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Stopover Models

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Collaborative work with

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NERC SCIENCE OF THE ENVIRONMENT

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ncse National Centre for Statistical Ecology

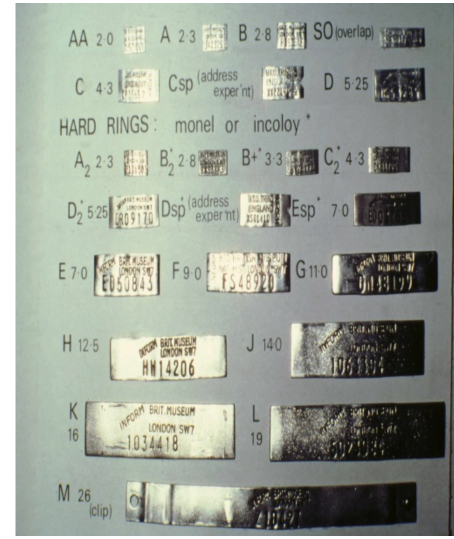
University of Kent

Overview

- Capture-recapture data
- Closed population models
- Open population models
- Stopover models
- Application 1: Great cormorants
- Application 2: Great crested newts
- Extensions and Current Work
- Software
- References

Capture-recapture data

- Capture-recapture data
  - 10010
  - 11011
  - 00101
  - …
- Data from marked animals
  - Population size



Closed population models

- Closed population: no immigration, emigration, death or births during the study
- p_t: probability an individual is captured at occasion t
- Capture-recapture data and probabilities
  - 10010 $p_1(1-p_2)(1-p_3)p_4(1-p_5)$
  - 11011 $p_1p_2(1-p_3)p_4p_5$
  - 00101 $(1-p_1)(1-p_2)p_3(1-p_4)p_5$
  - …

Closed population models

- Some individuals will not be captured at all during the study
- The encounter history for these individuals is given by
  - 00000 $(1-p_1)(1-p_2)(1-p_3)(1-p_4)(1-p_5)$
- It is the number of individuals who are never captured that we need to estimate to estimate in order to estimate the total population size.

Closed population models

- Form a likelihood function as

$$L \propto \frac{N!}{(N-D)!} \prod_{i=1}^{D} \Pr(h_i) \times \Pr(h_0)^{N-D}$$

- h_i: observed encounter history for individual i
- h_0: encounter history of never captured
- N: population size
- D: observed number of individuals
- Maximise L, to obtain *maximum-likelihood estimates* of p_t and N

Open population models

- Studied population might not be closed, but still want to be able to estimate population size
- Jolly-Seber model
  - POPAN/Schwarz-Arnason formulation

0 0 1 0 0

- Entry time into the study population

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- Departure time out of the study population

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Open population models

- If you assume the population is closed when it is not, the parameter estimates will be biased.

- Parameters for the Jolly-Seber model
  - N: **population size**
  - β_t: proportion of individuals first **available for capture** at occasion t+1, $\sum_{j=0}^{T-1} \beta_j$
  - p_t: probability an individual is **captured** at occasion t
  - ϕ_t: probability an individual present in the study area at occasion t **remains in the study area** until occasion t+1

Open population models

- When forming the probability of an observed encounter history we need to sum over possible entry and departure times.
  - Suppose individual is first captured at occasion f_i and last captured at occasion l_i
  - $x_{ij}=1$ if individual i is captured at occasion j, $x_{ij}=0$ otherwise

$$\Pr(h_i) = \sum_{b=1}^{f_i} \sum_{d=l_i}^{T} \beta_{b-1} \left(\prod_{j=b}^{d-1} \phi_j \right) (1-\phi_d) \left\{ \prod_{j=b}^{d} p_j^{x_{ij}} (1-p_j)^{1-x_{ij}} \right\}$$

Open population models

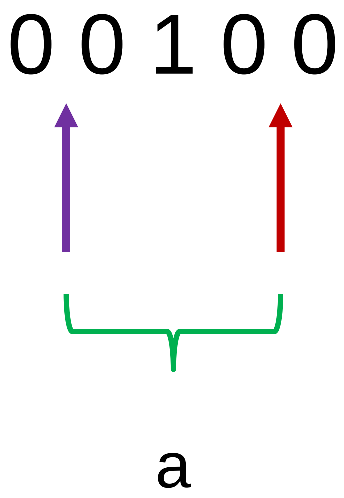
- Corresponding probability of an individual not captured during the study

$$\Pr(h_0) = \sum_{b=1}^{T} \sum_{d=1}^{T} \beta_{b-1} \left(\prod_{j=b}^{d-1} \phi_j \right) (1 - \phi_d) \left\{ \prod_{j=b}^{d} (1 - p_j) \right\}$$

$$L \propto \frac{N!}{(N-D)!} \prod_{i=1}^{D} \Pr(h_i) \times \Pr(h_0)^{N-D}$$

Stopover models

- Generalised version of the Jolly-Seber model
- Parameters are defined to be age-dependent
  - **age** corresponds to the time spent in the study area
  - arrival times and departure times are not independent



Stopover models

- Parameters
  - N: **population size**; this represents the total number of individuals who have been available for capture on at least one occasion
  - β_t: proportion of individuals first **available for capture** at occasion t+1, $\sum_{j=0}^{T-1} \beta_j=1$
  - $p_t(a)$: probability an individual which entered the study a occasions previously is **captured** at occasion t
  - $\phi_t(a)$: probability an individual present in the study area at occasion t, which entered the study a occasions previously, **remains in the study area** until occasion t+1.

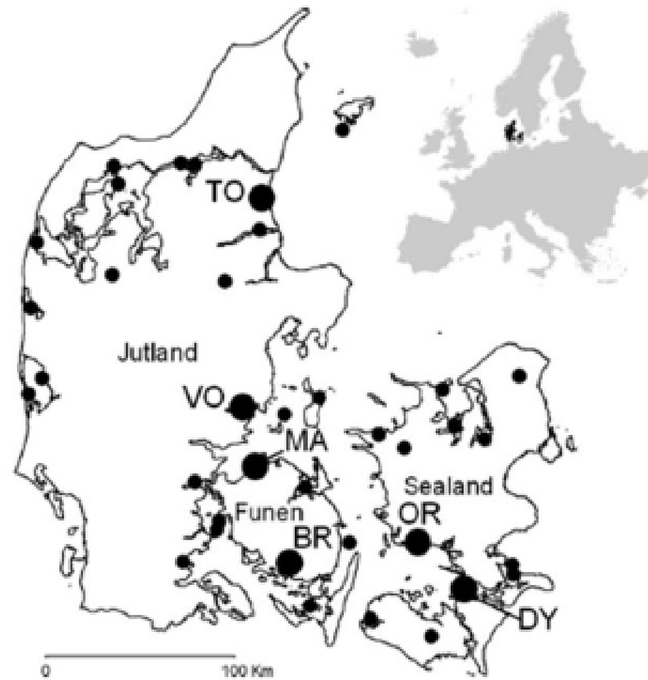
Stopover models

$$L \propto \frac{N!}{(N-D)!} \prod_{i=1}^{D} \Pr(h_i) \times \Pr(h_0)^{N-D}$$

$$\Pr(h_0) = \sum_{b=1}^{T} \sum_{d=b}^{T} \left(\beta_{b-1} \left\{ \prod_{j=b}^{d-1} \phi_j(a) \right\} \{1 - \phi_d(d-b+1)\} \left[\prod_{j=b}^{d} \{1 - p_j(a)\} \right] \right)$$

$$\Pr(h_i) = \sum_{b=1}^{f_i} \sum_{d=l_i}^{T} \left(\beta_{b-1} \left\{ \prod_{j=b}^{d-1} \phi_j(a) \right\} \{1 - \phi_d(d-b+1)\} \times \left[\prod_{j=b}^{d} p_j(a)^{x_{ij}} \{1 - p_j(a)\}^{1-x_{ij}} \right] \right),$$

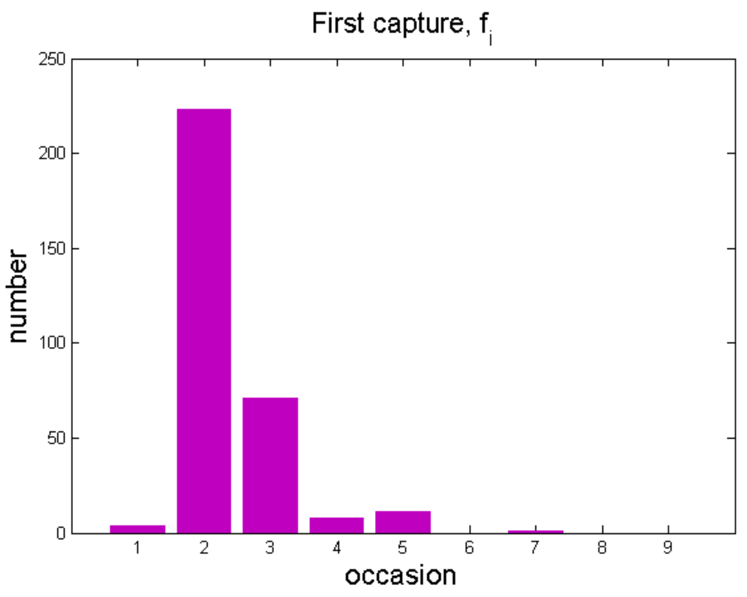
Application 1: Great cormorants

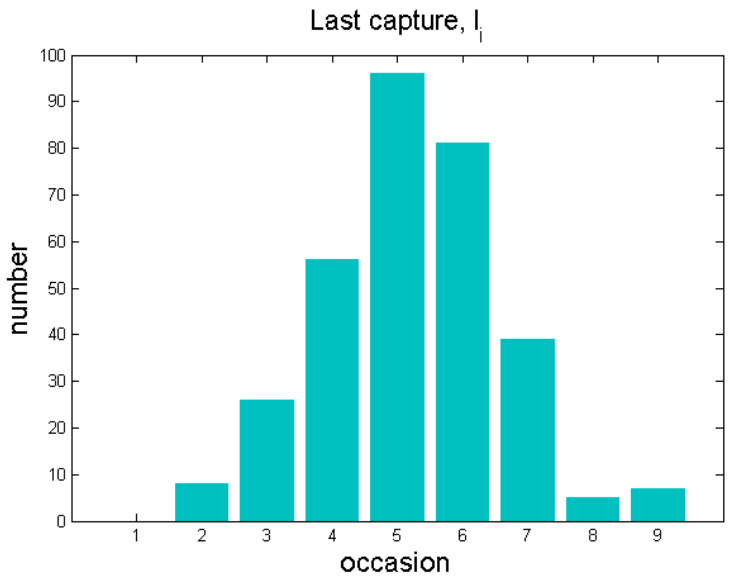


- Colony Vorsø
- Daily visits are made to the cormorant colonies during the breeding season, data summarised as monthly captures
- Records are made of whether or not the cormorants successfully breed

Application 1: Great cormorants

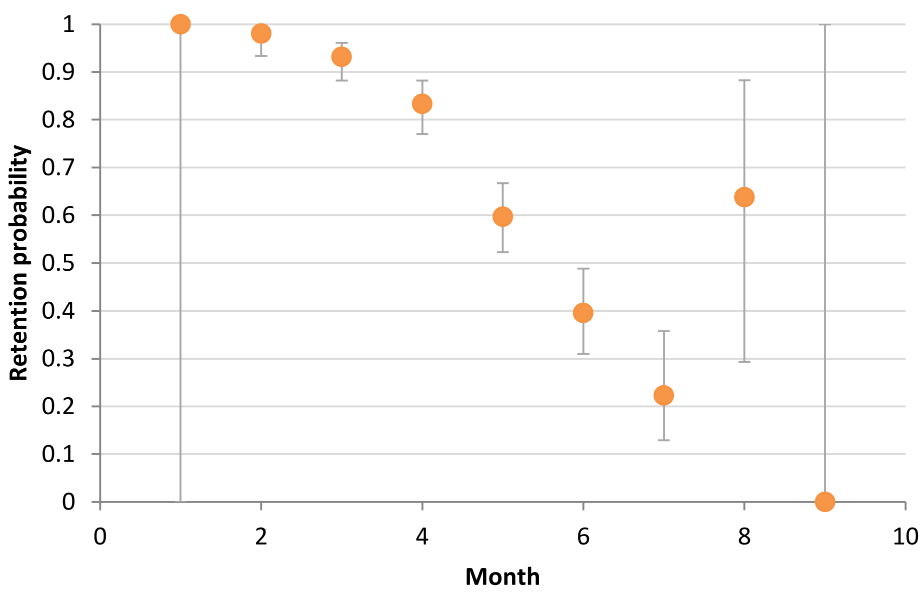
- 318 individuals
- 9 occasions – monthly February-October





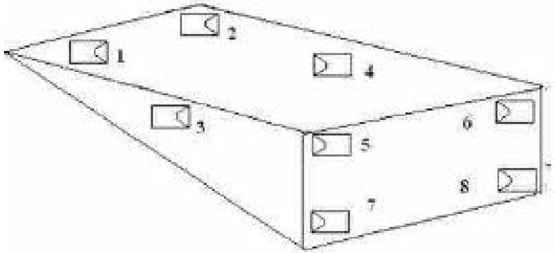
Application 1: Great cormorants

Model	AIC	ΔAIC	np	MLE of (N-D)
N,β(t),ϕ(.),p(.)	1459.38	332.32	6	11.6
N,β(t),ϕ(t),p(.)	1127.97	0.91	14	1.8
N,β(t),ϕ(a),p(.)	1156.24	29.18	14	1.2
N,β(t),ϕ(a+t),p(.)	1127.06	0.00	22	1.4



Application 2: Great crested newts

(a)



(b)

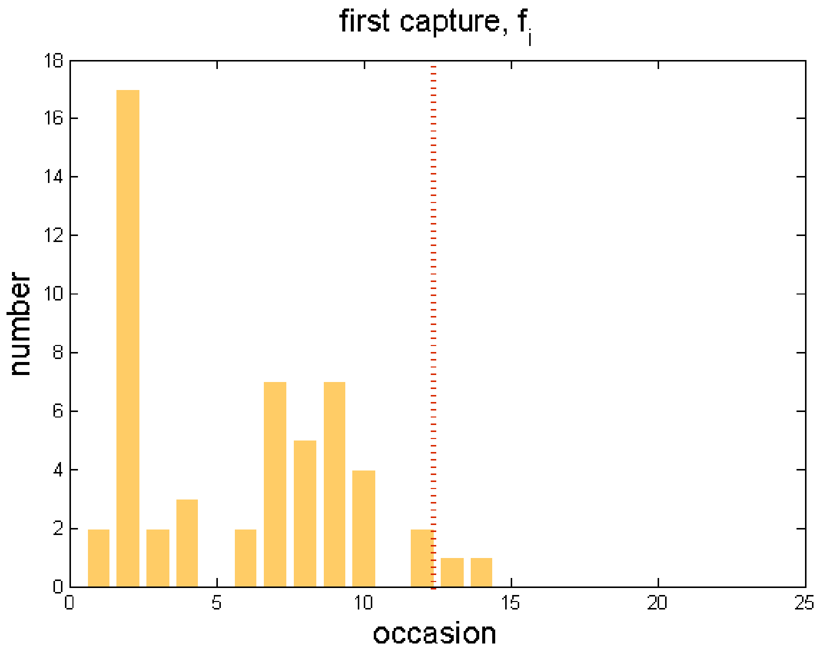
- Field study site at the University of Kent
- Data collected by Professor Richard Griffiths, Durrell Institute of Conservation and Ecology
- Data collected weekly during breeding season (February – June)

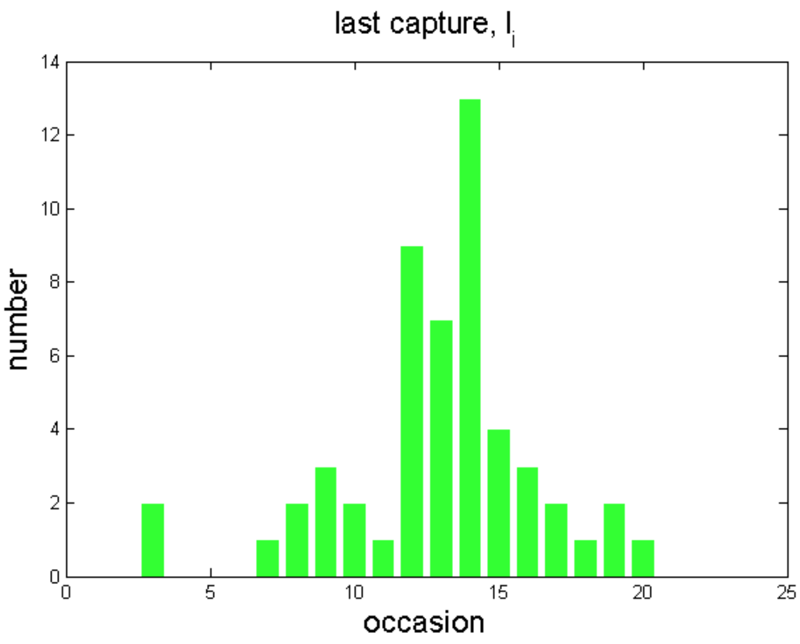
Application 2: Great crested newts

	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9	week 10	week 11	week 12	…
Jake	1												
Phillip	1	1					1		1				
Oliver		1							1				
Jennifer		1					1	1	1			1	
Woody		1							1				
Antonio		1										1	
Daniel		1											
Terri		1	1				1	1	1			1	
Pierce		1				1			1	1		1	
Norman		1											
Edith		1				1		1	1			1	
Richard		1		1		1	1		1	1			
David		1						1			1		
…													

- 2013 data – 53 individuals – 24 weeks

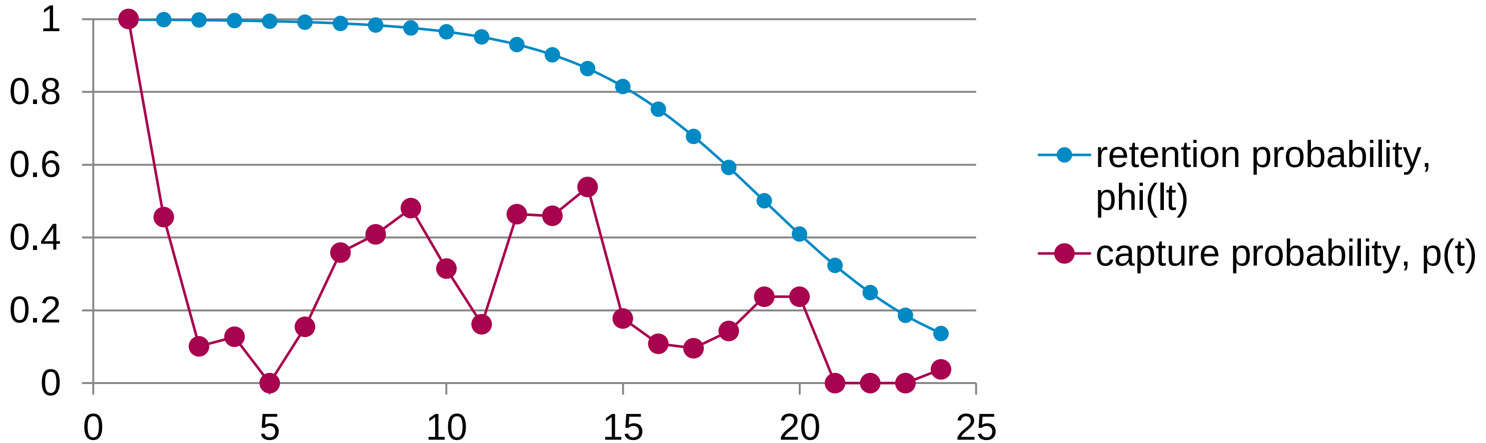
Application 2: Great crested newts





Application 2: Great crested newts

Model	AIC	ΔAIC	np	MLE of (N-D)
N,β(t),ϕ(.),p(.)	687.29	107.82	14	11.0
N,β(t),ϕ(lt),p(.)	620.72	41.25	15	1.8
N,β(t),ϕ(t),p(.)	648.72	69.25	37	1.9
N,β(t),ϕ(a),p(.)	681.53	102.06	37	0.3
N,β(t),ϕ(la),p(.)	647.26	67.80	15	1.5
N,β(t),ϕ(la),p(t)	585.24	5.77	38	1.3
N,β(t),ϕ(lt),p(t)	579.47	0.00	38	1.3



Extensions and Current Research

- Integrating capture-recapture-resighting data and counts of unmarked birds at stopover sites
  - Matechou et al, (2013a)
- Estimating age-specific survival when age is unknown:
  - Capture-recapture data (Matechou et al, 2013)
  - Ring-recovery data (McCrea et al, 2013)
- Integrating multiple years of stopover data
  - Worthington et al, (2014)
- Multisite developments
- To keep up to date with current research developments see www.rachelmccrea.co.uk

Software

- HetAge: Shirley Pledger R code
  - http://homepages.ecs.vuw.ac.nz/~shirley/
- R code:
  - Matechou et al, 2013b
- MATLAB code
  - www.capturerecapture.co.uk
- POPAN Jolly-Seber model
  - Program Mark: www.phidot.org

References

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