



Capture-recapture Some animal demography

Journée dynamique et génétique des populations
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Rémi Fraysse – Centre D'Ecologie Fonctionnelle et Evolutive (CEFE)

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Why do CMR ?

DEMOGRAPHY



Numbers ?

(CC) George Lamson



Survival ?

(CC) Diego Delso



Migrations ?

(CC) Peter Batty

What is Capture-Mark-Recapture (CMR) ?



(CC) Tony Wills

Year 1	Year 2	Year 3	Year 4	Year 5
1	0	1	1	0

Capture history, example

- 0 : Not Captured
- 1 : Captured

How to CMR ?



Rings
(CC) Tony Wills



Paint

White et al. (2020), Journal of Insect Science

How to CMR ?

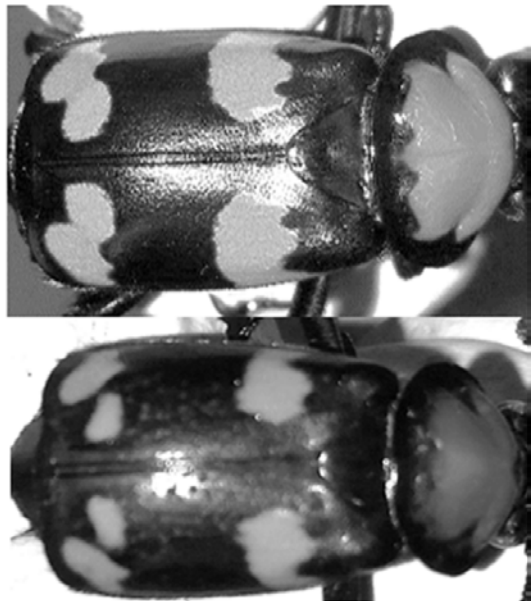


Rings
(CC) Tony Wills



Paint

White et al. (2020), Journal of Insect Science



Natural marks

Quinby et al. (2020),
Environmental Entomology



Scats (and others
eDNA samples)

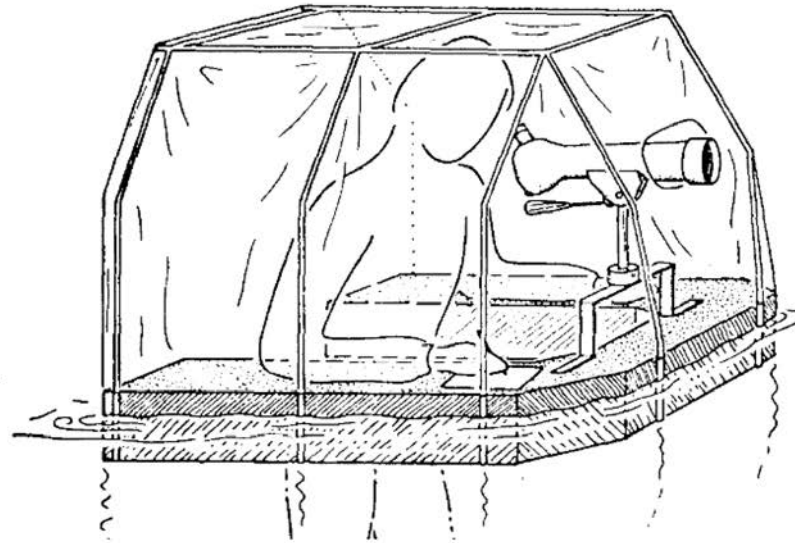
Lisa Hupp/USFWS

How to CMR ?



First capture:

- Manual
- On babies



Recaptures:

- Sight
- Adults



An aerial photograph of a massive, dense crowd of people, likely at a large-scale event or protest. The crowd is composed of individuals of various ages and ethnicities, filling the entire frame. The text 'Population size' is overlaid in the center in a large, white, sans-serif font.

Population size

**2 MILLION PEOPLE ACCORDING TO THE ORGANIZERS,
50 PEOPLE ACCORDING TO THE POLICE**

(CC) James Cridland

Model closed population

h : a capture history

	Year 1	Year 2	Year 3
h_0	0	0	0
h_1	1	0	0
h_2	0	1	0
h_3	0	0	1
h_4	1	1	0
h_5	1	0	1
h_6	0	1	1
h_7	1	1	1

Model closed population

h : a capture history

	Year 1	Year 2	Year 3	y
h_0	0	0	0	$n_0 = ?$
h_1	1	0	0	n_1
h_2	0	1	0	n_2
h_3	0	0	1	n_3
h_4	1	1	0	n_4
h_5	1	0	1	n_5
h_6	0	1	1	n_6
h_7	1	1	1	n_7

Model closed population

h : a capture history

	Year 1	Year 2	Year 3	y
h_0	0	0	0	$n_0 = ?$
h_1	1	0	0	n_1
h_2	0	1	0	n_2
h_3	0	0	1	n_3
h_4	1	1	0	n_4
h_5	1	0	1	n_5
h_6	0	1	1	n_6
h_7	1	1	1	n_7

$$y \sim \text{Multinomial}(N, P)$$

Model closed population

h : a capture history

	Year 1	Year 2	Year 3	y
h_0	0	0	0	$n_0 = ?$
h_1	1	0	0	n_1
h_2	0	1	0	n_2
h_3	0	0	1	n_3
h_4	1	1	0	n_4
h_5	1	0	1	n_5
h_6	0	1	1	n_6
h_7	1	1	1	n_7

$$y \sim \text{Multinomial}(N, P)$$

- N : Total population size
- $P = (P_{h_0}, \dots, P_{h_7})$
- p_t : probability of capture at year t (capture rate)

Model closed population


h : a capture history

	Year 1	Year 2	Year 3	y
h_0	0	0	0	$n_0 = ?$
h_1	1	0	0	n_1
h_2	0	1	0	n_2
h_3	0	0	1	n_3
h_4	1	1	0	n_4
h_5	1	0	1	n_5
h_6	0	1	1	n_6
h_7	1	1	1	n_7

$$y \sim \text{Multinomial}(N, P)$$

- N : Total population size
- $P = (P_{h_0}, \dots, P_{h_7})$
- p_t : probability of capture at year t (capture rate)

$$P_h = \prod_{t=1}^T p_t^{I(h_t > 0)} (1 - p_t)^{I(h_t = 0)}$$

A cheetah is chasing a gazelle in a savanna. The cheetah is on the right, running towards the left. The gazelle is on the left, running away from the cheetah. A thought bubble is above the gazelle, containing the text "Should have stayed in bed today". The word "Survival" is written in large white letters across the middle of the image.

Should have
stayed in bed
today

Survival

Model open population: survival

	Year 1	Year 2	Year 3	
h1	1	0	0	n1
h2	1	1	0	n2
h3	1	0	1	n3
h4	1	1	1	n4
h5	0	1	0	n5
h6	0	1	1	n6
h7	0	0	1	n7

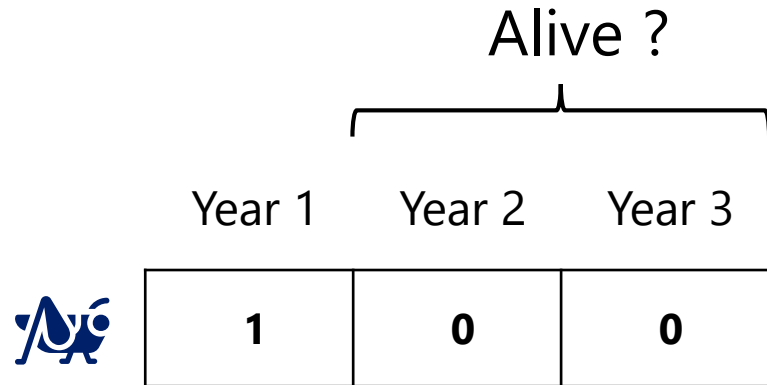
Model open population: survival

$$\mathbf{y}_1 \sim \text{Multinomial}(n_1, \mathbf{P}_1)$$

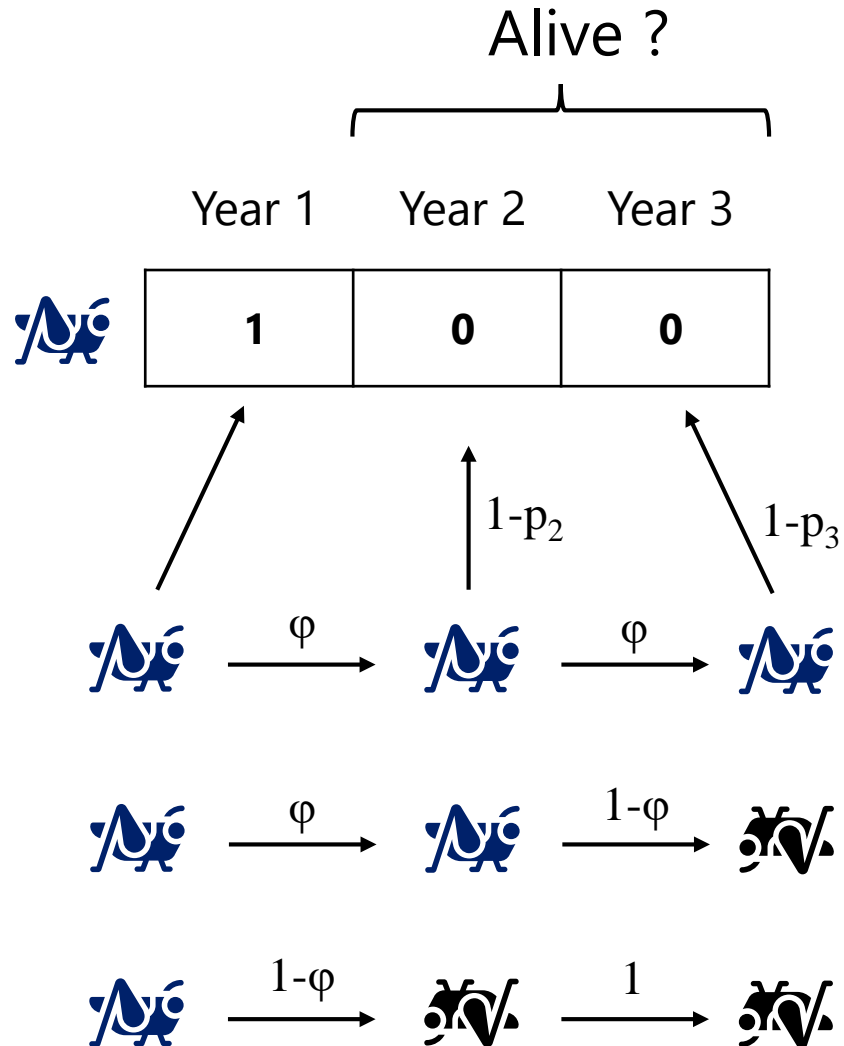
	Year 1	Year 2	Year 3		
h1	1	0	0	n1	} \mathbf{y}_1
h2	1	1	0	n2	
h3	1	0	1	n3	
h4	1	1	1	n4	
h5	0	1	0	n5	} \mathbf{y}_2
h6	0	1	1	n6	
h7	0	0	1	n7	} \mathbf{y}_3

- n_1 : Number of individual first seen at year 1
- $\mathbf{P}_1 = (P_{h1}, P_{h2}, P_{h3}, P_{h4})$
- φ : Survival probability
- p_t : probability of capture at year t (capture rate)

Model open population: survival



Model open population: survival



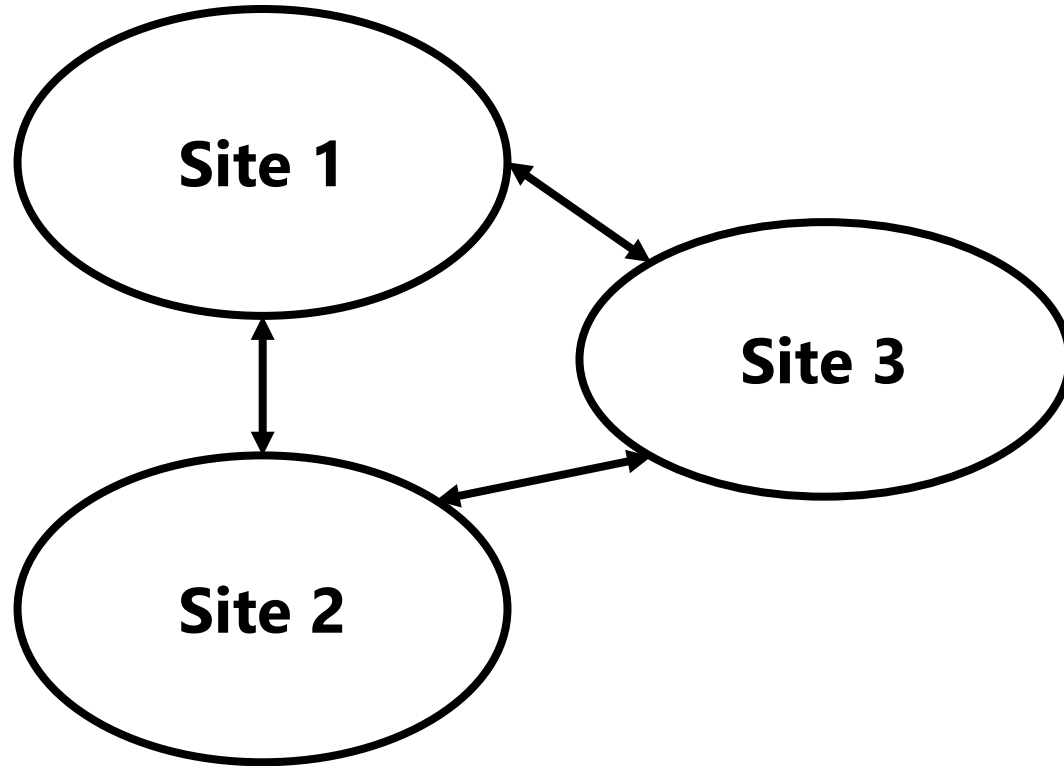
P(Unseen) :

sum over several possibilities

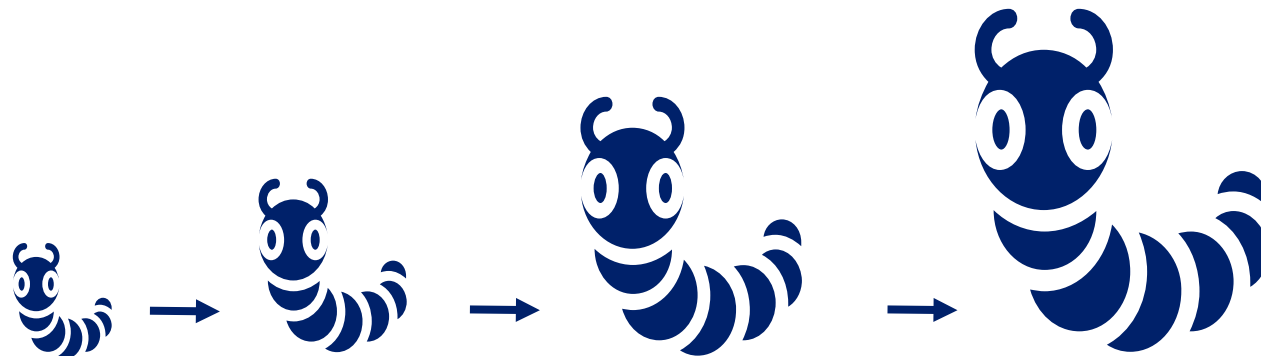
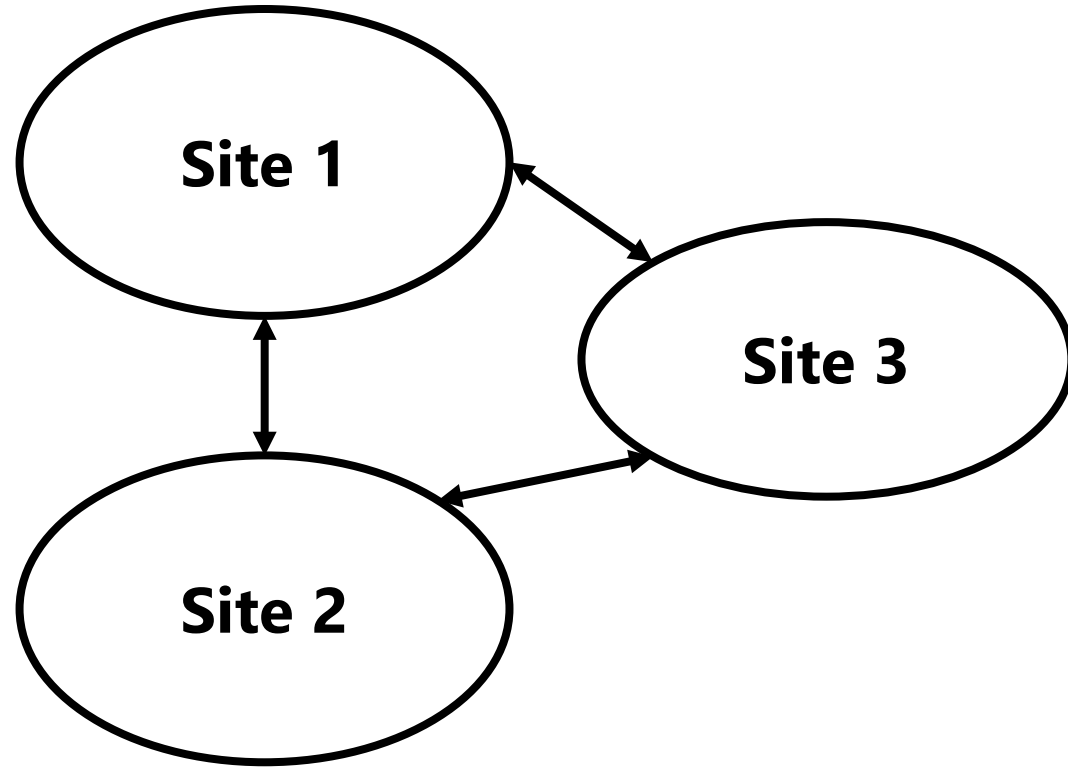
A flock of birds is silhouetted against a vibrant sunset sky. The birds are scattered across the frame, with some in the foreground and others further back. The sky transitions from a deep blue at the top to a bright orange and yellow near the horizon. A semi-transparent white rectangular box is centered over the middle of the image, containing the text "Multistate and hidden process" in a bold, white, sans-serif font. The bottom of the image shows the dark silhouette of a treeline or forest.

Multistate and hidden process

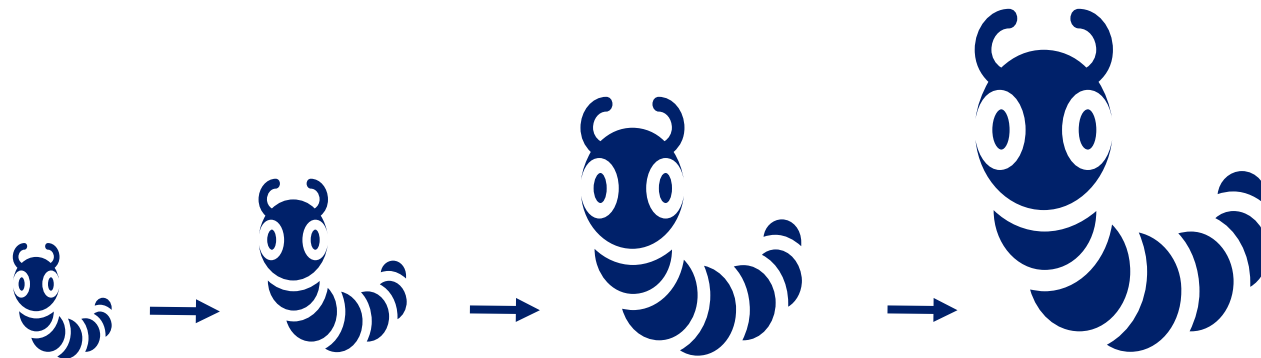
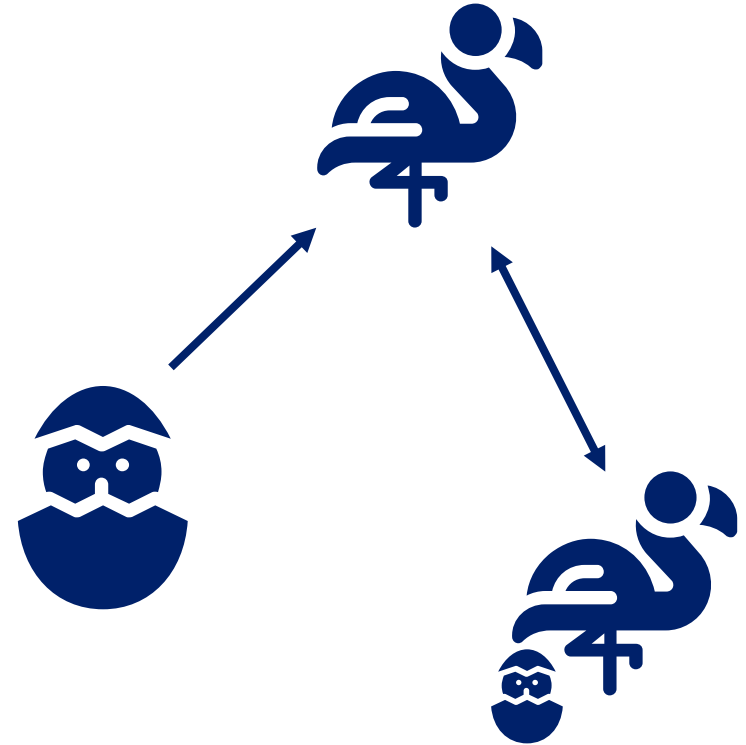
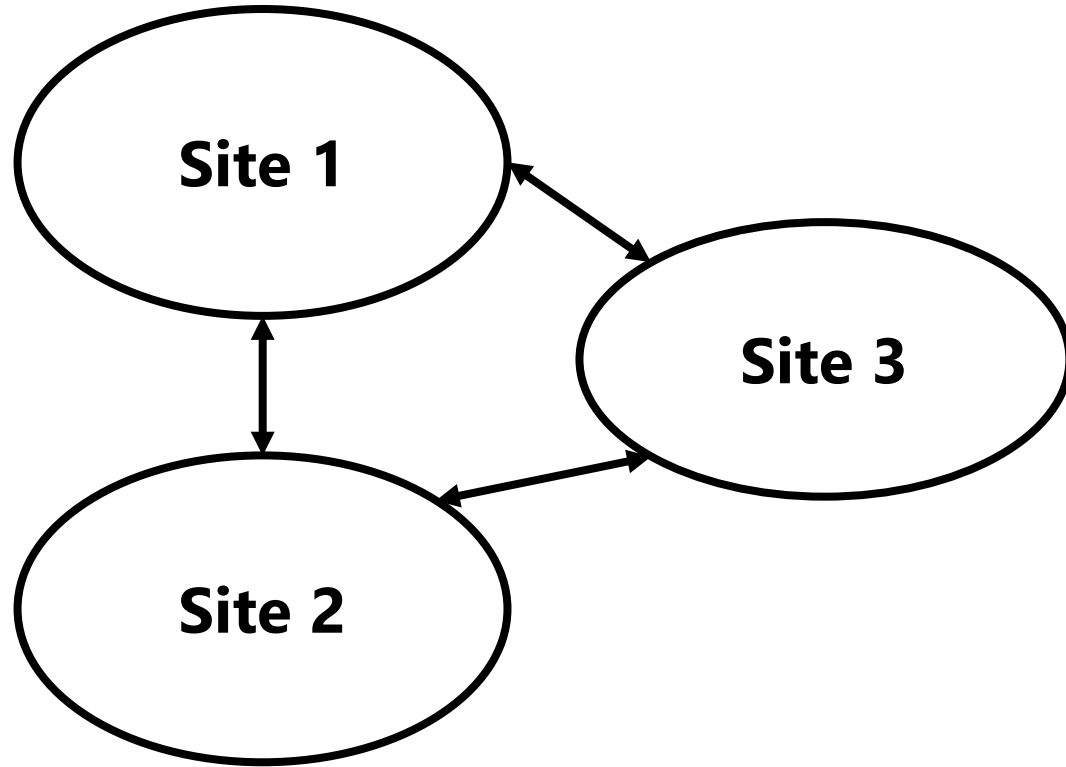
Multistate



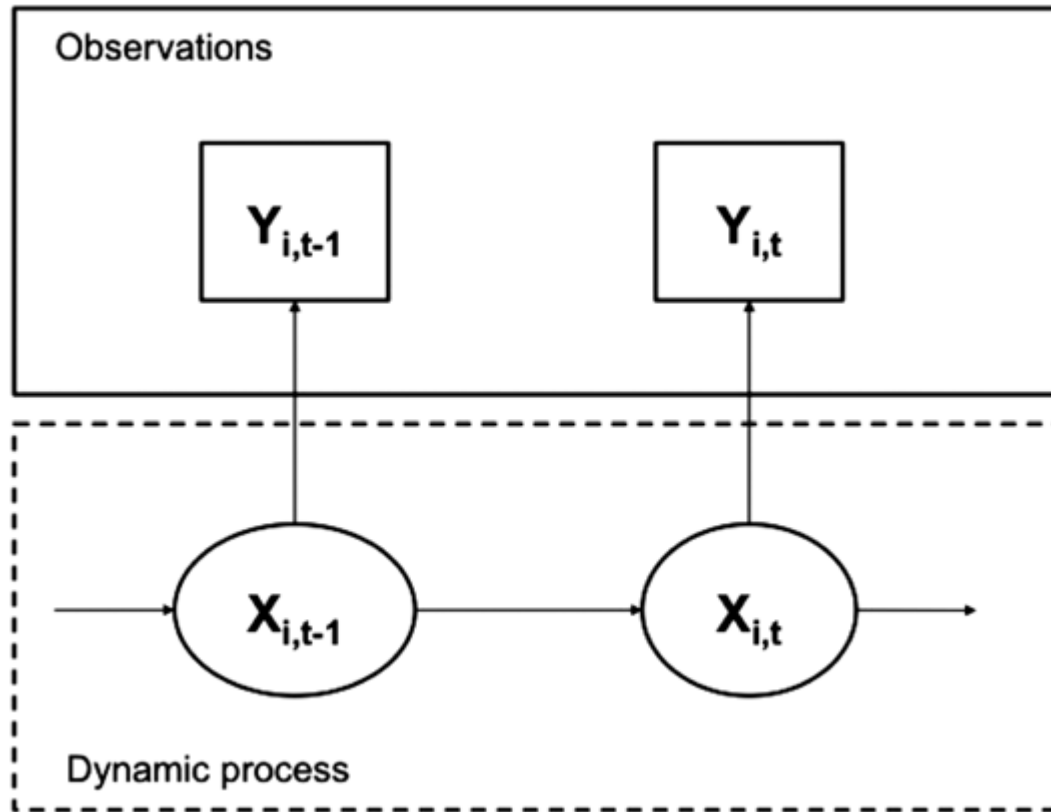
Multistate



Multistate

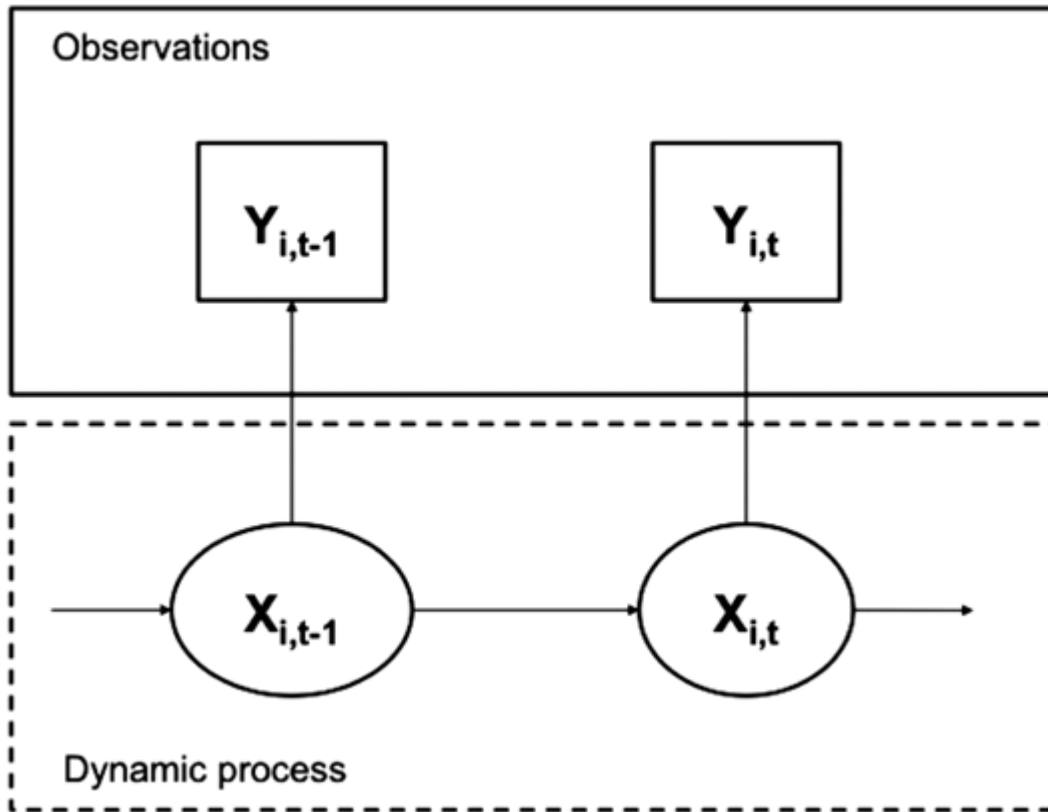


Hidden Process

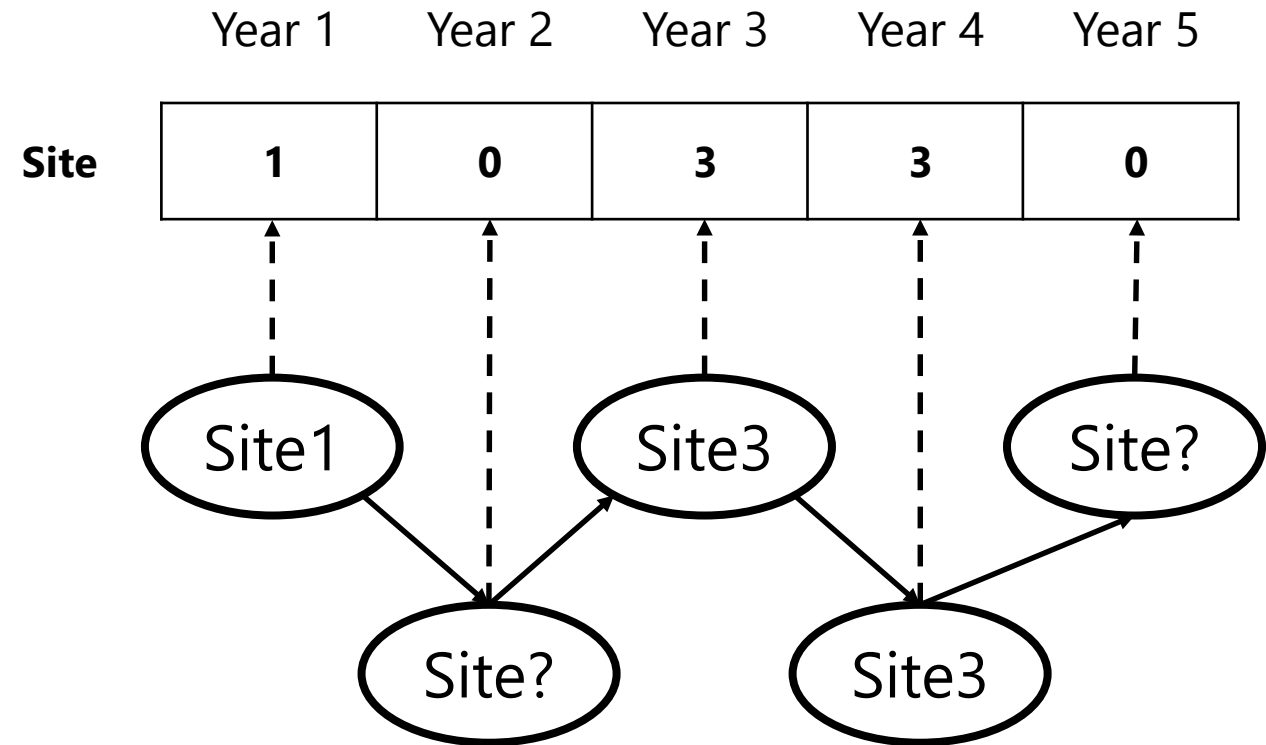


Gimenez et al. (2012),
Theoretical Population Biology

Hidden Process



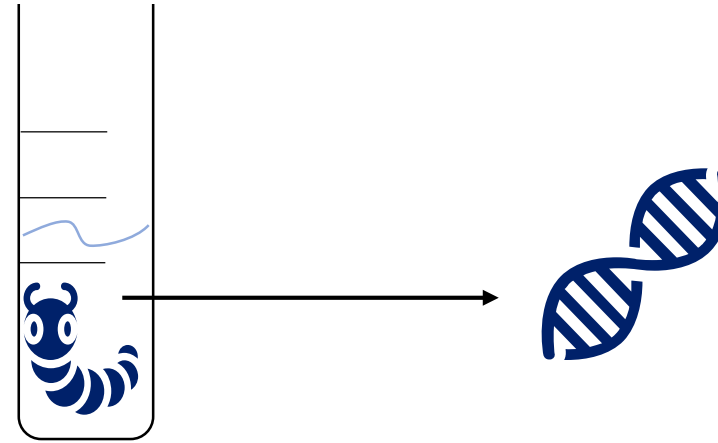
Gimenez et al. (2012),
Theoretical Population Biology



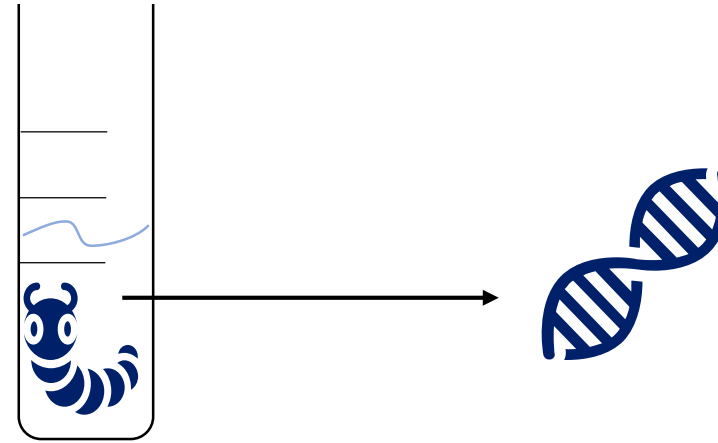
A person dressed as a ghost in a white sheet with two eye holes, holding a glowing lantern, stands in a field of tall, dry grass. The scene is dimly lit, suggesting dusk or dawn, with a dark forest in the background. A semi-transparent dark rectangle is overlaid on the center of the image, containing the title text.

Misidentifications creating ghosts

Misidentifications ?



Misidentifications ?



True History



	Day 1	Day 2	Day 3	Day 4	Day 5
Blue Worm	1	0	1	1	0

Observed History



	Day 1	Day 2	Day 3	Day 4	Day 5
Blue Worm	1	0	0	1	0
Orange Worm	0	0	1	0	0

Misidentifications ?

Observed Histories

Jour 1	Jour 2	Jour 3	Jour 4	Jour 5
1	1	0	0	0
1	0	0	1	0
0	0	1	0	0

y : Observed histories frequencies

$$y|N \sim \text{Multinomial}$$

Yoshizaki et al. (2011)

Link et al. (2010)

Misidentifications ?

Observed Histories

Jour 1	Jour 2	Jour 3	Jour 4	Jour 5
1	1	0	0	0
1	0	0	1	0
0	0	1	0	0

y : Observed histories frequencies

~~$y|N \sim \text{Multinomial}$~~

Yoshizaki et al. (2011)

Link et al. (2010)

Misidentifications ?

Observed Histories

Jour 1	Jour 2	Jour 3	Jour 4	Jour 5
1	1	0	0	0
1	0	0	1	0
0	0	1	0	0

Latent Histories

Jour 1	Jour 2	Jour 3	Jour 4	Jour 5
1	1	0	0	0
1	0	2	1	0

y : Observed histories frequencies

x : Latent histories frequencies

~~$y|N \sim \text{Multinomial}$~~

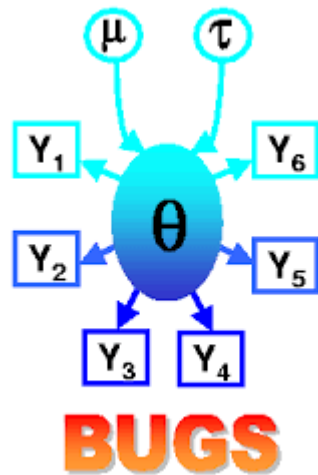
$x|N \sim \text{Multinomial}$

Estimating for real

A missing bracket?

Damn it!

Code ?



- BUGs: **B**ayesian inference **U**sing **G**ibbs **S**ampling)

```
model{
  # Priors
  phi ~ dbeta(1, 1)
  p ~ dbeta(1, 1)

  # Likelihood
  for(i in 1:nb_ind){
    # Known to be alive on first occasion
    z[i, f1[i]] <- 1

    for(t in (f1[i] + 1):nb_occ){
      # State model
      z[i, t] ~ dbern(phi * z[i, t - 1])

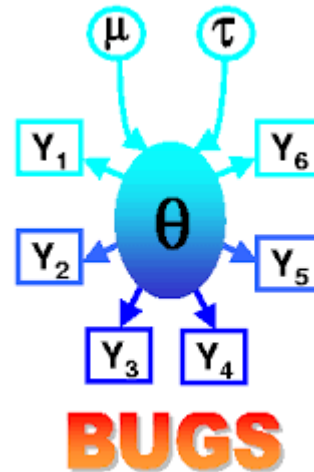
      # Observation model
      y[i, t] ~ dbern(p * z[i, t])
    }
  }
}
```

CJS model, BUGs

Software



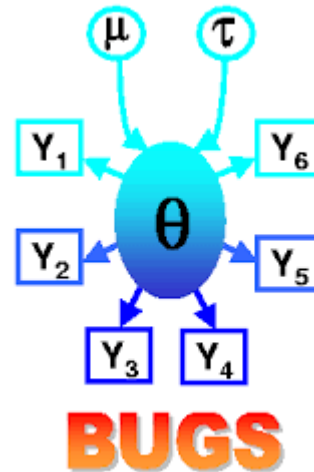
- Mark / RMark
- WinBUGs →
- Jags / Rjags →
- NIMBLE →



Software

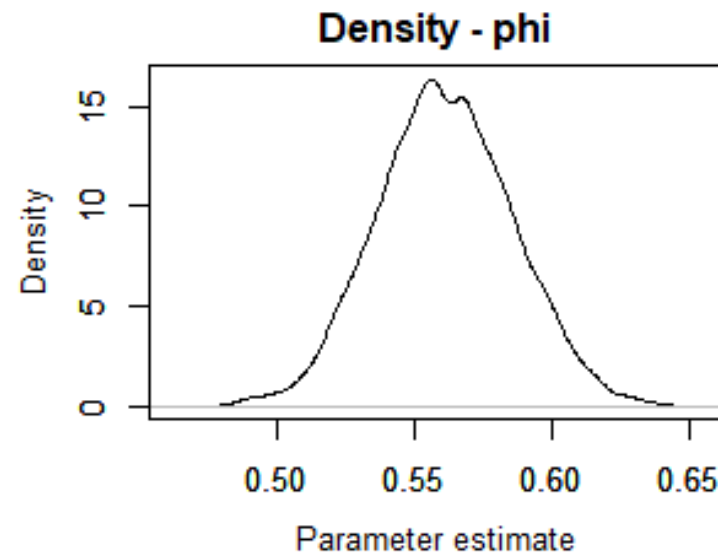
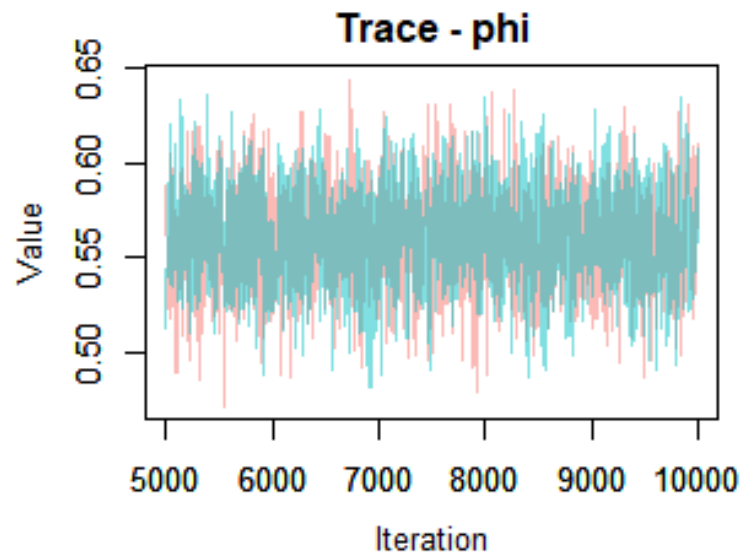
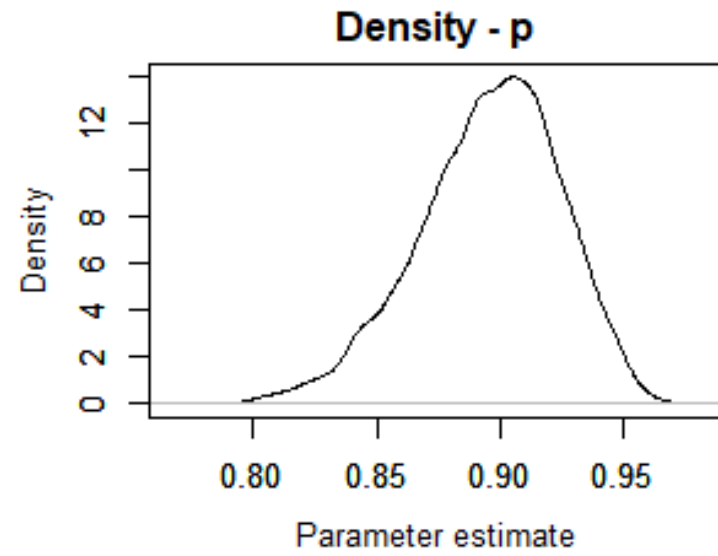
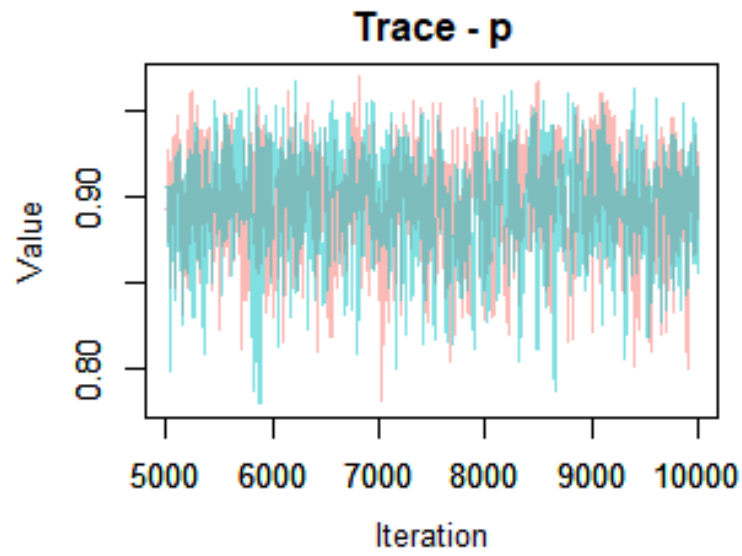


- Mark / RMark
- WinBUGs →
- Jags / Rjags →
- NIMBLE →



Example : American dipper





A middle-aged man with white hair and a goatee, wearing a light blue button-down shirt, is sitting in a brown leather chair. He is smiling broadly and giving a thumbs-up gesture with his right hand. The background is a bright, slightly blurred indoor setting with a window, a clock, and a wicker lampshade. A semi-transparent grey box is overlaid on the image, containing the word "Conclusion" in white text.

Conclusion

Other things

- Covariates: Survival = $f(\text{environment})$
- Heterogeneity
- Model selection – AIC
- Goodness of fit
- Spatial
- CKMR

Take Home message

- Estimation of Demography
 - abundance,
 - survival,
 - migrations,
 - effects of environmental variables
- Powerful methods
- But require big fieldwork

