Use of GPS-tracking Data to Locate Bird Nests and Estimate Reproductive Outcome

Simona Picardi

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Recursive Movement Patterns
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Central Place Foraging
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Revisitation Patterns:
- Consecutive days
- Percent days visited
- Percent attendance on top day
Central Place Foraging

Revisitation Patterns:
- Consecutive days
- Percent days visited
- Percent attendance on top day

Assumption: revisitation patterns differ between nests and non-nests
Workflow

package ‘nestR’

https://github.com/picardis/nestR
Tracking data

Prior info on revisitation patterns of nests?

Yes

Find recurrently visited locations

Coordinates known for some nests?

Yes

Visualize data to find trusted nests

Select nests and non-nests to compare

Find revisitation patterns that discriminate between nests and non-nests

Find nests among revisited locations

Estimate outcome of nesting attempts

No

No

Find recurrently visited locations

Coordinates known for some nests?

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    - No
- No
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Select nests and non-nests to compare

Temporal overlap criterion

Known attempt
Select nests and non-nests to compare

Temporal overlap criterion

April May June July August

Potential non-nest #1

Known attempt
Select nests and non-nests to compare

Temporal overlap criterion

- April
- May
- June
- July
- August

Potential non-nest #1

Known attempt

?
Select nests and non-nests to compare

Temporal overlap criterion

April    May    June    July    August

Potential non-nest #1

Known attempt

Potential non-nest #2
Select nests and non-nests to compare

Temporal overlap criterion

- April
- May
- June
- July
- August

Potential non-nest #1

Potential non-nest #2

Known attempt

thumb up emoji
Tracking data

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Discriminate between nests and non-nests

Classification And Regression Trees (CART)
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Find nests among revisited locations

No

Find nests among revisited locations

Find nests among revisited locations
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CART

or

Prior knowledge

Parameter values

Filtering

Revisited locations

Nests
Tracking data

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Estimate outcome of nesting attempts
Estimate outcome of nesting attempts

t 1 2 3 4 … T-3 T-2 T-1 T
Y 8 6 6 0 … 2 0 1 0
N 12 12 10 0 … 5 10 8 12

t $\rightarrow$ Day
Y $\rightarrow$ Nest visits
N $\rightarrow$ GPS fixes
### Estimate outcome of nesting attempts

<table>
<thead>
<tr>
<th>t</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
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<tr>
<td>3</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>...</td>
<td>2</td>
<td>...</td>
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<tr>
<td>T-3</td>
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<tr>
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- **t → Day**
- **Y → Nest visits**
- **N → GPS fixes**
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<td>0</td>
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<td>1</td>
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- **t → Day**
- **Y → Nest visits**
- **N → GPS fixes**
Estimate outcome of nesting attempts

$z_t = 1 \rightarrow \text{Alive}$

$z_t = 0 \rightarrow \text{Dead}$

$\phi_1$  
$z_1 \rightarrow z_2$  
$p_1$  
$Y_1$

$\phi_{T-1}$  
$z_{T-1} \rightarrow z_T$  
$p_{T-1}$  
$Y_{T-1}$
Estimate outcome of nesting attempts

\[ z_t = 1 \rightarrow \text{Alive} \]
\[ z_t = 0 \rightarrow \text{Dead} \]

\[ \phi_t \rightarrow \text{Probability of survival} \]
\[ p_t \rightarrow \text{Probability of detection} \]
Estimate outcome of nesting attempts

$z_t = 1 \rightarrow \text{Alive}$

$z_t = 0 \rightarrow \text{Dead}$

$z_t \sim \text{Bern}(z_{t-1} \times \phi_{t-1})$

$\phi_t \rightarrow \text{Probability of survival}$

$p_t \rightarrow \text{Probability of detection}$
Estimate outcome of nesting attempts

\[ z_t = 1 \rightarrow \text{Alive} \]
\[ z_t = 0 \rightarrow \text{Dead} \]

\[ Y_t \sim \text{Bernoulli}(z_t \times \phi_t) \]

\[ Y_t \sim \text{Binomial}(z_t \times p_t, N_t) \]

\[ \phi_t \rightarrow \text{Probability of survival} \]
\[ p_t \rightarrow \text{Probability of detection} \]

Takes into account:
- Missing data
- Missed visit detection
Estimate outcome of nesting attempts

\[ z_t = 1 \rightarrow \text{Alive} \]
\[ z_t = 0 \rightarrow \text{Dead} \]

\[ z_t \sim \text{Bern}(z_{t-1} \times \phi_{t-1}) \]
\[ Y_t \sim \text{Binom}(z_t \times p_t, N_t) \]
\[ \text{logit}(\phi_t) = \beta_{\phi_0} + \beta_{\phi_1} \times t \]
\[ \text{logit}(p_t) = \beta_{p_0} + \beta_{p_1} \times t \]

\[ \phi_t \rightarrow \text{Probability of survival} \]
\[ p_t \rightarrow \text{Probability of detection} \]

Takes into account:
- Missing data
- Missed visit detection
- Time-varying survival and detection
Application to Data
<table>
<thead>
<tr>
<th></th>
<th>Mediterranean gulls</th>
<th>Lesser kestrels</th>
<th>Wood storks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temporal resolution (min)</strong></td>
<td>15</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td><strong>Ground-truth</strong></td>
<td>Loc. + Outcome</td>
<td>Loc. + Outcome</td>
<td>Location only</td>
</tr>
<tr>
<td><strong>Number of tracks</strong></td>
<td>Breeding</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Non-breeding</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td><strong>Tagged at</strong></td>
<td>Incubation</td>
<td>Early chick-rearing</td>
<td>Non-breeding</td>
</tr>
</tbody>
</table>
Number of revisited locations (40 m buffer)

1379 511 9871
CART output

Percent_top_attendance < 26
- no
  - 23
  - 23
- yes
  - >= 26
    - no
      - 19
      - 3
    - yes
      - 4
      - 20

Consecutive_days < 7
- yes
  - 50
  - 51
- no
  - 48
  - 7

Percent_top_attendance < 79
- no
  - 107
  - 107
- yes
  - 21
  - 103

Consecutive_days < 14
- no
  - 86
  - 4
- yes
  - 15
  - 6
- yes
  - 6
  - 97

>= 7
- >= 7
  - no
    - 48
    - 7
  - yes
    - 2
    - 44

>= 14
Number of nests found

<table>
<thead>
<tr>
<th>Revisited locations</th>
<th>Filtering</th>
</tr>
</thead>
<tbody>
<tr>
<td>1379</td>
<td>30</td>
</tr>
<tr>
<td>511</td>
<td>45</td>
</tr>
<tr>
<td>9871</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>Mediterranean gulls</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Positive Predictive Value</td>
<td>73%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>92%</td>
</tr>
</tbody>
</table>

\[ PPV = \Pr(\text{known}|\text{detected}) \]

\[ S = \Pr(\text{detected}|\text{known}) \]
False Negative Rate 8% 10% 12%
False Positive Rate 0% 44% 7%

\[ FNR = \Pr(\text{not detected}|\text{known}) \]

\[ FPR = \Pr(\text{detected}|\text{non breeder}) \]
Probability of visit detection

- Graph showing the decrease in probability of visit detection over time (Days)
  - Graph 1: Probability decreases from 1.00 to 0.25 over 40 days
  - Graph 2: Probability decreases from 0.75 to 0.25 over 30 days
  - Graph 3: Probability decreases from 1.00 to 0.50 over 90 days

Graphs indicate a trend of decreasing probability over time for visit detection.
Conclusions

• Our method connects movement to reproductive success
Conclusions

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• Good performance despite data limitations
Conclusions

• Our method connects movement to reproductive success

• Good performance despite data limitations

• Applicable to any GPS-trackable birds
Conclusions

• Knowledge of biology of the species is critical
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• Knowledge of biology of the species is critical

• Need to tailor the analysis according to data characteristics
Future improvements

- Incorporate uncertainty in nest detection
Future improvements

• Incorporate uncertainty in nest detection

• Explicitly consider path geometry
Future improvements

• Incorporate uncertainty in nest detection

• Explicitly consider path geometry

• Identify nesting stages based on periodicity of visits
Thank you!

package ‘nestR’
https://github.com/picardis/nestR

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