Demographic Perspectives on Long-term Ecological Research in Organismal Biology

Brett K. Sandercock
Division of Biology, Kansas State University

• Improved assessment of community dynamics: closed population models
• Better metrics of habitat use: occupancy models
• Synthetic population modeling: seasonal components of demography, climate change
Demographic Parameters of Interest

Community
Transition rates: extirpation, species turnover
Abundance: species richness

Population
Transition rates: apparent survival, probability of changing states, recruitment, population growth
Abundance: number of individuals

Need to correct for probability of detection
Mark-recapture analyses based on encounter histories for individuals or species

Sandercock 2006 J. Wildl. Mgmt.
Species richness based on count data

\[ \hat{N} = \frac{C}{\hat{p}} \]
Closed Population Models Estimate Abundance

\( \hat{p} \) modeled as a function of: time, behavior, individual heterogeneity

<table>
<thead>
<tr>
<th>Time</th>
<th>( t_1 )</th>
<th>( t_2 )</th>
<th>( t_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LTER Repeated Sampling
Plants: Yes, 5 plots/transect
Grasshoppers: Yes, 2 periods
Fish: No
Birds: No
Avifauna

No. Spp. (C)

<table>
<thead>
<tr>
<th>Year</th>
<th>Fenced</th>
<th>Grazed</th>
<th>Initial Season</th>
<th>Intensive Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-97</td>
<td>2004-05</td>
<td></td>
<td>( \chi^2 = 3.0 ) ( P = 0.69 )</td>
<td>( \chi^2 = 2.83 ) ( P = 0.73 )</td>
</tr>
</tbody>
</table>

Herpetofauna

No. Spp. (N)

<table>
<thead>
<tr>
<th>Year</th>
<th>Rep1</th>
<th>Rep2</th>
<th>Rep3</th>
<th>Rep1</th>
<th>Rep2</th>
<th>Rep3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>34</td>
<td>30</td>
<td>25</td>
<td>32</td>
<td>28</td>
<td>23</td>
</tr>
<tr>
<td>1999</td>
<td>33</td>
<td>29</td>
<td>24</td>
<td>31</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>2000</td>
<td>32</td>
<td>28</td>
<td>23</td>
<td>30</td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td>2001</td>
<td>31</td>
<td>27</td>
<td>22</td>
<td>29</td>
<td>25</td>
<td>20</td>
</tr>
</tbody>
</table>

Johnson 2006 MSc thesis  Wilgers et al. 2006 Herpetologica
## Occupancy Instead of Abundance?

<table>
<thead>
<tr>
<th></th>
<th>$t_1$</th>
<th>...</th>
<th>...</th>
<th>...</th>
<th>$t_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plot 1</strong></td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td><strong>...</strong></td>
<td>O</td>
<td>•</td>
<td>O</td>
<td>•</td>
<td>O</td>
</tr>
<tr>
<td><strong>...</strong></td>
<td>O</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td><strong>Plot n</strong></td>
<td>•</td>
<td>O</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
</tbody>
</table>

### Two Parameters

**Occupancy ($\psi$)** = probability that a species is present at a sampling site (or proportion of sites occupied)

**Detection ($\rho$)** = conditional probability that a species is detected at a site, given presence

---

MacKenzie et al. 2005
Occupancy Models for Prairie Butterflies?

Tips for study design
Sites must be selected at random
**Rare species:** More sites, fewer visits
**Common species:** Fewer sites, more visits
Model $\psi$ and $\rho$ versus environmental covariates
Stochastic Population Models

Seasonal demography of migratory birds
- Demographic tradeoffs vs. migration
- Population limitation and regulation
- Targeted conservation
Upland Sandpiper Demography

Clutch size
• 3.9, 3.8-4.0 (n = 158)

Prob. of renesting
• 0.22, 0.08-0.43 (n = 81)

Chicks/egg
• 0.86, 0.81-0.92 (n = 68)

Sex ratio
• 0.48, 0.43-0.51 (n = 153)

Age at maturity
• 1-year
Survival of Nests

Nest = DSR\(^{(29\;d)}\) =

<table>
<thead>
<tr>
<th>Year</th>
<th>Daily Survival Rate (±SE)</th>
<th>Supervivencia por Día</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>0.96 ± 0.01</td>
<td>96% ± 1%</td>
</tr>
<tr>
<td>2002</td>
<td>0.96 ± 0.01</td>
<td>96% ± 1%</td>
</tr>
<tr>
<td>2003</td>
<td>0.98 ± 0.01</td>
<td>98% ± 1%</td>
</tr>
<tr>
<td>2004</td>
<td>0.95 ± 0.02</td>
<td>95% ± 2%</td>
</tr>
<tr>
<td>2005</td>
<td>0.96 ± 0.01</td>
<td>96% ± 1%</td>
</tr>
<tr>
<td>2006</td>
<td>0.97 ± 0.01</td>
<td>97% ± 1%</td>
</tr>
</tbody>
</table>

\(n = 190\) nests
Summer Survival

\[ S_{\text{sum}} = \text{WSR}^{(12 \text{ wk})} = \]

- 100%
- 81%
- 91%
- 92%
- 100%

\( n = 152 \) birds
\( n = 5 \) mortalities

Mong and Sandercock 2006 J. Wildl. Mgmt
Annual Survival

$n = 423$ adults

\[ \text{minAIC: } \phi^1_t, \phi^{2+}_{\text{sex}}, \rho_{\text{sex+t}} \]

- Prob. of detection low, varies with time and sex
- Effect of transients
- Annual survival of females = $0.66 \pm 0.09\text{SE}$
Synthesis

• Calculation of fecundity (female young per female)

\[
\text{Rep} = [\text{Nest Survival} + ((1 - \text{Nest}) \times \text{Renest})] \times \text{Clutch size} \times \text{Chicks/egg} \times \text{Sex ratio}
\]

• Calculation of survival during winter and migration

\[
S_{\text{win}} = \frac{S_{\text{ann}}}{S_{\text{sum}}}
\]

• Calculation of juvenile survival

\[
S_{\text{juv}} = S_{\text{win}} \times 50\%
\]

• Calculation of finite rate of population change (\(\lambda\))

\[
\lambda = (\text{Rep} \times S_{\text{juv}}) + (S_{\text{sum}} \times S_{\text{win}})
\]

• Life-stage simulation analyses (LSA), bootstrapping, based on uniform probability distributions
Life-stage Simulation Analysis

\[
S_{ju} = wS_{mr/nb}
\]

<table>
<thead>
<tr>
<th>Clutch size</th>
<th>Nest survival</th>
<th>Renesting</th>
<th>Chicks per egg</th>
<th>Sex ratio of young</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>0.15</td>
<td>0.1</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>3.9</td>
<td>0.25</td>
<td>0.2</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>4.0</td>
<td>0.35</td>
<td>0.3</td>
<td>1.2</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Finite rate of population change (λ)

<table>
<thead>
<tr>
<th>Clutch</th>
<th>Nest</th>
<th>Renest</th>
<th>Chick</th>
<th>Sex</th>
<th>S_{br}</th>
<th>S_{mr/nb}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.43</td>
<td>0.41</td>
</tr>
<tr>
<td>0.09</td>
<td>0.14</td>
<td>0.19</td>
<td>0.00</td>
<td>0.01</td>
<td>0.25</td>
<td>0.24</td>
</tr>
<tr>
<td>0.08</td>
<td>0.29</td>
<td>0.39</td>
<td>0.02</td>
<td>0.03</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Stochastic Population Models

30-yr precipitation data
3-yr field study: dry \(z = -1.13\), normal \(+0.19\), wet \(+0.93\)
Fecundity, growth, survival for stage-structured model

\[
\begin{pmatrix}
0 & 0 & F_3 & F_4 \\
G_{12} & S_{22} & 0 & 0 \\
0 & G_{23} & S_{33} & 0 \\
0 & 0 & G_{34} & S_{44}
\end{pmatrix}
\]

50-yr projections
Independent, identical distributed series (\textit{iid})

Reed et al. 2007 \textit{J. Mammal.}
Count-based Population Viability Analyses

• Possible to conduct stochastic modeling with unstructured models if population change linked to environmental conditions
Summary

• Benefits of demographic perspective: estimates with less bias and greater precision, improvements in sampling efficiency, greater synthesis
• Opportunities for novel improvements without new experiments, reversal treatments, exclosures.