Modeling Population Dynamics Using Count Data

Outline

A. Objectives, background

B. Traditional models of population dynamics

  – Exponential, logistic, Ricker, Gompertz, etc...

  – State-space models, *a la* De Valpine and Hastings (2002)

  – **R** exercise

C. Open population N-mixture models

  – Kery et al. (2009) model

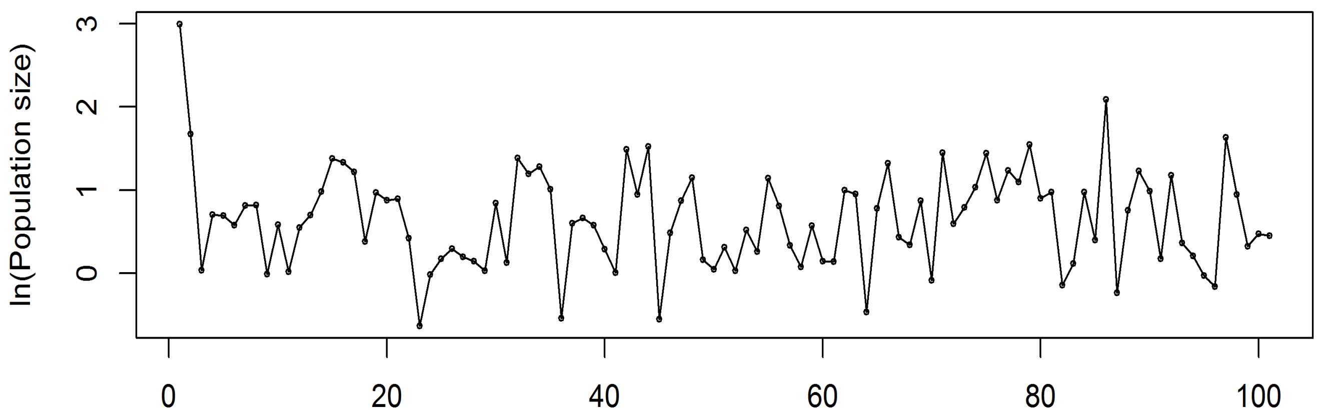
  – Dail and Madsen (2011) model

  – **R** exercise

Objectives

Traditional models

- Estimate population growth rate
- Demographic contributions to growth
- Population viability analysis
- Test for density dependence



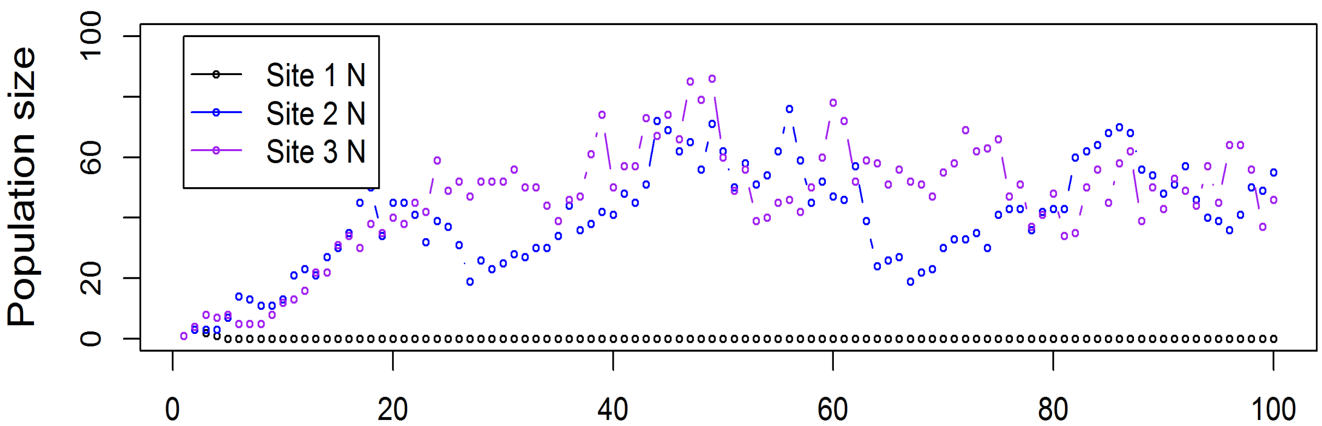
Objectives

Traditional models

- Estimate population growth rate
- Demographic contributions to growth
- Population viability analysis
- Test for density dependence

N-mixture models

- Estimate population size
- Model spatial variation in abundance
- Account for imperfect detection



Demographic Contributions to Population Growth

Open population: A population whose abundance (N) changes during some time interval due to births (B), deaths (D), immigration (I) or emigration (E).

$$N_t = N_{t-1} + B + I - D - E$$

Demographic Contributions to Population Growth

Impossible to estimate each of these parameters without marked individuals.

But we (possibly) can estimate reduced information parameters.

$$\left.\begin{array}{l}\text{Births}\\[1em]\text{Immigation}\end{array}\right\}\text{Recruitment rate}$$

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Modeling Approaches

Non-spatial, vital rates not estimated

- Count data (May, 1976; De Valpine and Hastings, 2002; Dennis et al., 2006)

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Spatial, vital rates not estimated

- Count data (Kery et al., 2009)

Spatial, vital rates possibly estimated

- Capture-recapture data (Nichols et al., 2000; Gardner et al., 2010)
- Count data (Dail and Madsen, 2011)

Classical Models of Population Growth

Exponential

$$N_{t+1} = N_t e^r = N_t \lambda$$

Logistic

$$N_{t+1} = N_t r(1 - N_t/K)$$

Ricker

$$N_{t+1} = N_t e^{r(1-N_t/K)}$$

Gompertz

$$X_{t+1} = a + cX_t$$

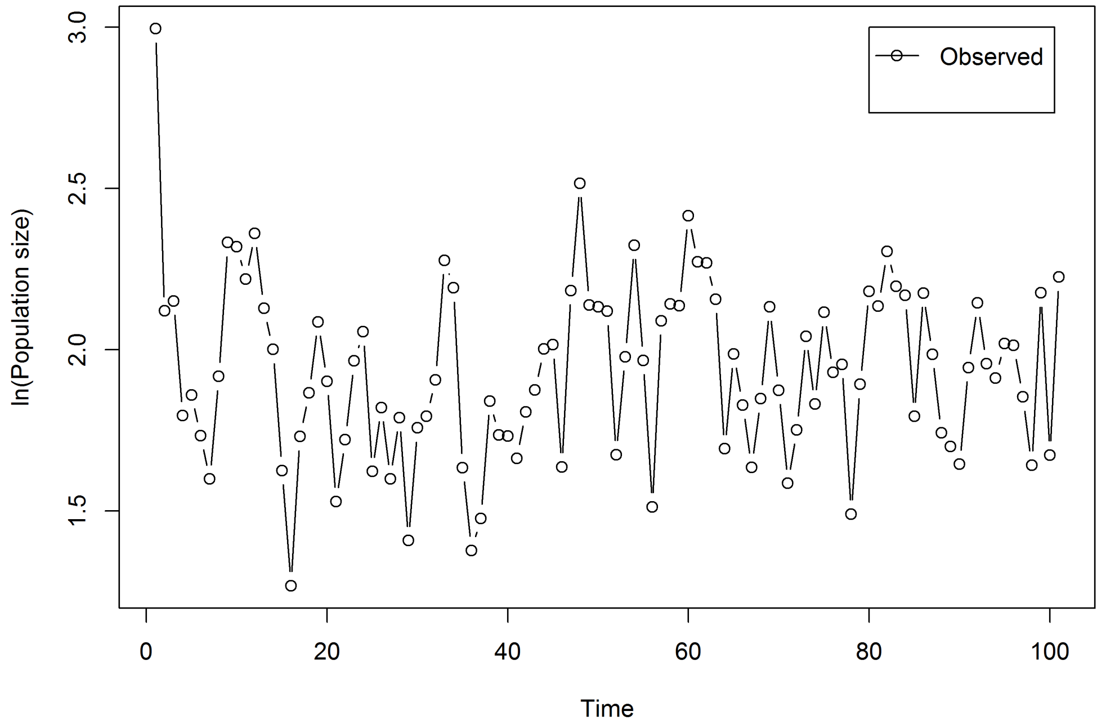
State-space Models

Estimate process noise and observation error.

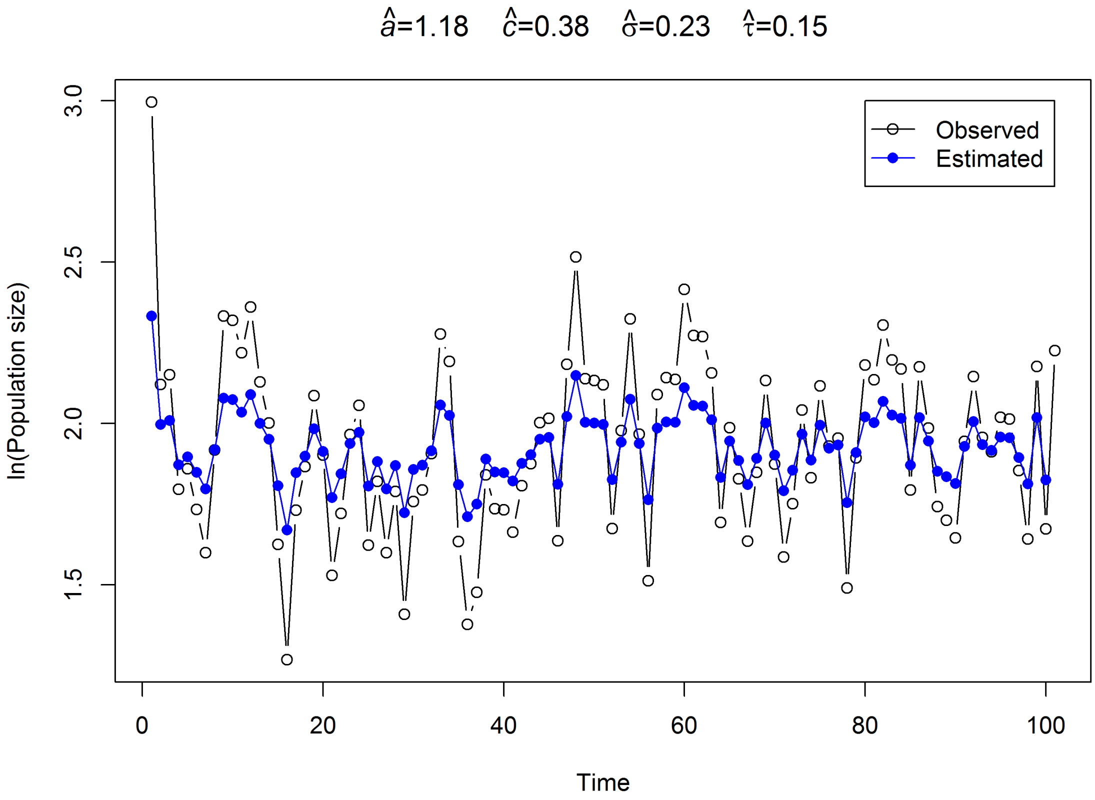
$$X_{t+1} = a + cX_t + \epsilon_t$$
$$\epsilon_t \sim \text{Normal}(0, \sigma^2)$$
$$Y_t \sim \text{Normal}(X_t, \tau^2)$$

X_t = log-transformed abundance at time t
σ^2 = variance of random process variation
Y_t = log-transformed count at time t
τ^2 = variance of random observation error
a = intrinsic rate of increase
c = strength of density dependence

State-space Models



State-space Models



R exericise:

Fitting State-space Models

OPEN script-state-space.R

State-space Models

Limitations of standard state-space models

- Ignore spatial variation
- Implausible model for observation error
- Demographic contributions to pop growth ignored
- Parameters are weakly identified

Open Population N-mixture Models

Key advantages

- Spatial and temporal variation can be modeled
- Observation error has clear interpretation
- Actual population size can be estimated in some cases

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Three varieties

- Temporary emigration (Chandler et al., 2011)
- Trend (Kery et al., 2009)
- Demographic (Dail and Madsen, 2011)

Open Population N-mixture Models

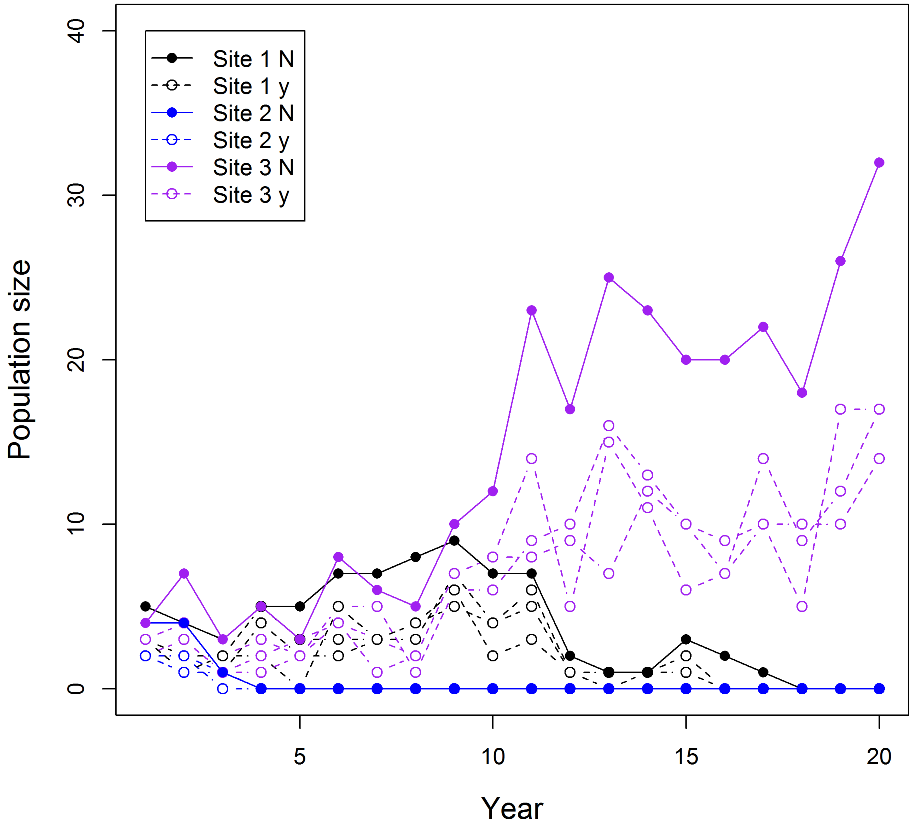
- Data

  y_{ijt} = count at site i during secondary period j within primary period t.

Table 1: Count data with $R = 4$ sites, $T = 2$ primary periods and $J = 3$ secondary periods.

	Season 1			Season 2		
	visit 1	visit 2	visit 3	visit 1	visit 2	visit 3
site1	3	3	2	0	0	0
site2	0	0	0	2	4	3
site3	2	0	0	0	0	2
site4	0	0	2	0	0	1

Open Population N-mixture Models



Open Population N-mixture Models

Closed population model (Royle, 2004)

$$N_i \sim \text{Poisson}(\lambda_i)$$
$$y_{ij} \sim \text{Binomial}(N_i, p)$$

N_i — latent variable, population size at site i
λ_i — expected population size at site i
p — detection probability

Open Population N-mixture Models

Temporary emigration model (Chandler et al., 2011)

$$
\begin{aligned}
M_i &\sim \text{Poisson}(\lambda) \\
N_{it} &\sim \text{Binomial}(M_i, \phi) \\
y_{ijt} &\sim \text{Binomial}(N_{it}, p)
\end{aligned}
$$

M_i — latent variable, super population size at site i
N_{it} — latent variable, abundance at site i during time t
λ — expected superpopulation size
ϕ — probability of being exposed to sampling (1-temporary emigration)
p — detection probability

Open Population N-mixture Models

Trend model (Kery et al., 2009)

$$
\begin{aligned}
N_{it} &\sim \text{Poisson}(\lambda_{it}) \\
\log(\lambda_{it}) &= \alpha + r \times \text{year}_t \\
y_{ijt} &\sim \text{Binomial}(N_{it}, p)
\end{aligned}
$$

where

N_{it} = abundance at site i during year t
λ_{it} = expected abundance at site i during year t
r_i = is a “trend” parameter
y_{ijt} = observed count at site i, replicate j, and year t
p = detection probability

Open Population N-mixture Models

R exericise:

Fit Kery et al. (2009) N-mixture model to lizard data using `JAGS`

OPEN script-lizard.R

Open Population N-mixture Models

Demographic model (Dail and Madsen, 2011)

$$
\begin{aligned}
N_{i1} &\sim \text{Poisson}(\lambda) \\
S_{it} &\sim \text{Binomial}(N_{it-1}, \omega) \\
G_{it} &\sim \text{Poisson}(N_{it-1}\gamma) \\
N_{it} &= S_{it} + G_{it} \\
y_{ijt} &\sim \text{Binomial}(N_{it}, p)
\end{aligned}
$$

N_{it} — latent variable, abundance at site i during year t
S_{it} — latent variable, survivors
G_{it} — latent variable, recruits
λ — mean abundance during $t = 1$
ω — apparent survival
γ — recruitment rate
p — detection probability

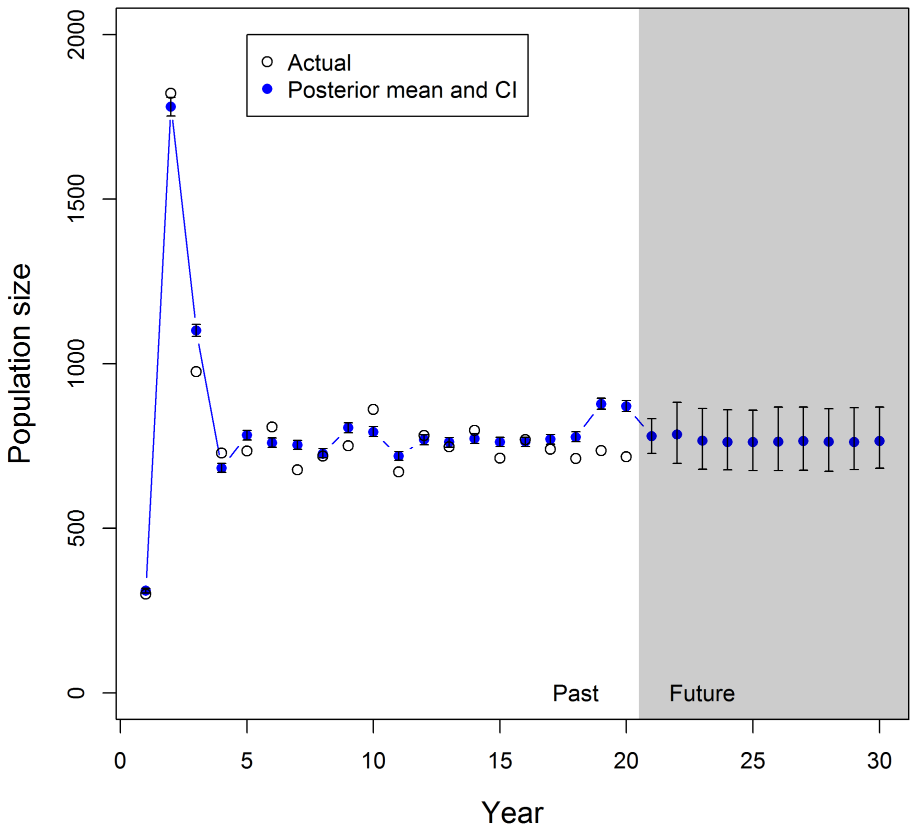
Open Population N-mixture Models

Simpler alternative, exponential growth model

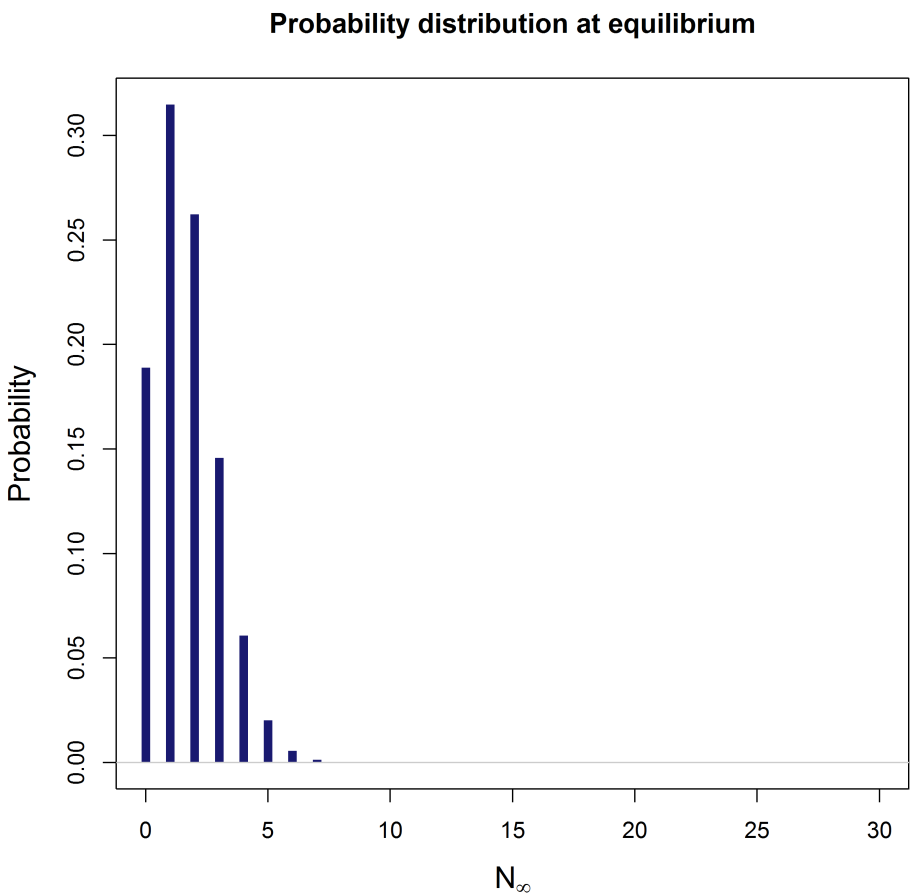
$$N_{i1} \sim \text{Poisson}(\lambda)$$
$$N_{it} \sim \text{Poisson}(\gamma N_{it-1})$$
$$y_{ijt} \sim \text{Binomial}(N_{it}, p)$$

N_{it} — latent variable, abundance at site i during year t
λ — mean abundance during $t = 1$
γ — finite rate of increase
p — detection probability

Population projections



Population projections



Exercise

photo credit: Mikey Lutmerding

Open Population N-mixture Models

R exericise:

Fit open N-mixture models to simulated data and BBS data using `pcountOpen` and `JAGS`

OPEN script-dailMad.R

References

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