Capture-recapture Models for Open Populations (CJS)

Population Modeling
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Capture-recapture Models for Open Populations

- Open: gains and losses of animals between sampling periods
- Studies typically conducted over longer time periods
- Estimation focus is on survival, population size and recruitment

Cormack (1964)

- Estimated survival rates of fulmars
- Capture-resighting data of G. Dunnet
- Captures and resightings at the breeding colony each year
- Estimated annual survival, 0.94

Capture History Data

Row vector of 1's (indicating capture/resighting) and 0's (indicating no capture/resighting)

Examples:

10110010 Caught in periods 1,3,4,7 of an 8-period study

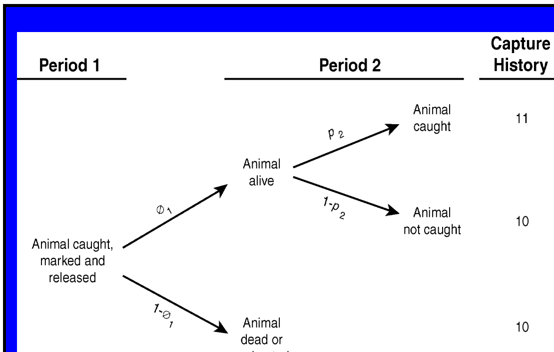
01101011 Caught in periods 2,3,5,7,8 of an 8-period study

Conditional Modeling of Capture History Data

Model parameters under the Cormack-Jolly-Seber (CJS) single-age model:

ϕ_i = survival probability, i to i+1

p_i = capture probability at time i



Conditional Capture History Modeling

$$P(10110|\text{Release in }1) = \phi_1(1-p_2)\phi_2 p_3 \phi_3 p_4 (1-\phi_4 p_5)$$

$$P(01001|\text{Release in }2) = \phi_2(1-p_3)\phi_3(1-p_4)\phi_4 p_5$$

Parameter Estimation

- Multinomial likelihood, conditional on new releases in each sample period
- Data: numbers of new releases each period and number of animals with each capture history
- Model: probability structure for each capture history
- Maximum likelihood (e.g., program MARK)

CJS Model Assumptions

- All marked animals within stratum have similar capture and survival probabilities at time *i*
- Marks are not lost, overlooked or incorrectly recorded
- Mortality during the sampling period is negligible
- Independence of fates (affects variance estimates only)

Program MARK

- Computes parameter estimates and measures of uncertainty (variances, confidence intervals)
- Computes model selection statistics (AIC)
- Computes likelihood ratio tests between competing models
- Other software available: e.g., MSURGE, ESURGE

Developments and Uses

- Capture-history dependence (trap responses in survival and capture probabilities)
- Time-specific (e.g., environmental) covariates
- Multiple groups (e.g., sexes, treatments, habitats)
- Individual covariates (for static covariates such as mass at fledging)

Capture-history Dependence

- Trap response in capture probability
  - Animals have different *p* depending on whether or not they were caught the previous period
- Trap response in survival probability
  - Marked and unmarked animals have different ϕ

Capture-history Dependence in *p*

$$P(1011 | \text{Release in } 1) = \phi_1(1-p_2)\phi_2 p'_3 \phi_3 p_4$$

$$P(1001 | \text{Release in } 1) = \phi_1(1-p_2)\phi_2(1-p'_3)\phi_3 p'_4$$

p_i = capture probability for animals caught at *i-1*
p'_i = capture probability for animals not caught at *i-1*

Capture-history Dependence in ϕ: Initial Marking Effect

$$P(1011 | \text{Release at } 1) = \phi'_1(1-p_2)\phi_2 p_3 \phi_3 p_4$$

$$P(0111 | \text{Release at } 2) = \phi'_2 p_3 \phi_3 p_4$$

ϕ = survival probability for marked animals

ϕ'_i = survival probability for (previously) unmarked animals

Transient Parameterization

$$\phi_i = \phi_i^r$$

$$\phi_i' = \tau_i \phi_i^t + (1-\tau_i)\phi_i^r = (1-\tau_i)\phi_i^r$$

because $\phi_i^t = 0$

ϕ_i^r = survival of residents

ϕ_i^t = survival of transients

τ_i = proportion transients among unmarked

Covariate Modeling: Time- and Group-Specific

- Older approach:
  - Estimate parameters, e.g. θ_t
  - Use regression approach to estimate relationship between θ_t and time-specific covariate, x_t
- Current approach: build model directly into likelihood and estimate relationship directly in 1 step

Covariate Modeling: Time- and Group-Specific

- Frequently use linear-logistic model:

$$\phi_t = \frac{e^{(\beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + ...)}}{1 + e^{(\beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + ...)}}$$

- Estimate β's directly (sometimes called "ultrastructural modeling")

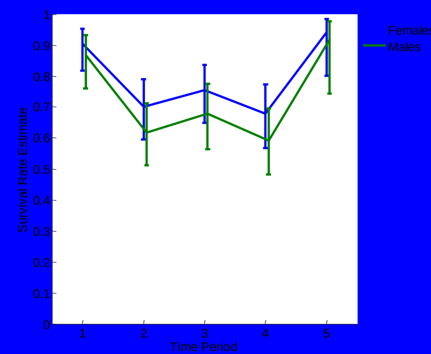
Linear-logistic Modeling: Parallel Group Effects

- Additive models with time and group effects but no time-group interaction
- Hypothesis is that parameter may differ by group (*g*) and over time (*t*), but temporal variation occurs in parallel

$$\phi_t^g = \frac{e^{(\beta_0 + \beta_1 * g + \beta_2 * t)}}{1 + e^{(\beta_0 + \beta_1 * g + \beta_2 * t)}}$$

Linear-logistic Modeling: Parallel Group Effects

- Example: time- and sex-specificity of 6-week survival in meadow voles, *Microtus pennsylvanicus*, Patuxent Wildlife Research Center



Covariate Modeling: Individual Covariates

- Each captured animal has 1 or more associated covariates
- Ask whether covariate is related to survival or capture probabilities
- Restriction: covariate applies to animal for duration of study (i.e., individual covariate cannot vary over time)
- For time-varying covariates use multistate modeling or newer continuous models

Estimation of Abundance and Recruitment

- Approaches developed by Jolly (1965) and Seber (1965) independently of Cormack (1964) and each other
- Use same kind of modeling as Cormack, but extended to abundance estimation
- Basic idea is to apply the *p* estimated based on marked animals to unmarked animals as well
- So abundance is estimated as:
  (marked + unmarked animals in catch) / (estimated capture probability)

Estimation of Abundance, N_i, and Recruitment From i to i+1, B_i

$$\hat{N}_i = \frac{n_i}{\hat{p}_i}$$

$$\hat{B}_i = \hat{N}_{i+1} - \hat{N}_i \hat{\phi}_i$$

n_i= number of animals caught/detected at sample period i

Special Application: Estimation of Birds Passing Through a Migration Stopover Site

$$\hat{N}^* = \hat{N}_1 + \sum_{i=1}^{K-1} \hat{B}_i$$

where N^* = total birds passing through site over the interval $(1, K)$

Estimation of Abundance, N_i, and Recruitment From i to i+1, B_i

- Key assumption needed for JS abundance and recruitment estimation not needed for CJS survival estimation
- Marked and unmarked animals have similar capture probabilities