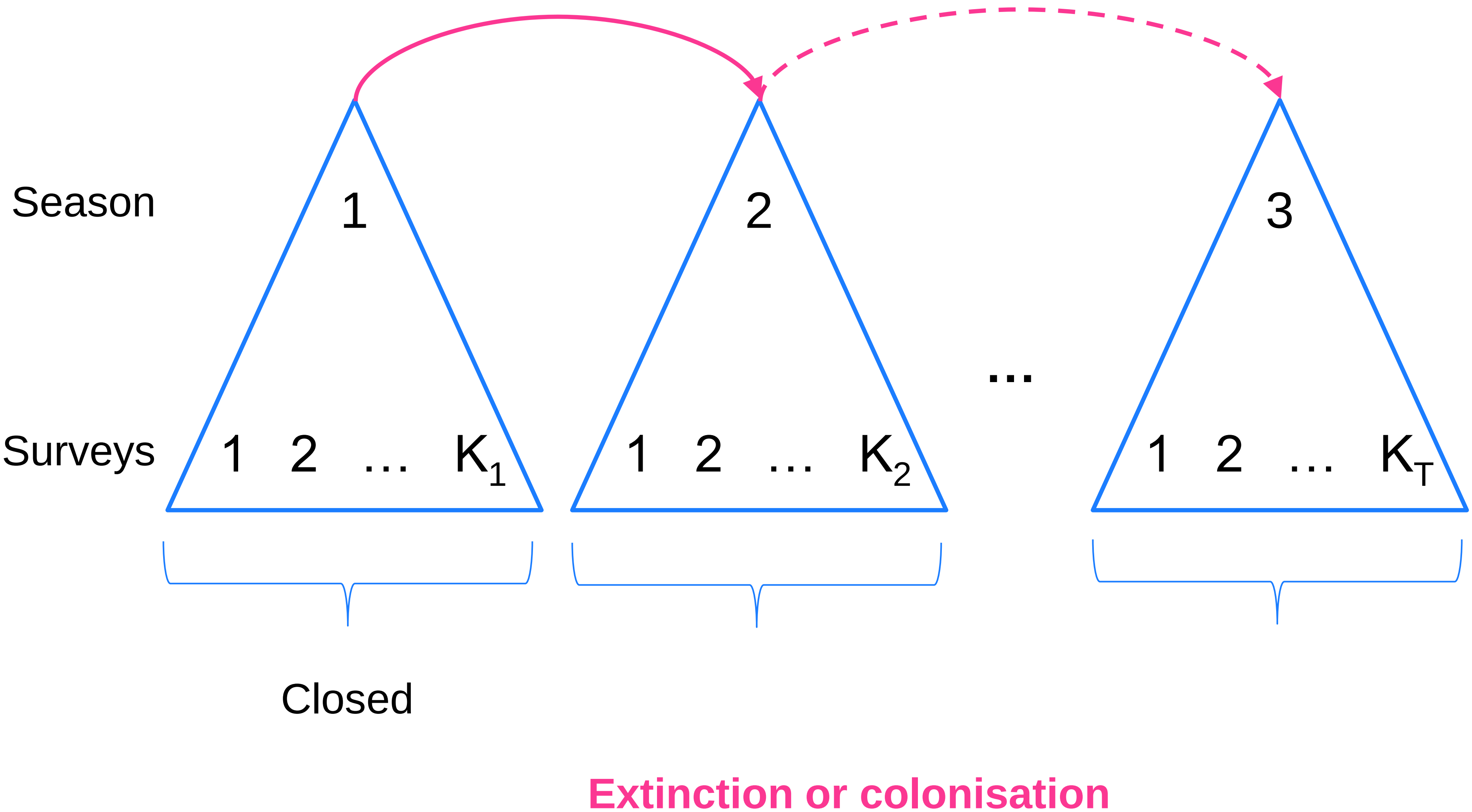


Advanced models: multiple-season models

- Example detection history:

110 000 010

- New Parameters

COLONISATION

- γ_t: the probability that an unoccupied site in season t is occupied by the species in season t+1

EXTINCTION

- ε_t: the probability that a site occupied in season t is unoccupied by the species in season t+1

Advanced models: multiple-season models

- Example detection history:

110   000   010

- Extended Parameters
  - ψ_t: probability a site is occupied in season t
  - p_{tj}: probability of detecting the speices in the j^{th} survey of a site during season t

Example: Northern spotted owl

- MacKenzie et al (2006), p. 209
- s = 55 potential breeding territories
- Surveyed between 1997 and 2000 (T=5)
- $K_{average}$=5.3; K_{max}=8

Competing models

- Occupancy status does not change
  - $\psi(.)$,p(year)
- Random changes in occupancy (no dependence on whether previously occupied)
  - $\psi(1997)$, $\varepsilon=(1-\gamma)$, p(year)
- Markovian changes in occupancy
  - $\psi(1997)$, $\varepsilon(.)$, $\gamma(.)$, p(year)
- Constant occupancy and colonisation
  - $\psi(.)$, $\gamma(.)$, p(year)
  - ε: derived parameter determined from the dynamic process

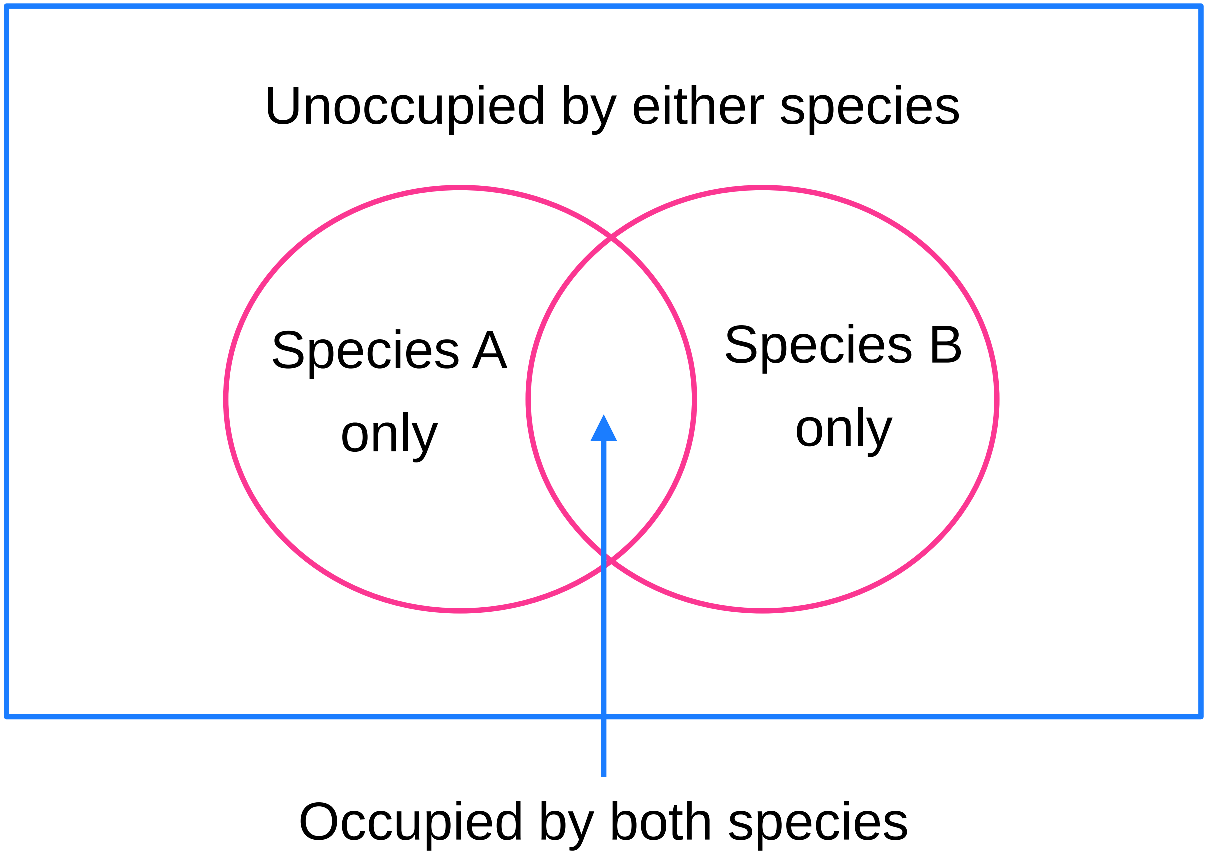
Results

Model	ΔAIC	np
ψ(.),γ(.),p(year)	0.00	7
ψ(1997),γ(.), ε(.), p(year)	1.57	8
ψ(1997),γ(year), ε(year), p(year)	3.69	14
ψ(1997),γ(.), {ε=1-γ}, p(year)	91.58	7
ψ(1997),γ(year), {ε=1-γ}, p(year)	97.37	10
ψ(.),p(year)	202.61	6

- Changes in occupancy best represented by Markov process
- Equilibrium state (no year-dependence in colonisation or extinction)

Advanced models: multiple species models

- Species interactions

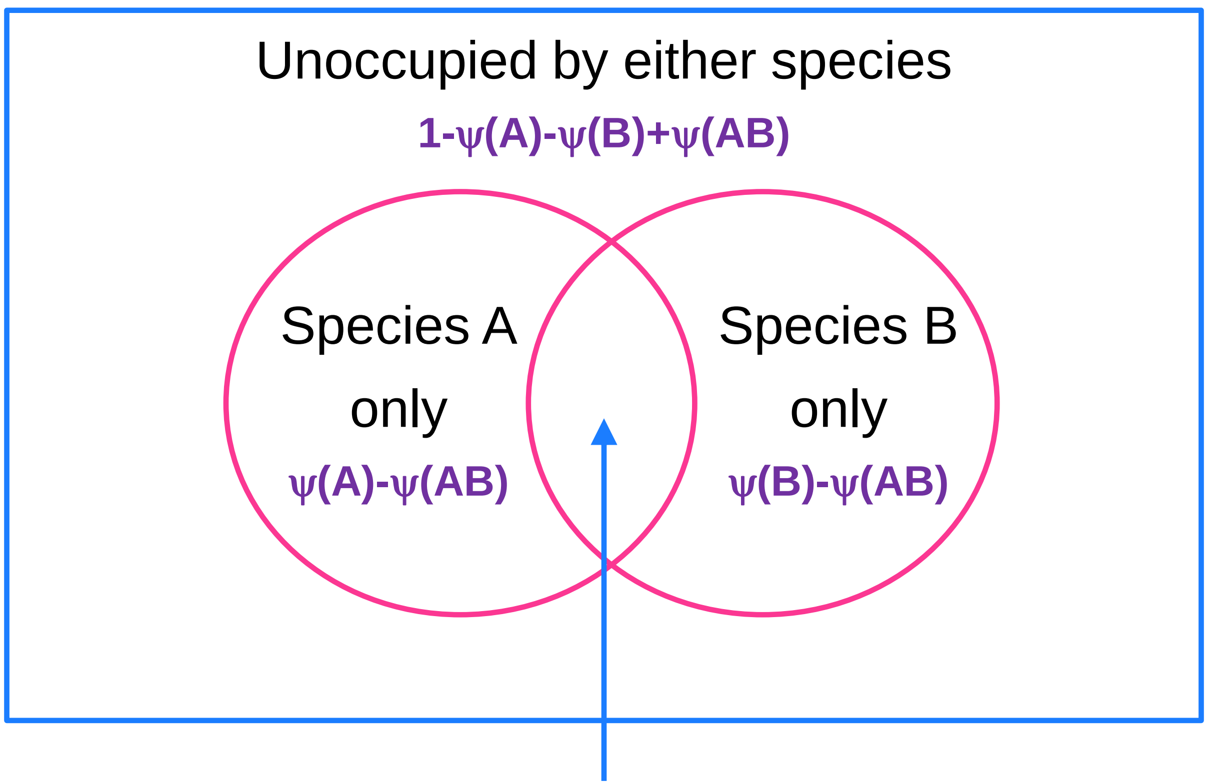


Advanced models: multiple species models

- Species interactions:
- ψ(A): probability species A occupies a site
- ψ(B): probability species B occupies a site
- ψ(AB): probability both species occupy a site site

Advanced models: multiple species models

- Species interactions



Occupied by both species ψ(AB)

Advanced models: multiple species models

- ψ(A): probability species A occupies a site
- ψ(B): probability species B occupies a site
- ψ(AB): probability both species occupy a site site

- p_j(A): probability of detecting species A during the j^{th} survey, given only species A is present

- p_j(B): probability of detecting species B during the j^{th} survey, given only species B is present

Advanced models: multiple species models

- $r_j(AB)$: probability of detecting both species during j^{th} survey, given both are present
- $r_j(Ab)$: probability of detecting species A but not B during j^{th} survey, given both are present
- $r_j(aB)$: probability of detecting species B but not A during j^{th} survey, given both are present
- $r_j(ab)$: probability of detecting neither species during j^{th} survey, given both are present

- $r_j(ab) = 1 - r_j(AB)-r_j(Ab)-r_j(aB)$

Advanced models: multiple species models

- Depending on parameters of inetrest, there are reparameterised forms:

- Species interaction factor

$$\varphi = \frac{\psi(AB)}{\psi(A)\psi(B)}$$

- “how much more or less likely the species are to co-occur at a site compared to what would be expected if they co-occurred independenly”

Computer software: Presence

- Presence can be downloaded here:
- http://www.mbr-pwrc.usgs.gov/software/presence.html
- The same webpage has a manual and tutorials to help you get started with the software.
- The citation for Presence is:
- Hines, J. E. (2006). *PRESENCE2 - Software to estimate patch occupancy and related parameters.* USGS-PWRC. http://www.mbr-pwrc.gov/software/presence.html

Computer software: unmarked in R

- R package `unmarked` can be used to fit occupancy models
- Details of unmarked can be found here:
  - http://cran.r-project.org/package=unmarked
- Fiske and Chandler (2011) unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software*. **43**, 1-23

Useful References

- MacKenzie, Nichols, Royle, Pollock, Bailey and Hines (2006) *Occupancy Estimation and Modeling: Inferring patterns and dynamics of species occurrence.* Academic Press.
- Guillera-Arroita, Ridout and Morgan (2010) Design of occupancy studies with imperfect detection. *Methods in Ecology and Evolution.* 1, 131-139

- Gurutzeta Guillera-Arroita's website and blog:
- https://gguilleraresearch.wordpress.com/