A proposed methodology for adjusting productivity indices given missing effort in constant-effort mist-netting data

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November 2000

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Key words: Demographic monitoring – indexing productivity – capture probabilities – constant effort mist-netting – MAPS Program – Constant Effort Scheme – seasonal activity – diurnal activity – behavior.

30th November, 2000

Introduction

Constant-effort mist-netting (CEMN) protocols involve banding individual birds caught in nets at a number of monitoring sites (or stations), in such a manner that the locations of both nets and sites remain constant across all years of operation. Normally, nets are opened at regular intervals (visits or periods) during a certain portion of the year. During each visit the nets are opened for a prescribed number of hours and checked for captured birds at regular intervals (netting session or net run). Importantly, the timing of individual net openings and closures are carefully recorded enabling effort to be quantified in units of net-length-hours. Such protocols are normally conducted during the breeding season to provide such measures as the annual changes in numbers of adult and juvenile birds captured, annual reproductive indices (expressed as the ratio of juvenile to adults), and estimates of apparent adult survivorship from mark-recapture models.

Two large-scale CEMN schemes exist; the Constant Effort Sites (CES) Ringing Scheme that monitors avian populations in scrub and wetland habitats throughout Britain and Ireland (Baillie 1990, Peach et al. 1996), and the Monitoring Avian Productivity and Survivorship (MAPS) program that collects and analyzes constant-effort banding data from a network of over 500 monitoring stations (and many habitat types) across North America (DeSante et al. 1995). In both of these schemes species-specific annual productivity is indexed as the proportion of juveniles in the catch.

Unfortunately, such schemes are not entirely “constant-effort” due to the vagaries of weather, equipment failure, operator illness and other random events (e.g., the presence of dangerous animals). The missing effort is distributed both randomly, such as in the case of illness, and systematically, perhaps due to predominant local weather patterns (e.g., extreme high temperatures by late morning in Texas). Missing effort may involve an entire visit to a station, all nets during part of a visit (e.g., during a rainstorm), or one or more nets at a station (e.g., those exposed to direct intense sunlight later in the day). Intuitively, it is clear that missing effort can bias productivity indices. If missing effort occurs early in the breeding season, the number of adult individuals captured will be low, biasing productivity high. Conversely, if effort is missed later in the season, the number of juveniles will be disproportionately under-estimated compared to the number of adults and thus productivity will be biased low.

Peach et al. (1998) proposed a year- and species-specific correction method for CES data based on the numbers of individuals captured at stations for which 100% effort exists. However, the correction was not applied to site (station) visits for which between 80% and 100% of effort was achieved under the assumption that such levels of effort were often due to missed netting sessions towards the end of the visit when capture rates are declining. An analysis of MAPS data for the Pacific Northwest region of North America (Nott and DeSante, in press) shows that although pronounced diurnal declines in capture rates do exist for some species (e.g., MacGillivray's Warbler), other species have relatively even capture rates over the hours of the visit (e.g., "Western" Flycatcher). These different patterns are likely related to foraging behavior. For example, a gleaner may concentrate its foraging activities into the earlier hours when invertebrates are slow moving and hidden in foliage, litter and bark. Conversely, a sallying species is likely to be relatively more active later in the day when flying insects become more active.

In summary, the patterns of adult and juvenile capture rates vary not only across time (diurnally and seasonally), but also across species, and perhaps space, due to regional differences in diurnal weather patterns. This suggests that any method correcting for missing effort in MAPS data should consider the expected number of captures by both visit and netting session. So, in order to provide comparable annual adult population estimates as well as productivity indices, we must be able to correct for the bias introduced by missing effort at appropriate temporal and spatial scales. The following method differs from that adopted by Peach et al. (1998) in two major ways. First, it accounts for the species- and age-specific diurnal behavioral patterns (by netting session) represented in capture rates, not just seasonal behavioral patterns (by visit). Secondly, the method deals with all levels of missing effort and does not ignore lower levels between 0 and 20%, which may bias indices of productivity depending upon the time of day and stage of the breeding season during which it is missed.

Proposed Methodology

From MAPS data for a single species captured during a single breeding season at a number of monitoring sites in a given geographic region (or other grouping of sites), the following information, essential to the correction methodology, can be extracted:

Temporal patterns of completed effort: $\mathbf{E(V, S)}$ (1)

A matrix of the proportion of effort completed (effort completed/effort expected) may vary between each of 10 visits (**V** = {1 .. 10}), and each of thirty-six 10 minute duration netting sessions (**S** = {1 .. 36}).

Temporal patterns of age-specific captures: $\mathbf{P_A(V, S)}$ (2)

A matrix of the numbers of adult captures (**A**=1) and juvenile captures (**A**=2) by visit and session.

At this stage it is important to note that we are interested in estimates of the expected number of individuals captured. Because some individuals are caught more than once (including juveniles) we must first, from the data, define age- and species-specific relationships (to allow for behavioral aspects such as "trap dependence") between annual numbers of captures and the numbers of individuals represented by those captures ($C_{\mathbf{A}}$):

$$\mathbf{N_A = C_A.(\Sigma_V \Sigma_S P_A)} \quad (3)$$

Essentially, the problem becomes one of providing a rigorous method of correcting for missing effort that allows estimation of the expected numbers of captures in each age class ($\mathbf{P'_A}$):

$$\mathbf{P'_A(V, S) = \mathit{f}(V, S) \ . \ (P_A(V, S))} \quad (\text{given } \mathbf{E(V, S)}) \quad (4)$$

Hence, the expected number of age-specific captures (N) can be expressed as:

$$\mathbf{N'_A = C_A.(\Sigma_V \Sigma_S P'_A)} \quad (5)$$

The simplest correction method (f(V, S)) would utilize the reciprocal of the effort matrix to estimate the expected numbers of captures:

$$\mathbf{P'_A(V, S) = (E\ (V, S))^{-1}\ .\ P'_A(V, S)} \qquad (6)$$

This method, however, is not applicable at the level of a single station with visits or net sessions for which no effort was recorded because the expected numbers of captures would become infinite. To circumvent this problem we can apply this method to spatially pooled data, assuming each cell in the regional effort matrix contains non-zero data, to construct age-specific "capture profiles" (CP_A) that express the proportion of the total number of adult and juvenile captures you would expect by visit and netting session:

$$\mathbf{CP_A} = \mathbf{P'_A(V, S) / (\Sigma_V \Sigma_S P'_A)} \qquad (7)$$

Then, at the level of a single station, given that effort is missing for some visits and/or netting sessions, we may numerically integrate under the age-specific response surfaces where effort is missing. This is effected by summing the expected proportions of captures ($\mathbf{CP_A (V, S)}$) for those visits and netting sessions that were successfully completed at that station ($\mathbf{e(V, S) = 1}$), providing total age-specific proportions of captures.

$$\mathbf{X_A} = \mathbf{\Sigma_V \Sigma_S CP_A} \qquad (8)$$

The reciprocal of this total proportion is multiplied by the number of captures ($\mathbf{n'_A}$) at the station to provide the expected total number of captures for that station, which in turn is multiplied by C_A (from Equation 3) to provide a less biased estimate of the numbers of individuals in each age class ($\mathbf{n_A}$).

$$\mathbf{n_A} = \mathbf{C_A\ .\ \Sigma_V \Sigma_S n'_A\ .\ X^{-1}} \qquad (9)$$

Acknowledgements

We thank the DoD Legacy Resources Management Program for financial support for this work. We thank Peter Boice and Alison Dalsimer of the Legacy Program, Joe Hautzenroder and Chris Eberly of the DoD Partners in Flight Program, and Robert Johnson of the US Army Corps of Engineers, Huntsville Division for logistical support.

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