Measuring ‘ecological’ distance in spatial capture-recapture models

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American mink in riparian corridors

The views expressed in these slides are that of the author only.
Spatial Capture-Recapture (SCR)

Acknowledges the inherent spatially nature of ecological processes and observation processes:

- effective area sampled ~ absolute density
- heterogeneous encounter probabilities

but, useful for many other challenges in ecological research:

- movement, space-use, resource selection, survival, recruitment
Spatial Capture-Recapture (SCR)

Acknowledges the inherent spatially nature of ecological processes and observation processes:

- effective area sampled ~ *absolute* density
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but, useful for many other challenges in ecological research:

- movement, space-use, resource selection, survival, recruitment, *connectivity/landscape resistance* (Royle et al., 2013)
Spatial Capture-Recapture (SCR)

Retaining the spatial information about trap locations and therefore about individual encounter locations:

Non-spatial encounter history

\[ y_{i,k} = [y_{i,k}, y_{i,k}, \ldots, y_{i,k}] \]

Spatial encounter history

\[ y_{i,k} = [y_{i,1,k}, y_{i,2,k}, \ldots, y_{i,J,k}] \]
Spatial Capture-Recapture (SCR)

A typical SCR data set therefore consists of:

- spatial locations of each trap - $x_j$
- individual-by-trap/location spatial encounter histories – $y_{i,j}$

Biologically: Observations $y_{i,j}$ occur as a result of movement around an home range center and frequency of detection decreases with distance between trap and activity center $s_i$

Statistically: Observations $y_{i,j}$ are realizations of a probability distribution whose mean is a latent variable $s_i$ i.e. a random-effects model

Model for encounter probability (many exist):

$$y_{i,j} \sim \text{Binomial}(K, p_{i,j})$$

$$p_{i,j} = f(d[s_i, x_j])$$
Modeling movement using SCR

Bivariate normal encounter model:

\[ y_{i,j} \sim \text{Binomial}(K, p_{i,j}) \]

\[ p_{i,j} = \alpha_0 \exp(-\alpha_1 d[s_i, x_j]^2) \]

\[ \alpha_1 = 1/(2\sigma^2) \]
Modeling movement using SCR [poorly in some cases?]

Bivariate normal encounter model:

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Euclidean distance:

- circular home range
- uniform landscape [use]

\[ \rightarrow \text{Biologically unrealistic} \]
Modeling movement using SCR [*poorly in some cases?*]

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Euclidean distance:

- circular home range
- uniform landscape [use]

Biologically unrealistic

Movement is not equally likely through all habitats:

- cost/resistance
Stream networks & riparian species – my motivation!

The American mink *Neovison vison*:

- economically important
- community regulator
- top predator (aquatic)
- indicators of ecosystem health

A perfect model system:

- semi-aquatic (∴ non-Euclid. movement)
- habitat specialist (∴ non-Euclid. movement)
- landscape (dist. to water) ‘easy’ to define
So, how should we measure distance?
Distance as the *what*? moves…

Three ways to measure distance:

- **Euclidean distance** - distance as the ‘crow flies’
Distance as the *what?* moves…

Three ways to measure distance:

- **River/stream distance** - distance as the ‘*fish swims*’
Distance as the *what?* moves…

Three ways to measure distance:

- ‘Cost weighted’ distance - distance as the ‘mink moves’
Distance as the *MINK* moves…

Cost weighted ‘*mink moves’* distance:

- Spatially varying landscape resistance (distance to water)
- Usually arbitrarily defined
- Use observations of movements to *estimate* resistance, $r$

[within SCR framework!]
Estimating landscape resistance using SCR

Gaussian encounter model:

\[ y_{x,x'} \sim \text{Binomial}(K, p_{x,x'}) \]

\[ p_{x,x'} = \alpha_0 \exp(-\alpha_1 d[x, x']^2) \]

Royle et al., 2013
Estimating landscape resistance using SCR

Gaussian encounter model:

\[ y_{x,x'} \sim \text{Binomial}(K, p_{x,x'}) \]

\[ p_{x,x'} = \alpha_0 \exp(-\alpha_1 d_{lcp}[x, x']^2) \]

\[ d(x, x') = \sum_{i=1}^{m-1} \text{cost}(l_i, l_{i+1}) \|l_i - l_{i+1}\| \]

Royle et al., 2013
Estimating landscape resistance using SCR

Gaussian encounter model:

\[ y_{x,x'} \sim \text{Binomial}(K, p_{x,x'}) \]

\[ p_{x,x'} = \alpha_0 \exp(-\alpha_1 \text{d}_{lc}[x, x']^2) \]

\[ d(x, x') = \sum_{i=1}^{m-1} \text{cost}(l_i, l_{i+1}) \| l_i - l_{i+1} \| \]

\[ \text{cost}(l_i, l_{i+1}) = f(r, z(l_i) - z(l_{i+1})) \]

Royle et al., 2013
Estimating landscape resistance using SCR

Gaussian encounter model:

\[ y_{x,x'} \sim \text{Binomial}(K, p_{x,x'}) \]

\[ p_{x,x'} = \alpha_0 \exp(-\alpha_1 d_{lcp}[x, x']^2) \]

\[ d_{lcp}(x, x') = \min \left[ \sum_{i=1}^{m-1} \text{cost}(l_i, l_{i+1}) \| l_i - l_{i+1} \| \right] \]

\[ \text{cost}(l_i, l_{i+1}) = f[r, z(l_i) - z(l_{i+1})] \]

Royle et al., 2013
The cost function - learning about the space-use

\[ \log[\text{cost}(x, x')] = r \frac{z(x) + z(x')}{2} \]

\( r \) provides information about space use patterns and behavior

Euclidean distance
(‘crow flies’)

\( r = 0 \)

Stream distance
(‘fish swims’)

\( r \to \infty \)
The cost function - learning about the space-use

\[
\log[\text{cost}(x, x')] = r \frac{z(x) + z(x')}{2}
\]

\( r \) provides information about space use patterns and behavior.

Euclidean distance ('crow flies')

- \( r = 0 \)

Ecological distance ('mink moves')

- \( 0 < r < \infty \)

Stream distance ('fish swims')

- \( r \to \infty \)
Testing the theory: Mink-like simulation study
Mink-like simulation study - Data

- water layer
Mink-like simulation study - Data

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- distance to water covariate
  (200m x 200m grid cells)
Mink-like simulation study - Data

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- 100 traps (5 clusters of 20)
Mink-like simulation study - Data

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- distance to water covariate (200m x 200m grid cells)
- 100 traps (5 clusters of 20)
- \( N = 200 \) mink located along the water way

\[ \alpha_0 = 0.38; \sigma = 0.25; r = 2.5 \]
Mink-like simulation study - Data

- water layer
- distance to water covariate (200m x 200m grid cells)
- 100 traps (5 clusters of 20)
- $N = 200$ mink located along the water way
- generate spatial encounter histories using:
  \[ \alpha_0 = 0.38; \sigma = 0.05; r = 2.5 \]
Mink-like simulation study - Data

- water layer
- distance to water covariate (200m x 200m grid cells)
- 100 traps (5 clusters of 20)
- \( N = 200 \) mink located along the water way
- generate spatial encounter histories using:
  \[ \alpha_0 = 0.38; \sigma = 0.05; r = 2.5 \]
- Fit the model (repeat 253 times)
Mink-like simulation study - Results

1. Retrieving known parameter values using the ‘mink moves’ ecological distance model:

   Statistical properties of $\hat{\theta} = [\alpha_0, \sigma, \bar{N}, r]$
Mink-like simulation study - Results

Estimating parameters of known values $\theta = [\alpha_0, \sigma, \bar{N}, r]$

<table>
<thead>
<tr>
<th></th>
<th>$\alpha_0$</th>
<th>$\sigma$</th>
<th>$\bar{N}$</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Known</strong></td>
<td>-0.50</td>
<td>0.050</td>
<td>200.00</td>
<td>2.50</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>-0.50</td>
<td>0.049</td>
<td>200.32</td>
<td>2.55</td>
</tr>
<tr>
<td><strong>RMSE</strong></td>
<td>0.06</td>
<td>0.012</td>
<td>10.77</td>
<td>0.24</td>
</tr>
<tr>
<td><strong>% Bias</strong></td>
<td>0.1</td>
<td>-2</td>
<td>0.2</td>
<td>1.9</td>
</tr>
</tbody>
</table>

$(\hat{\theta} - \theta)/\theta$
Mink-like simulation study - Results

1. Retrieving known parameter values using the ‘mink moves’ ecological distance model:

   \[ \hat{\theta} = [\alpha_0, \sigma, \bar{N}, r] \] recovered with little bias

2. Compare the ‘performance’ of two competing models:

   \[ M_{\text{ecological}} - \text{‘mink moves’ model estimating landscape resistance} \]

   \[ M_{\text{euclidean}} - \text{‘crow flies’ model assuming stationary home ranges} \]
Mink-like simulation study - Results

Comparing estimates of $\overline{N}$ (and $\overline{D}$) using Euclidean vs. ecological distance:

% bias in $N$ ($D$)
- Euclidean: 2.2
- Ecological: 0.2

$\overline{D} = \overline{N} / A$
Mink-like simulation study - Results

Comparing space-use patterns (home range *shapes*) assuming Euclidean *vs.* ecological distance:

- Simulated space-use data (‘truth’)
- Estimated using ‘ecological distance’
- Estimated using ‘Euclidean distance’
Mink-like simulation study - Models

1. Retrieving known parameter values using the ‘mink moves’ ecological distance model:
   
   ✓ Unbiased estimators of $\hat{\theta} = [\alpha_0, \sigma, \bar{N}, r]$

2. Compare the ‘performance’ of two competing models:

   $M_{ecological} – ‘mink moves’$ model estimating landscape resistance
   vs.

   $M_{euclidean} – ‘crow flies’$ model assuming stationary home ranges
Testing the theory: Mink-like simulation study
Application to a population of American mink
Mink study - Data

- Study area = 293.04 km$^2$ (515km of stream)
- Scat detection dogs
- Genetic identification of individuals
- 25 transects = 255 ‘effective traps’
- 37 unique individuals

<table>
<thead>
<tr>
<th>Frequency</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td># individuals (in n traps)</td>
<td>24</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>
Mink study - Results

1. Compare the two competing models:

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   vs.

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### Mink study - Results

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<table>
<thead>
<tr>
<th>Model</th>
<th>( N_{\text{params}} )</th>
<th>AIC</th>
<th>( \Delta \text{AIC} )</th>
<th>Density (se)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{\text{ecological}} )</td>
<td>4</td>
<td>366.59</td>
<td>-</td>
<td>1.06 (0.50)</td>
</tr>
<tr>
<td>( M_{\text{euclidean}} )</td>
<td>3</td>
<td>372.70</td>
<td>6.11</td>
<td>1.08 (0.54)</td>
</tr>
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</table>
Mink study - Results

1. Compare the two competing models:

\[
M_{\text{ecological}} - \text{‘mink moves’ model estimating landscape resistance}
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\[
M_{\text{euclidean}} - \text{‘crow flies’ model assuming stationary home ranges}
\]

*Space-use/home range shape: \( r = 20.35 \)*
Mink study - Results

1. Compare the two competing models:

- $M_{\text{ecological}}$ – ‘mink moves’ model estimating landscape resistance
- $M_{\text{euclidean}}$ – ‘crow flies’ model assuming stationary home ranges

7 x more ‘costly’ to move 100m away from water than along water
Mink study - Results

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1. Compare the ‘performance’ of two competing models:

\[ M_{\text{ecological}} \] – ‘mink moves’ model estimating landscape resistance

\[ M_{\text{euclidean}} \] – ‘crow flies’ model assuming stationary home ranges

95% Home range size

- \[ M_{\text{ecological}} \] 3.2 km²
- \[ M_{\text{euclidean}} \] 12.9 km²
Alternative distance measures and SCR…

Advantages of measuring *ecological distance*:

- relax the Euclidean assumptions of SCR methods
- no bias in estimators of abundance/density BUT
  - estimation of landscape resistance parameter
  - shape/size of irregular home-ranges/space-use