# Integrating spatial capture-recapture and telemetry data


**Rahel Sollmann**
**UC Davis, Davis, CA, USA**
**Department of Wildlife, Fish, and Conservation Biology**

# Estimating abundance

- Inability to perform census → Need to estimate $N$
- Gold standard: capture-recapture models
- Requires repeated 'capture' of identifiable individuals

| | Occasion | | | |
|---|---|---|---|---|
| **Individual** | 1 | 2 | 3 | … |
| 1 | 0 | 1 | 1 | … |
| 2 | 1 | 0 | 1 | … |
| … | … | … | … | … |
| *n* | 0 | 0 | 1 | … |

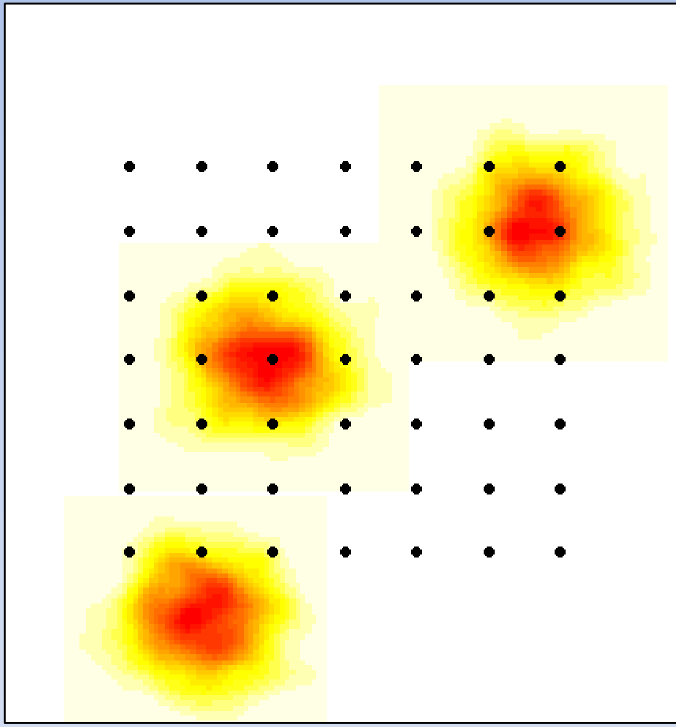
- Provides information about the probability of detecting an individual, $p$
- Allows estimating $N = n/p$

# Traditional capture-recapture

***Problem: Spatial nature of sampling not accommodated***

1. Extent of area sampled

- Animal movement beyond trapping grid
- *Ad hoc* estimates of 'effective sampled area'
- Choice of area estimator influences density estimate



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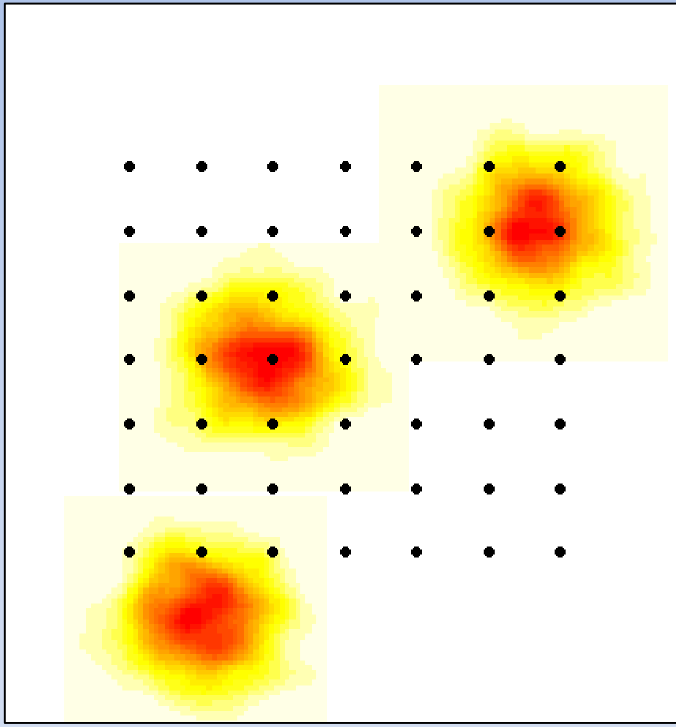


1. Extent of area sampled

- Animal movement beyond trapping grid
- *Ad hoc* estimates of ‘effective sampled area’
- Choice of area estimator influences density estimate

2. Exposure to trapping

- Home range location relative to traps influences trap exposure
- Induces heterogeneity in detection probability

# Motivation for spatial capture-recapture

- ***To account for different exposure to the trap array***
- Explicitly include individual location and movement into the model

- ***To eliminate ambiguity of effective area sampled***
- Formally link abundance and area

(Efford, 2004; Royle and Young, 2008)

# Data

| | Occasion | | | |
|---|---|---|---|---|
| **Ind.** | 1 | 2 | 3 | … |
| 1 | 0 | 1 | 1 | … |
| 2 | 1 | 0 | 1 | … |
| … | … | … | … | … |
| *n* | 0 | 0 | 1 | … |

Traditional capture-recapture

| **Trap 3** | **Occasion** | | |
|---|---|---|---|
| **Ind.** | 1 | 2 | 3 |

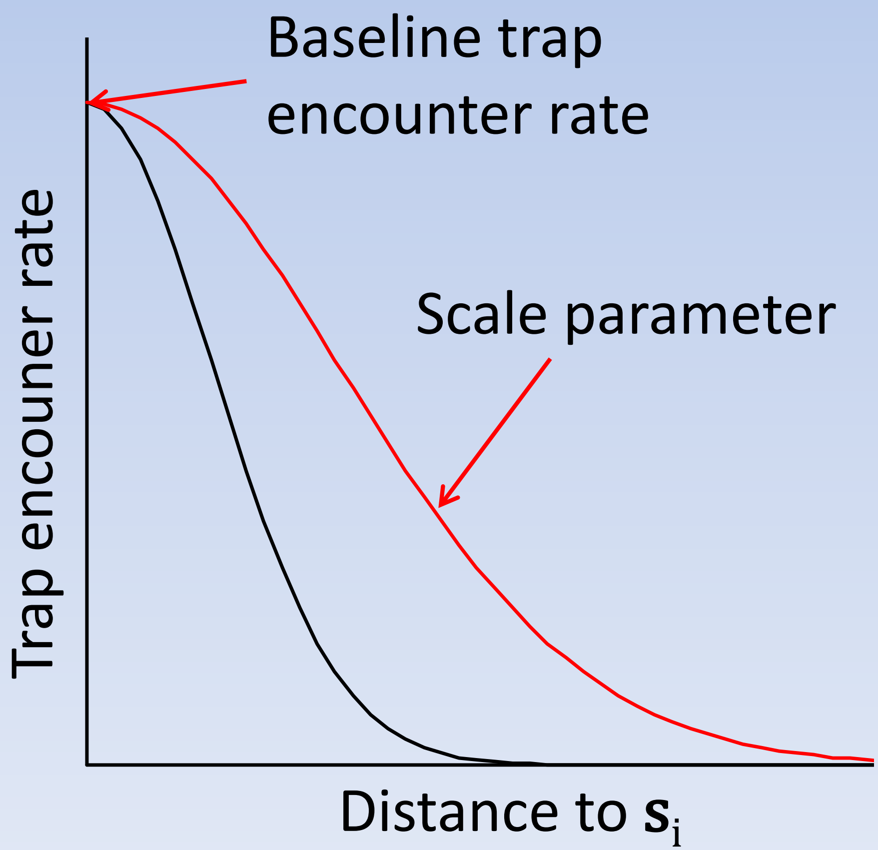
| **Trap 2** | **Occasion** | | | |
|---|---|---|---|---|
| **Ind.** | 1 | 2 | 3 | … |
| | | | | … |
| | | | | … |
| | | | | … |
| | | | | … |

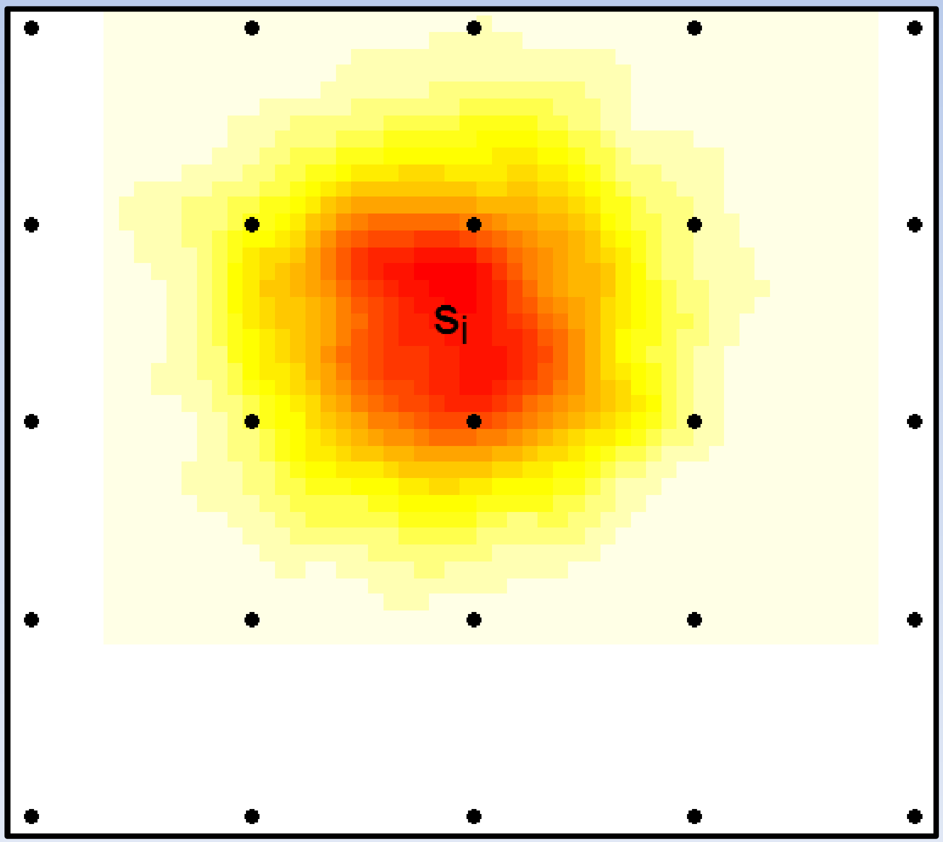
Spatial capture-recapture

| **Trap 1** | **Occasion** | | | |
|---|---|---|---|---|
| **Ind.** | 1 | 2 | 3 | … |
| 1 | 0 | 1 | 1 | … |
| 2 | 1 | 0 | 1 | … |
| … | … | … | … | … |
| *n* | 0 | 0 | 1 | … |

# Trap encounter model

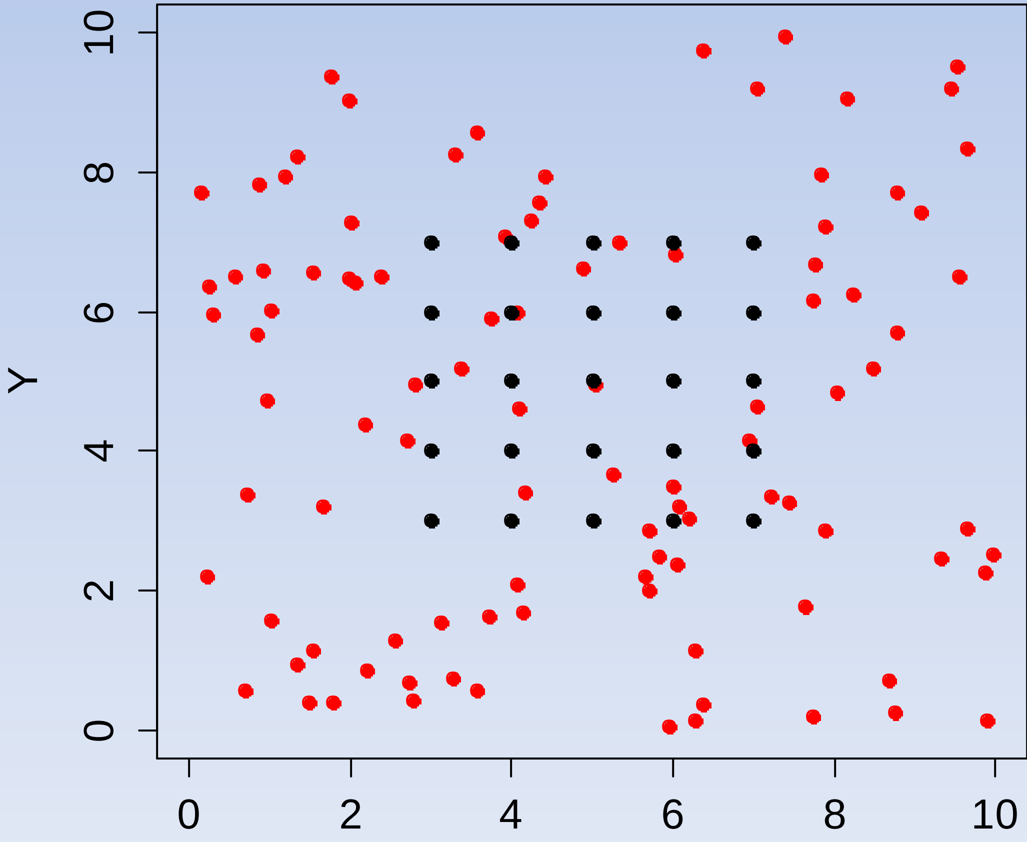
- Each individual $i$ has an activity center $\mathbf{s}_i$
- Encounter rate with trap $j$, $\lambda_{ij} = f(distance[j, \mathbf{s}_i])$
- Observation model, e.g.: $y_{ij} \sim Poisson(\lambda_{ij})$



# Estimating s and $N$

- Locations of capture provide incomplete information about **s**
- **s** is modeled as the outcome of a spatial point process (SPP)
- Homogeneous PP: $[s_1, s_2, \ldots . s_N]$ are uniformly distributed in state-space $S$.



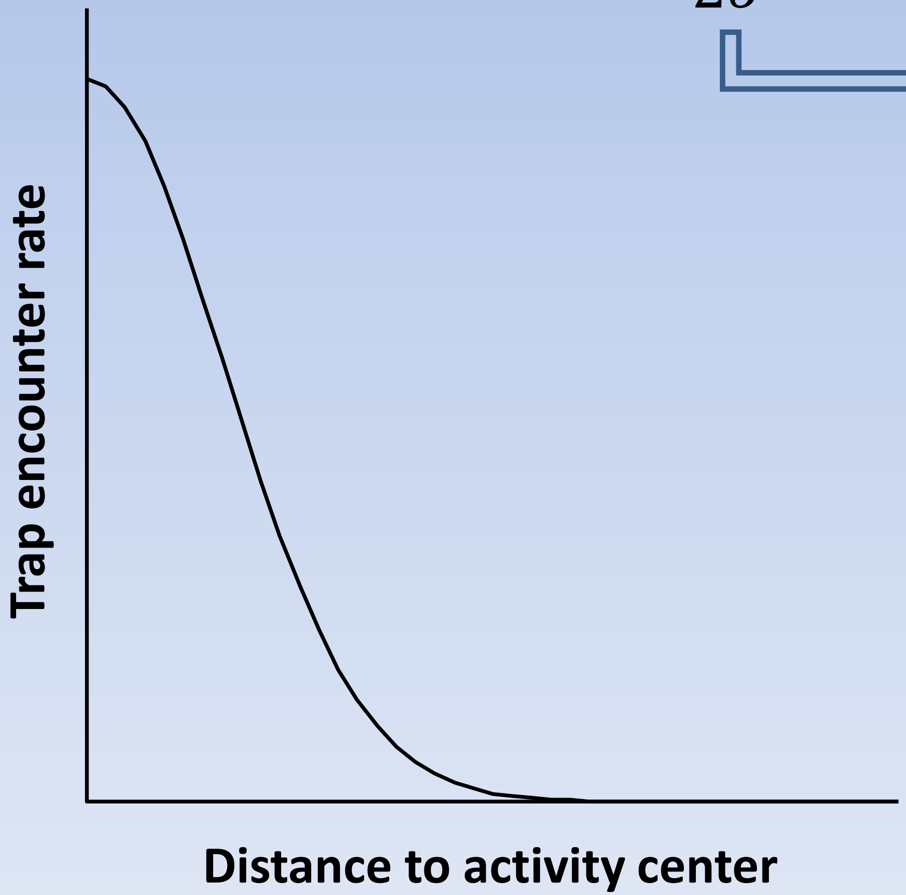

- $S$ is pre-defined: Area that includes **s** of all animals exposed to sampling
- $N$ = number of **s** in $S$

  → parameter of the SPP
- $D = N/A(S)$

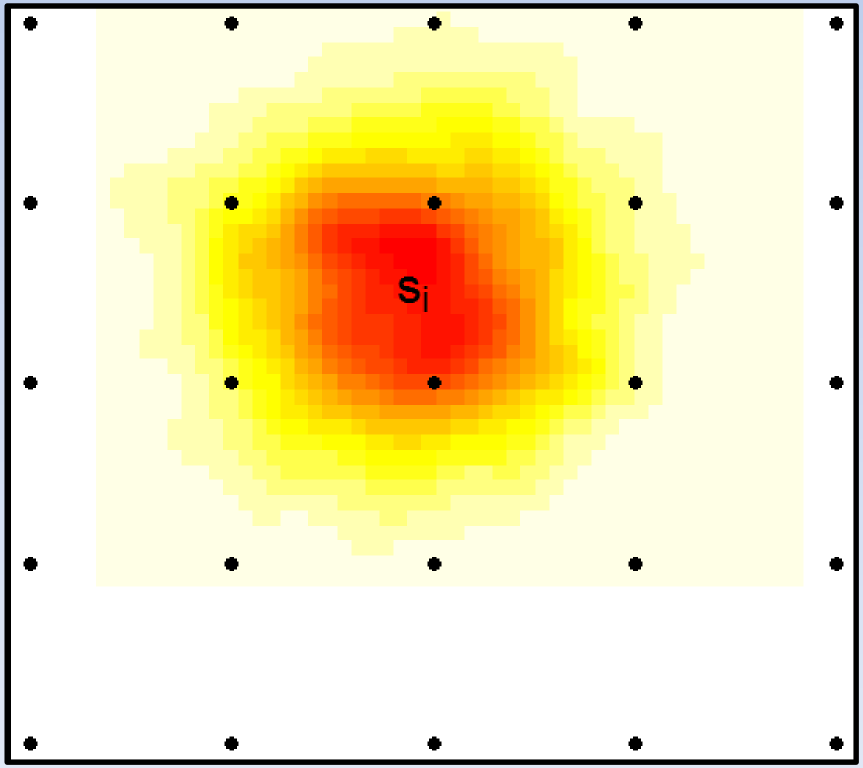
# SCR and space use

Half-normal trap encounter model

$$\lambda_{ij} = \lambda_0 * \exp(-\frac{d_{ij}^2}{2\sigma^2})$$




Bivariate normal model of space use



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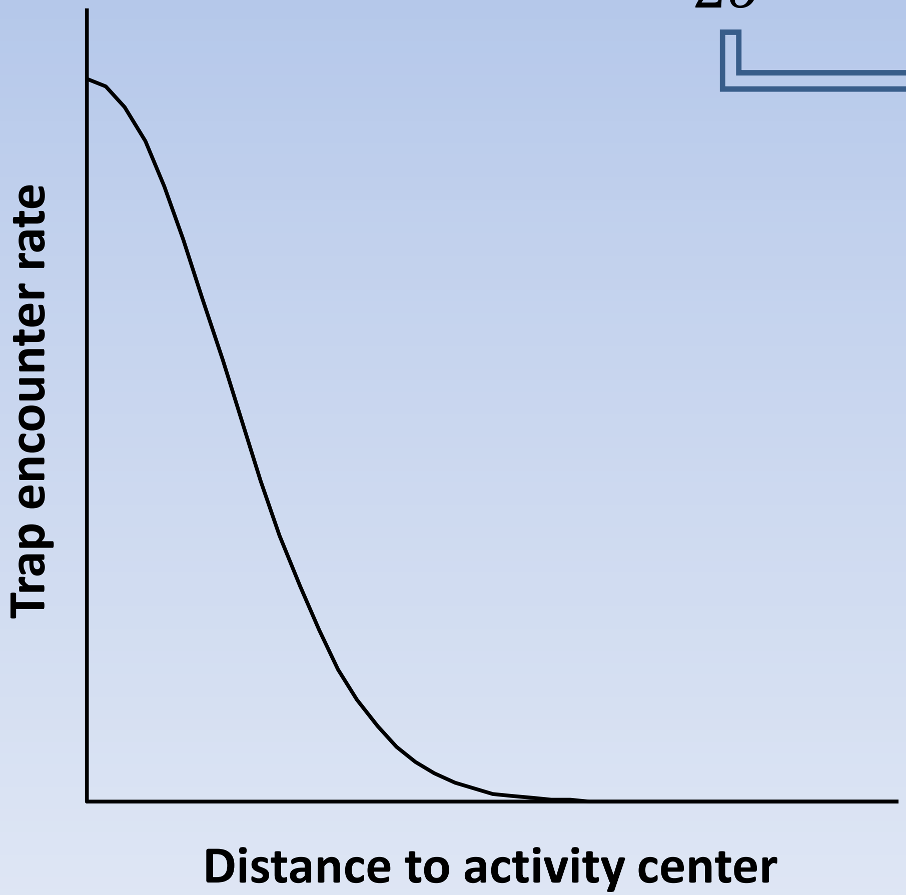



Bivariate normal model of space use

- Most use near the activity center
- Decline in use with distance form **s** is symmetrical
- $N(\mu, \Sigma);\ \Sigma = \begin{bmatrix} \sigma^2 & 0 \\ 0 & \sigma^2 \end{bmatrix}$

# SCR and telemetry data

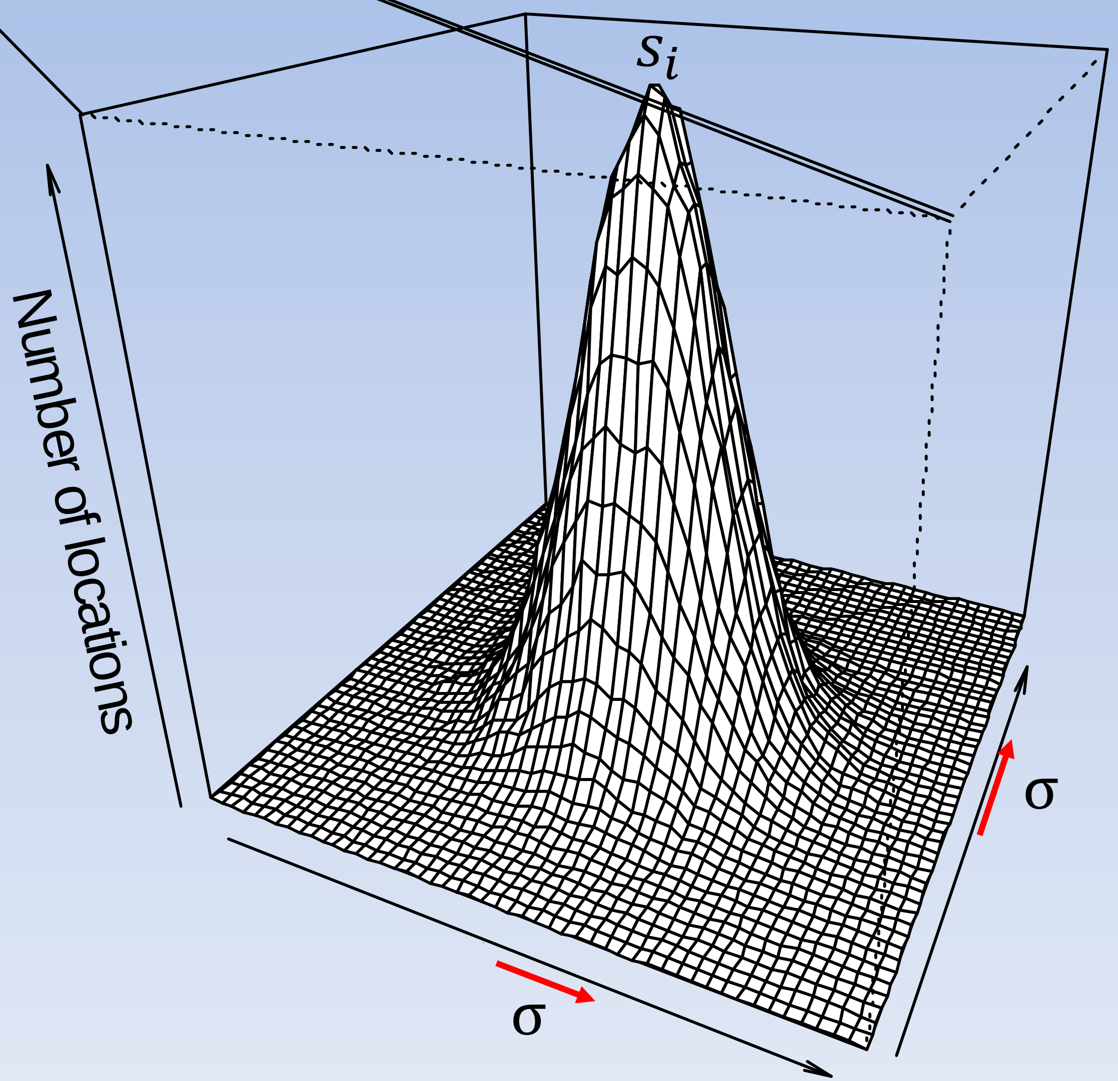
Telemetry data

- X,Y coordinate pairs that can be modeled with a bivariate normal distribution
- $\boldsymbol{l}_i \sim N(s_i, \Sigma);\ \Sigma = \begin{bmatrix} \sigma^2 & 0 \\ 0 & \sigma^2 \end{bmatrix}$

- where $s_i$ = individual activity center
- and $\sigma \equiv$ scale parameter of the half-normal trap encounter model

# SCR and telemetry data

Bivariate normal movement model for telemetry data



# SCR and telemetry data

Integrated model

- Telemetry data helps estimate activity centers of collared individuals, scale parameter of detection function
- Improved parameter precision
- Particularly useful in sparse data situations
  - Few individuals in SCR data
  - Few spatial recaptures

# SCR and telemetry data: Example 1

Spatial mark-resight to estimate Florida panther density

- Only portion of the population is marked (with radio-collars)
- Resighting with camera-traps: only marked individuals can be identified

→ Estimate number of unmarked animals to get abundance *N*

- Based on number of unmarked records per camera
- Assume unmarked records were generated by the same processes as marked records

Sollmann et al. 2013, JApplEcol

# Photographic data

Two 9-month sampling seasons

Collared individuals

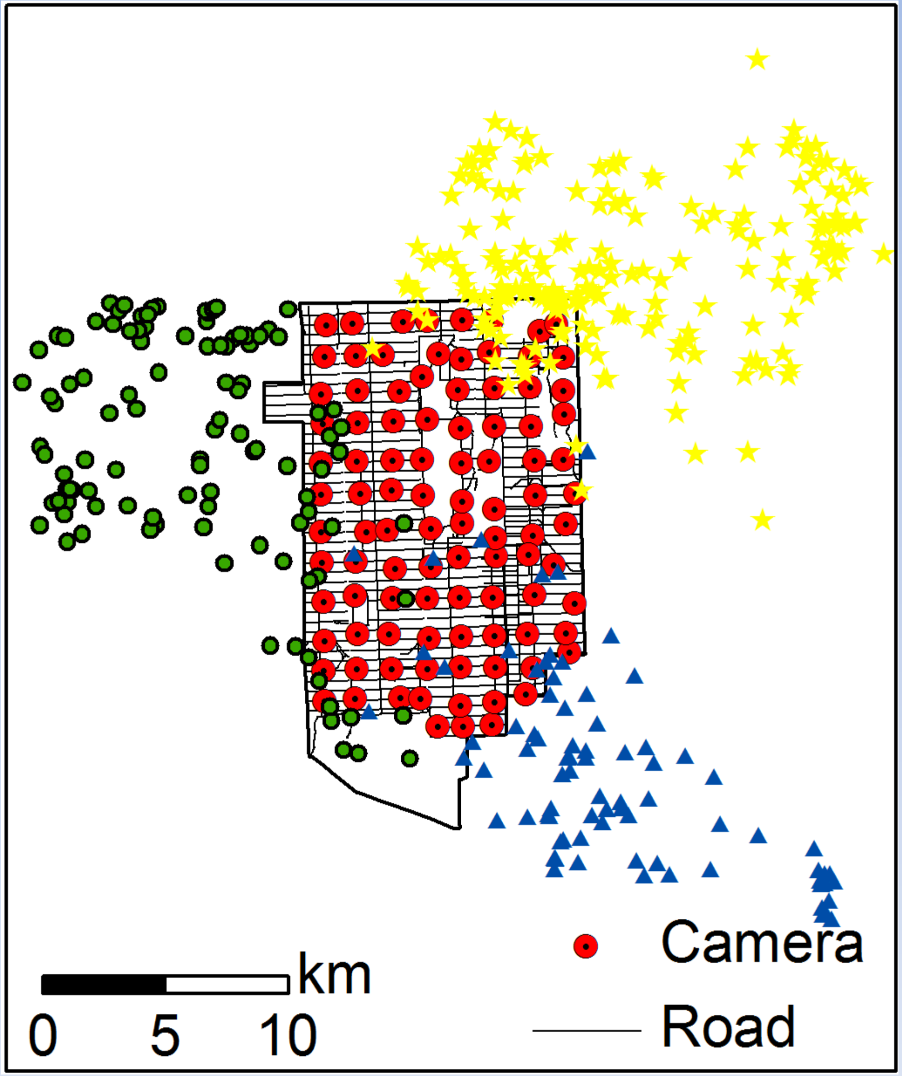
| | Individuals | Pictures |
|---|---|---|
| Season 1 | 2 | 2 |
| Season 2 | 2 | 15 |

Unidentified

| | Pictures |
|---|---|
| Season 1 | 131 |
| Season 2 | 176 |

Pictures: David Shindle, Conservancy of Southwest Florida

# Telemetry data




Average 99.5 (SD 10.6) locations/season

# Model results

## Movement and detection

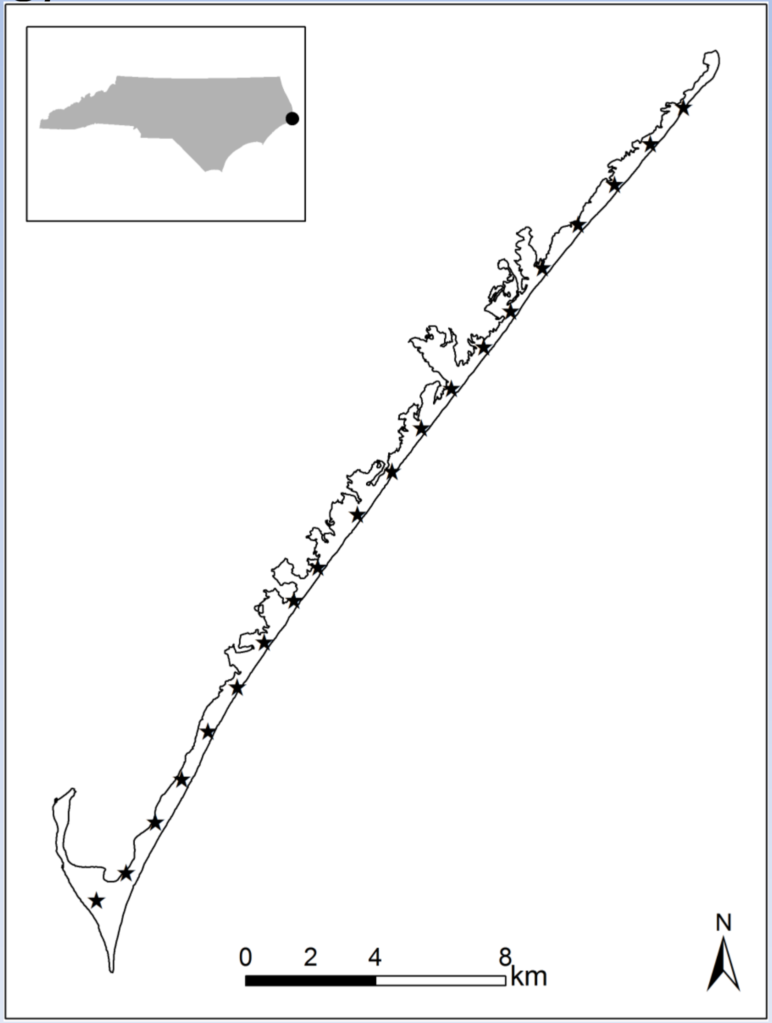
| Parameter | Mean (SE) | CI |
|---|---|---|
| $\sigma$ | 4.45 (0.11) | 4.24 – 4.68 |
| $\lambda_0$ | 0.09 (0.02) | 0.06 - 0.14 |

## Density

| Occasion | Density [per 100 km$^2$] | CI |
|---|---|---|
| 1 | 1.51 | 0.81 – 2.73 |
| 2 | 1.46 | 0.76 – 2.97 |

# SCR and telemetry data: Example 2

- Camera trap mark-resight study to estimate raccoon abundance on South Core Banks (36 km island, NC)




Sollmann et al., 2013, Ecology

# Lack of spatial resightings

- Low number of spatial resightings due to camera-trap spacing
- Data to estimate $\sigma$ extremely sparse

Telemetry data

- More and higher resolution location data
- Inform parameters of location and movement

# Results

| | Range |
|---|---|
| $\lambda_0$ | 0.016 – 0.192 |

| | Mean | SE |
|---|---|---|
| $\sigma$ | 0.492 | 0.010 |
| $N$ | 304.455 | 35.274 |

- $\sigma$ small compared to 1.8-km trap spacing
- $N$ reasonable considering later removal of 150 individuals

# SCR and space use

Half-normal trap encounter model

→ Bivariate normal model of space use

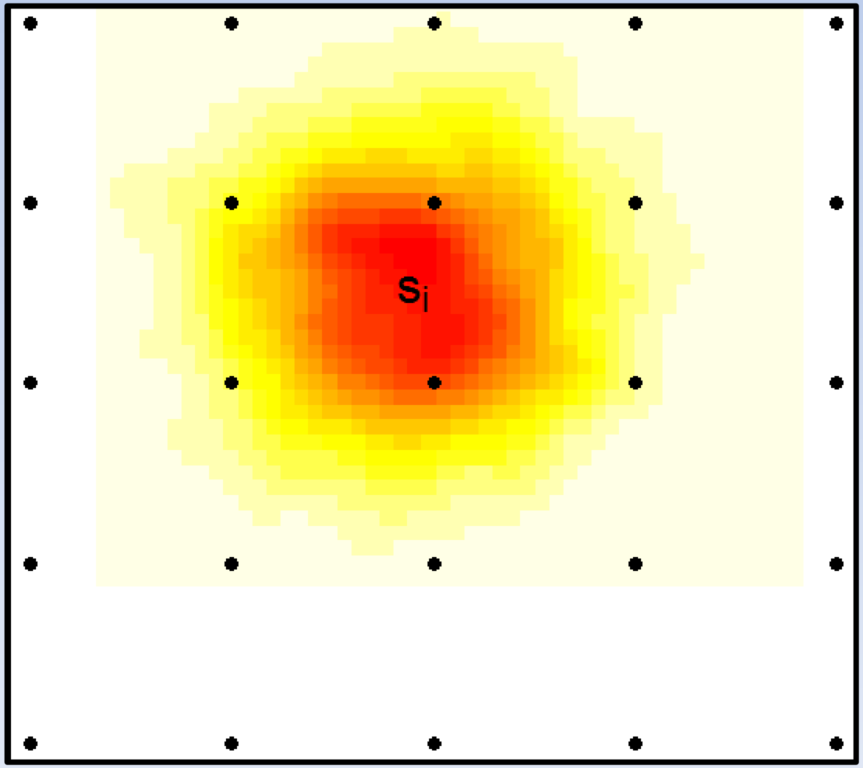
→ Isometric home ranges

What if animals use different habitats within their home ranges differently?

→ 3rd order habitat selection

→ asymmetric home ranges

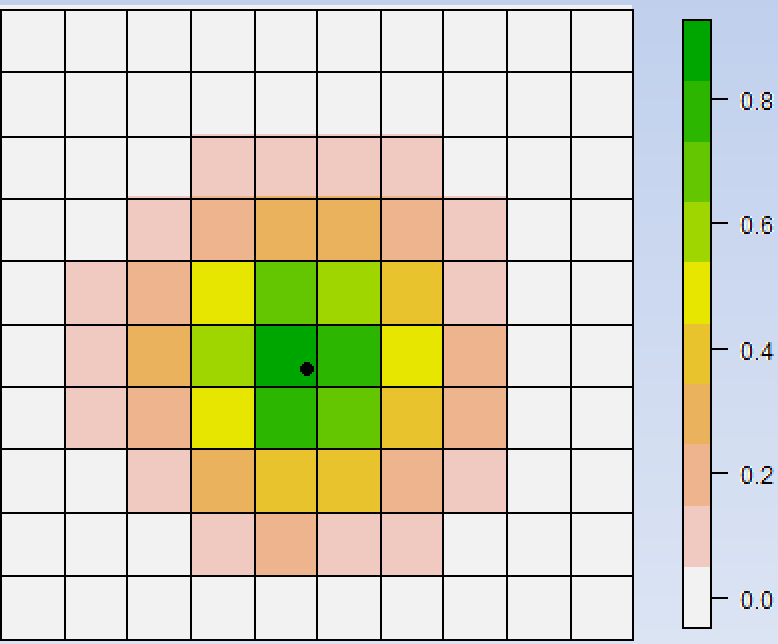
→ expected trap encounter rate varies by type of habitat



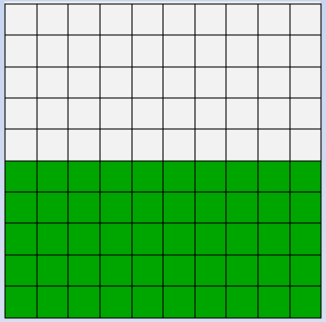
# SCR and habitat selection

- Space use within home range: third order habitat selection

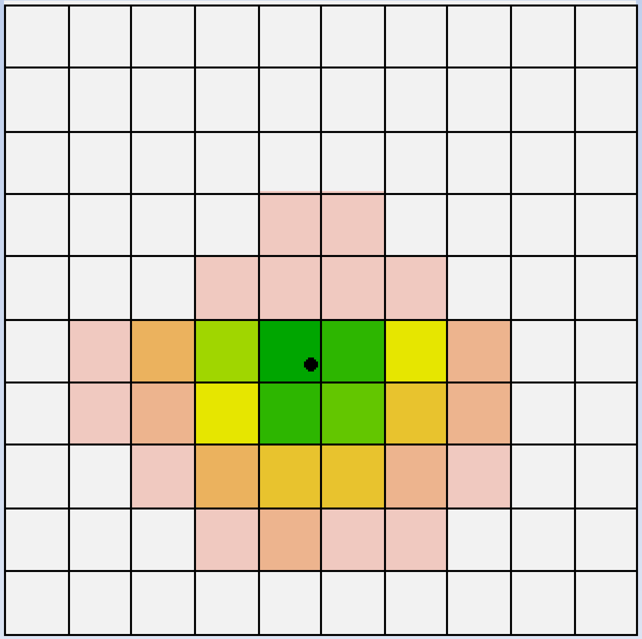
No selection
→ isometric home range




Covariate *X*



Selection for *X*="green"
→ irregular home range



# SCR and habitat selection

- Space use within home range: third order habitat selection
- Can be incorporated into SCR

Concept

- Trap encounter rate is proportional to space use
- Encounter model can be modified to incorporate spatial covariates, $X$

$$\lambda_{ij} = \exp(\alpha_0 + \alpha_1 X - f(distance[j, \mathbf{s}_i]))$$

- SCR estimates $\alpha_1$ (along with other parameters) from encounter data
- Royle et al. 2013, MEE

# SCR and habitat selection

- Distribution of telemetry locations across grid cells (in discrete space) provides additional (often more) information on habitat use

Trap encounter model

- $\lambda_{ij} = \exp(\alpha_0 + \alpha_1 X - f(distance[j, \mathbf{s}_i]))$

Telemetry model (for locations $\boldsymbol{l}$)

$$\pi_g = \frac{\exp(\alpha_1 X - f(distance[g, \mathbf{s}_i]))}{\sum \exp(\alpha_1 X - f(distance[g, \mathbf{s}_i]))}$$

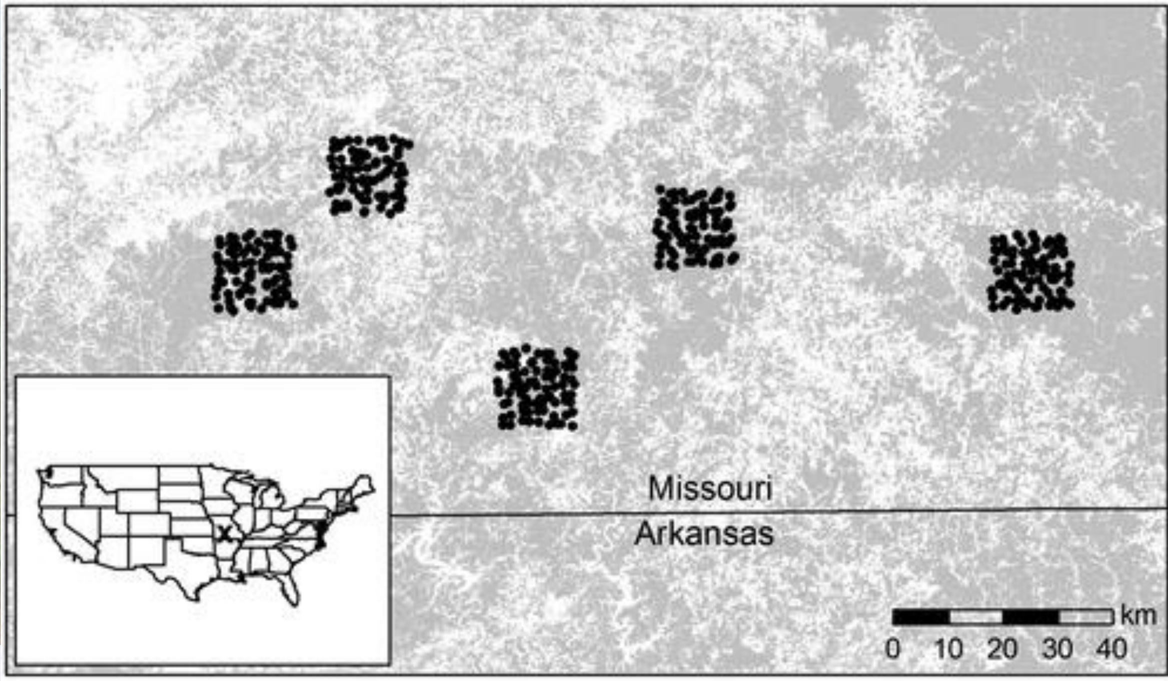
- where $\pi_g$ is the use intensity of grid cell *x*

$$\boldsymbol{l}_i \sim Multinomial(\boldsymbol{\pi}, n)$$

- where *n* = number of telemetry locations

# SCR and habitat selection: Example

- Habitat associations in a recolonizing, low-density black bear population (Sollmann et al. 2016, Ecosphere)
- 92 black bears detected across 5 hair snare grids
- 20 individuals with GPS collars (4 – 64 locations)
- Space use a function of slope, percent forest



# SCR and habitat selection: Example

- Densities ranged from $0.84 \pm 0.51$ to $10.26 \pm 2.40$ individuals/100km$^2$ across grids
- Both percent forest and slope had a positive effect on bear space use

→ In line with other studies of black bear habitat use

# Incorporating telemetry data into SCR can…

- Improve precision of parameter estimates when SCR data are sparse
- Offset lack of spatial recaptures due to inappropriate trap spacing
- Improve estimates of covariate effects on space use (resource selection functions, 3rd order habitat selection)

# Upcoming R exercises

- Simulate sparse SCR data and telemetry locations assuming isometric home ranges (no habitat selection)
- Fit SCR model with and without telemetry data
- Simulate SCR data and telemetry locations assuming habitat selection
- Fit SCR model with and without telemetry data
- R package: oSCR (Sutherland, Royle and Linden)

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THANK YOU!
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