Modeling pair-wise dependent capture outcomes in mark-recapture experiments

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Introduction

Mark-recapture models often formulate the model likelihood as a product of individual likelihood components, thereby assuming independence among individuals. However, there exist many non-trivial situations, such as mating pairs, where we can expect to observe a dependency between individuals.

We present an extension of the multistate space Cormack-Jolly-Seber (CJS) model proposed by Gimenez et al (2007) that accommodates a pair-wise dependency in capture outcomes among individuals within a mating pair.

Motivation: McLeod River Harlequin Duck Study

The motivation comes from a long-term study of harlequin ducks (12 years) in the McLeod river region located Alberta, Canada. Harlequin ducks typically exhibit long term pair bonds, which are formed on the wintering grounds (West Coast) prior to their migration to the McLeod river region for reproduction. In addition to basic capture histories, this study has maintained an in-depth database of all mating pairs throughout the 12 years duration.

Model Development

We assume all mating pairs are formed prior to the start of the experiment (i.e. on the wintering ground), that a linear dependence in capture outcomes exists within mating pairs (but with independence between pairs) and the process of survival is independent. We will be consider an experiment with T capture occasion.

For mating pair j there are four possible female/male pair states: alive/alive, alive/dead, dead/alive and dead/dead. Let \( Z_{j,s} \) be a random state vector talking the values (1, 0, 0, 0), (0, 1, 0, 0), (0, 0, 1, 0) and (0, 0, 0, 1) to represent these states on occasion \( s \). Individuals without mates will be restricted to two of the possible four states depending on sex.

The fundamental model parameters are as follows:

\[ \phi_{s,t} \] - Survival probability for \( t + 1 \) for an individual of sex \( s \) \in \{M, F\} in pair \( j \) on occasion \( t \).

\[ p_{s,t} \] - Marginal capture probability for an individual of sex \( s \) \in \{M, F\} in pair \( j \) on occasion \( t \).

\[ \rho \] - Correlation coefficient between capture outcomes for paired individuals.

Our formulation assumes that a linear dependence occurs in the capture outcomes of the 12 years duration.

In addition to basic capture histories, the study of harlequin ducks (12 years) in the McLeod river region located Alberta, Canada. Harlequin ducks typically exhibit long term pair bonds, which are formed on the wintering grounds (West Coast) prior to their migration to the McLeod river region for reproduction. In addition to basic capture histories, the study has maintained an in-depth database of all mating pairs throughout the 12 years duration.

Example (Simulation Study)

Table 2: Parameter estimates from the simulation study (n = 1200) for the proposed rho-CJS model (fit with WinBUGS) and a regular CJS model (fit with MARK)

\[ \begin{array}{cccccc}
\text{Model} & \text{Parameter} & \text{True Value} & \text{Est. (MARK)} & \text{SD (MARK)} & \text{Est. (WinBUGS)} & \text{SD (WinBUGS)} \\
\hline
\text{rho} & 0 & 0.006 & 0.7053 & 0.0057 & 0.0067 & 0.7642 & 0.0066 \\
\text{phi} & 0 & 0.666 & - & 0.6638 & 0.0097 & 0.6449 & 0.6833 \\
\text{phi} & 1 & 0.68 & - & 0.6778 & 0.0096 & 0.6719 & 0.6830 \\
\text{phi} & 2 & 0.066 & - & 0.066 & 0.0088 & 0.066 & 0.047 \\
\text{phi} & 3 & 0.006 & - & 0.006 & 0.0087 & 0.0064 & 0.0388 \\
\end{array} \]

Table 3: Probabilities for pair-wise capture outcomes among female and male of mating pair.

\[ \begin{array}{c|cccc}
Y_{1,0} & Y_{1,1} & Y_{1,2} & Y_{1,3} \\
\hline
1 & 0 & 0 & p_{1} \\
0 & 0 & 0 & 1 \\
0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 \\
0 & 1 & 1 & 0 \\
\end{array} \]

Marginal (Y1)

Discussion

The proposed rho-CJS formulation handles pair-wise dependency in capture outcomes between mating pairs. Information that is auxiliary to the capture histories of normal CJS type experiments is used to determine mating pairs. The proposed model formulation also results in individual capture history frequencies (e.g. \( \text{phi} \)) that will be identical to a regular CJS experiment. As such, pair-wise dependency in capture outcomes of this type does not affect regular CJS type models. Our formulation however has the added advantages of being able to estimate the capture correlation within a mating pair as well as improved capture probability precision. The precision increase results from the additional zero observations introduced into the data by mates that were known to exist, but were never captured. Future model extensions will allow for pairing after the commencement of the experiment and for mate switching during the experiment. This modeling framework may have great utility for a number of long lived species where mate pairing is well known.

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