SEPARATING MORTALITY AND EMIGRATION: MODELLING SPACE USE, DISPERSAL AND SURVIVAL WITH ROBUST-DESIGN SPATIAL-CAPTURE-RECAPTURE DATA

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Appendix S1: Derivation of trap and individual specific capture probabilities by competing risk theory

We here derive the trap-and-individual-specific capture probabilities for the multinomial encounter SCR model (Efford, Borchers & Byrom 2009; Royle et al. 2013) using competing risk theory (Kalbfleisch & Prentic 2002, Chap. 8).

The multinomial encounter model assumes that an individual can be captured in at most one trap in a given secondary session, but that each trap can capture multiple individuals in the same session (Efford, Borchers & Byrom 2009; Royle et al. 2013). The data thus consists of indices of the traps at which each marked individual is captured at every trapping session. Let H_{ijk} denote the index of the trap where individual i is captured in secondary session j within primary session k. When a marked individual is not captured in a given session, H_{ijk} is set to zero. The observation likelihood is thus categorical,

$$H_{ijk} \sim \mathrm{Cat}(\boldsymbol{\pi}_{ijk}), \qquad 1.$$

where $\boldsymbol{\pi}_{ijk}$ is a 1×(R+1) vector with the first element being the probability of not being captured and the subsequent elements are the probabilities of being captured in trap 1 to R. Other observation models can be used, such as Poisson or binomial, depending on the type of trap (e.g., camera traps, DNA sampling, etc.; see Royle et al. (2013) for more details).

The elements of $\boldsymbol{\pi}_{ijk}$ should sum to one, and they depend on the locations of all other traps as an individual can only be captured once in a given trapping session. Let $h(t; i, j, k, r)$ be the hazard function for capture of the given individual (i) during the given trapping session (jk) in trap r depending on time t. Individuals and/or traps may be exposed to capture over different intervals of time, from $t_{1,ijkr}$ to $t_{2,ijkr}$. The probability of the individual not being captured in *any* trap, i.e., the first element of $\boldsymbol{\pi}_{ijk}$, conditional on the individual being alive in primary session k is then given by the general survival function,

$$(\pi_{ijk}[1] | z_{ik} = 1) = \exp\left(-\sum_{r=1}^{R} \int_{t_{1,ijkr}}^{t_{2,ijkr}} h(t; i, j, k, r)\, dt\right) \qquad 2.$$

Here z_{ik} is the alive/dead state of the individual where the value 1 indicates that the individual is alive and the value 0 indicates that it is dead. If the individual is dead, the probability of not being captured is 1, $(\pi_{ijk}[1] | z_{ik} = 0) = 1$.

To simplify notation, we will assume that individuals and traps are exposed to trapping over the same time interval and denote the time-averaged trap-specific capture hazard rates over this interval (with duration 1) as h_{ijkr}. The risk of being captured in any trap is the sum of the trap-specific risks, $h_{ijk*} = \sum_r h_{ijkr}$, and the probability of the individual not being captured in any trap given that it is alive (eq. 2) then simplifies to $\exp(-h_{ijk*})$, and the unconditional probability of not being captured is

$$\pi_{ijk}[1] = \exp(-h_{ijk*} z_{ik}) \qquad 3.$$

To derive the trap-specific capture probabilities, we first find the trap-specific probability density function for capture at time-fraction τ within a secondary session as the trap-specific capture hazard rate multiplied by the probability of not already being captured at time τ, $f(\tau; i, j, k, r) = h_{ijkr} \exp(-h_{ijk*}\tau)$. Integrating this density function from 0 to 1 gives us the trap-specific capture probability,

$$\pi_{ijk}[r + 1] = (1 - \pi_{ijk}[1]) \frac{h_{ijkr}}{h_{ijk*}} \qquad 4.$$

Note that this result is identical to the one derived by Royle and Gardner (2011), but the competing risk formulation has the advantage that it can easily be generalized to situations where the trap hazard rates vary over continuous time, and where individuals and/or traps are not exposed for capture over the same time intervals (e.g., if individuals are released after capture at different times or if traps are checked (or fail) at different times).

References

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