Estimating Abundance from Camera Data

Introductions

Schedule / Format

- Today
    - Morning
        - Understand the camera problem
        - Sampling
        - Introduce estimators
    - Afternoon
        - Estimation details
        - Assumptions
        - Field considerations

Schedule / Format

- Tomorrow
  - Morning
    - Participants work on their own data

- Please ask questions
  - We can modify the schedule to meet your needs

Motivating the Camera Problem

Camera data are unique!

Camera Observations

- Photo
  - Is there an animal in the photo?
  - What kind of animal (species/age/sex)?
  - Where was the camera?
  - When was the photo taken?
  - Is the animal marked in some way?
  - Can you read the mark with certainty?

Common Analysis Methods

- Occupancy
- Capture-recapture
- Spatial capture-recapture
- *N*-mixture

- All miss fundamental issues with camera data

Issues with Camera Data

- Movement
  - Animals must move to get into the field of view
  - Trigger motion sensor

Occupancy

Capture-recapture

Spatial capture-recapture

N-mixture

Issues with Camera Data

- Logistical complexity
  - Cameras are expensive
  - Deployment is complex
  - Maintenance is complicated
  - Number of photos is huge
  - Animal populations operate at large spatial scales

✓ Occupancy

✗ Capture-recapture

✗ Spatial capture-recapture

✗ N-mixture

Issues with Camera Data

- Individual identification
  - Animals can be difficult to enumerate in a photo
  - Individual ID may not be possible

✓ Occupancy

✗ Capture-recapture

✗ Spatial capture-recapture

✗ N-mixture

Objective

- Estimator for camera data
  - Not affected by movement
  - Does not require marked animals
  - Does not require counts of animals in a photo
  - Logistically feasible at large scales
  - Estimates abundance

Sampling

The answer is hidden in plain sight

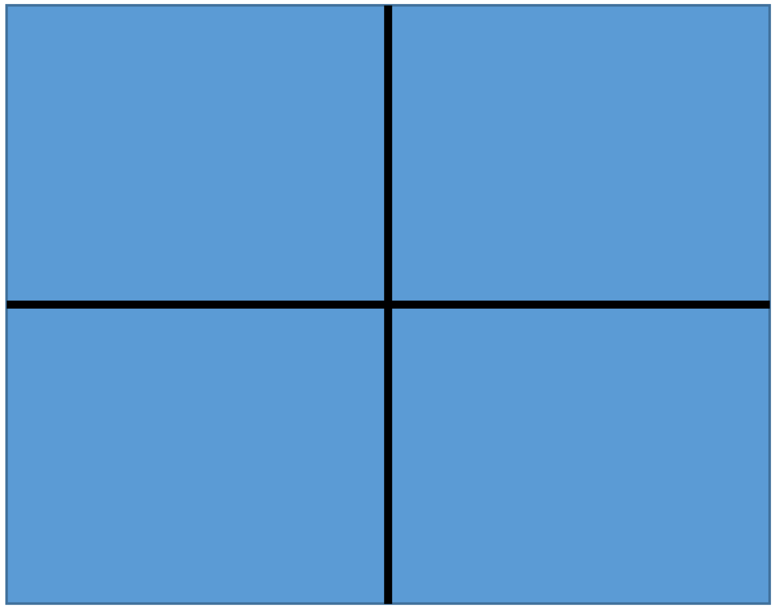
Sampling

- Basics are common knowledge
  - Use a subset to make inference to the whole
- Details are not intuitive

Motivating Example

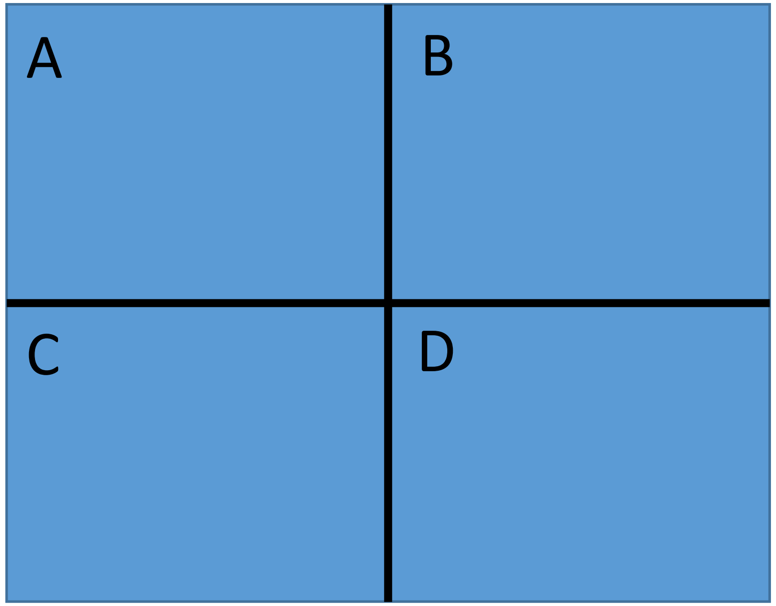
- Sampling frame (entire blue area)
  - Area of inference
  - Study area

- Sampling Units (smaller squares)
  - Area measured
  - Camera viewshed
  - Survey plot



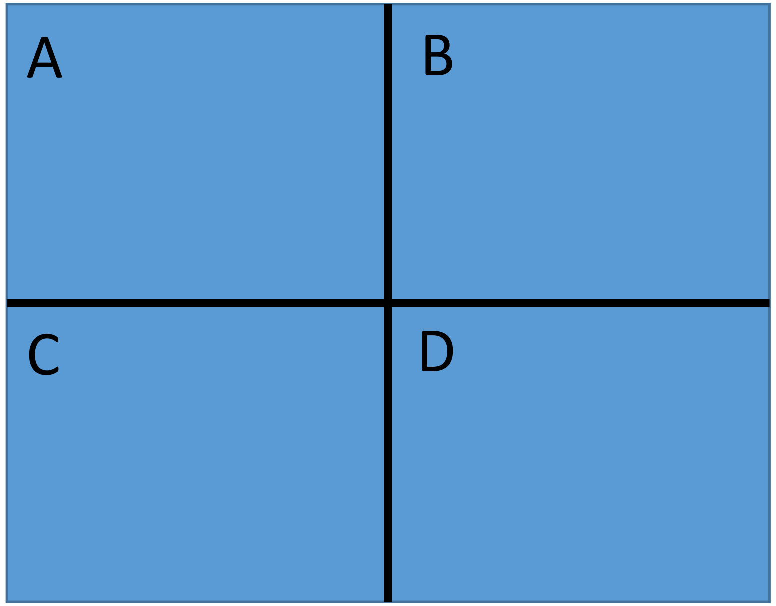
Motivating Example

- Sample
  - Selected sampling units for inference
- Sampling distribution
  - All possible combinations of samples of the same size
  - How many combinations of samples of size 1 are there?
  - How many of size 2?



Motivating Example

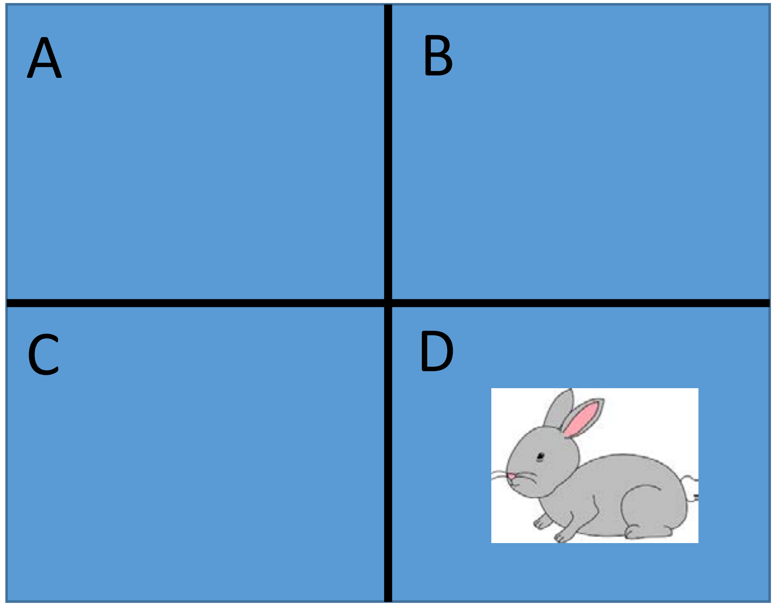
- Sample of size 1
  - Represents ¼ of sampling frame
  - Estimate = Count / (1/4)



Motivating Example

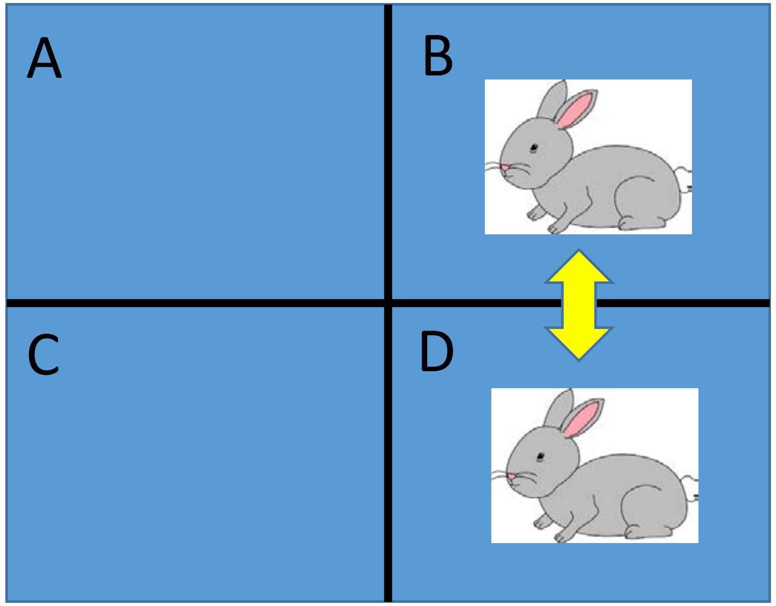
- Sample of size 1
  - Represents ¼ of sampling frame
  - Estimate = Count / (1/4)

Plot	Count	Fraction	Estimate
A	0	0.25	0
B	0	0.25	0
C	0	0.25	0
D	1	0.25	4
Average			1



Motivating Example – now add movement

- Sample of size 1
  - Represents ¼ of sampling frame
  - Estimate = Count / (1/4)

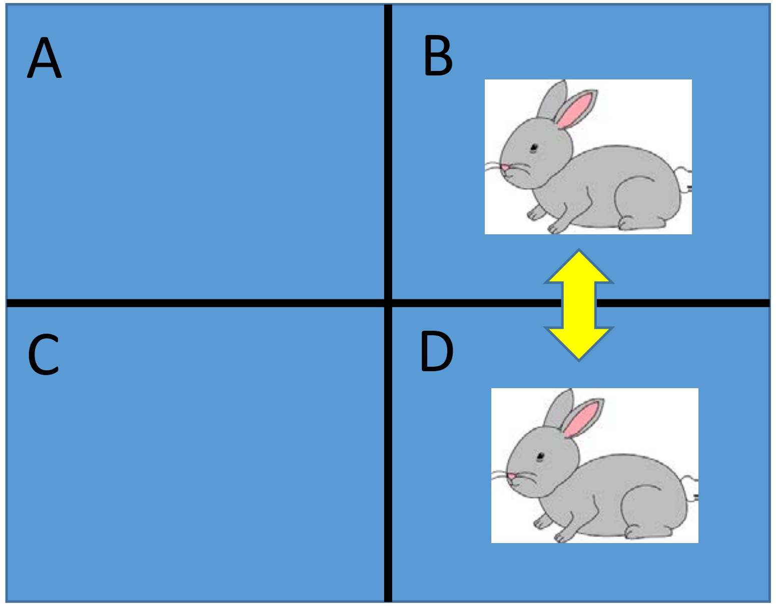


Motivating Example – now add movement

- Sample of size 1
  - Represents ¼ of sampling frame
  - Estimate = Count / (1/4)

Plot	Count	Fraction	Estimate
A	0	0.25	0
B	1	0.25	4
C	0	0.25	0
D	1	0.25	4
Average			2

!!!

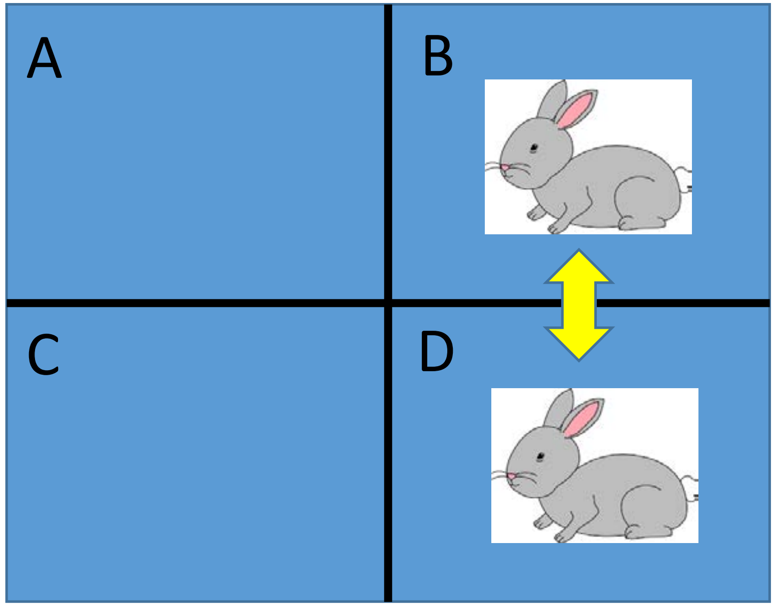


Motivating Example – now add movement

- Bias – how did it happen?
  - No double counting
  - No plots repeated across samples

Plot	Count	Fraction	Estimate
A	0	0.25	0
B	1	0.25	4
C	0	0.25	0
D	1	0.25	4
Average			2

!!!



Sampling – take home messages

- Sampling provides unbiased estimates of anything you can measure without a model

- Movement of the object of interest (animal) must be slow relative to the duration of the survey

Camera data estimators

Data Generation

- Photo
  - Time photo was taken
  - Area visible in the photo
  - Animal present or not
  - Camera with the detection
  - Time Lapse or motion trigger

Data Generation

- When will be get a picture of a cougar?

Data Generation

- Distributions
  - What is the distribution of times to the next photo?

Data Generation

- Distributions
    - What is the distribution of times to the next photo?
        - Exponential

Data Generation

- Distributions
  - What is the distribution of times to the next photo?
    - Exponential

  - Let‘s step through the distribution on the whiteboard…

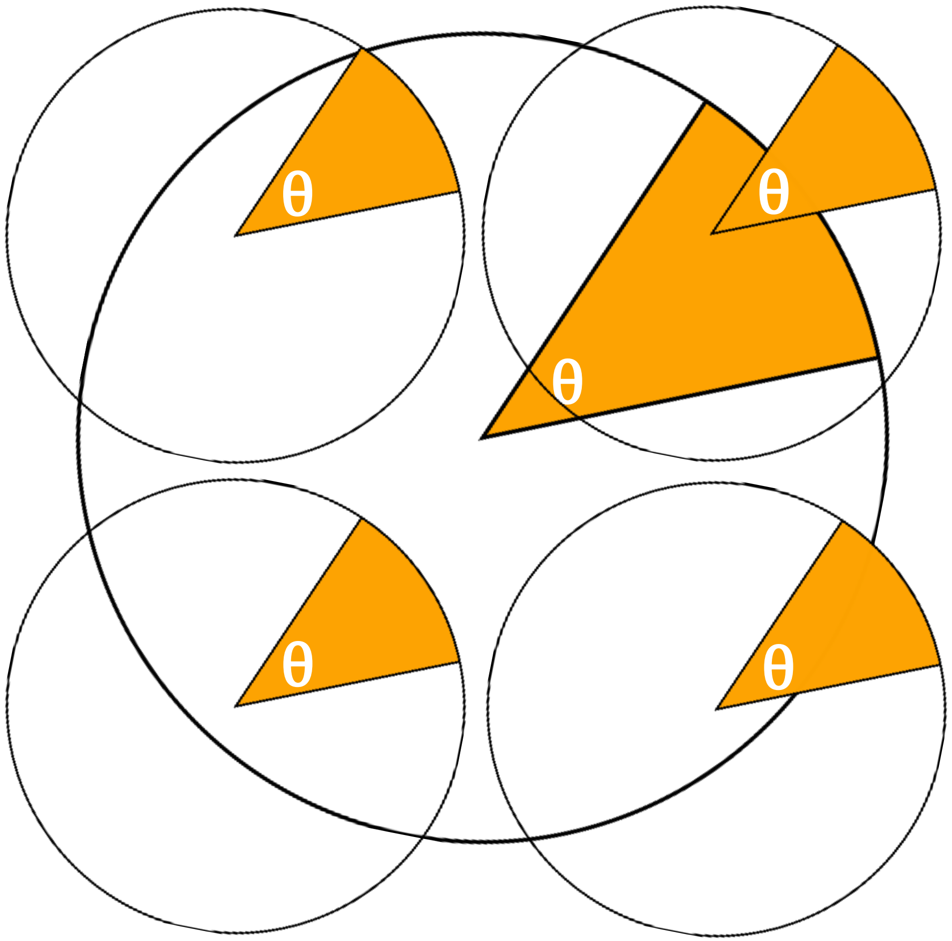
“Events”

$$N \sim \mathrm{Pois}(\lambda)$$

$$S \sim \mathrm{Exp}(\lambda)$$

“Waiting time”

Cameras



$$\hat{N} = \frac{total\ counted}{\#\ plots\ sampled} * \frac{study\ area\ size}{\pi r^2 \frac{\theta}{360}}$$

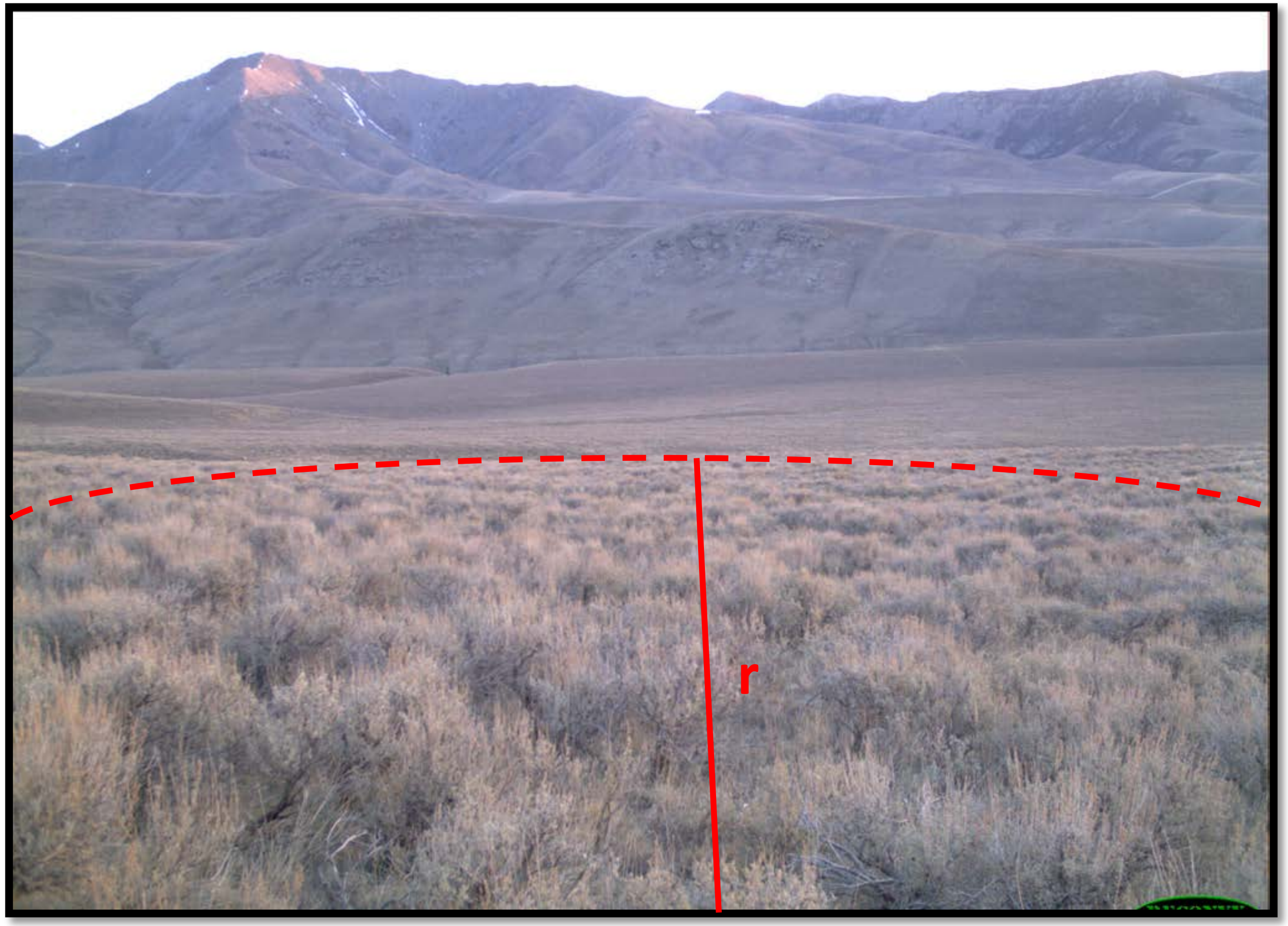
Abundance ↑ # Photos ↑

Abundance ↑ # Cameras with animals ↑

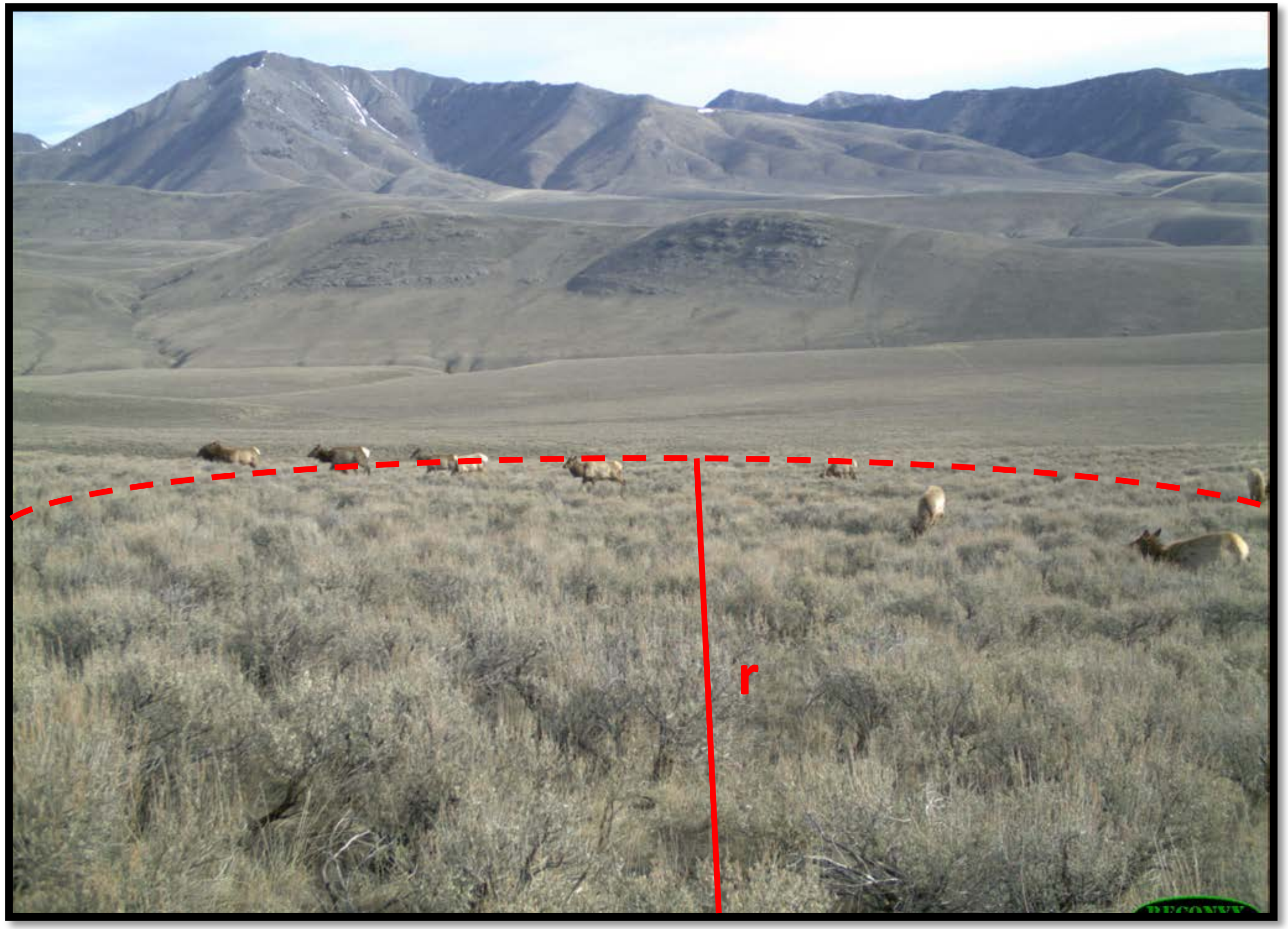
Abundance ↑ # Cameras until detection ↓

Want to estimate	Observe
"Event"	"Waiting Time"

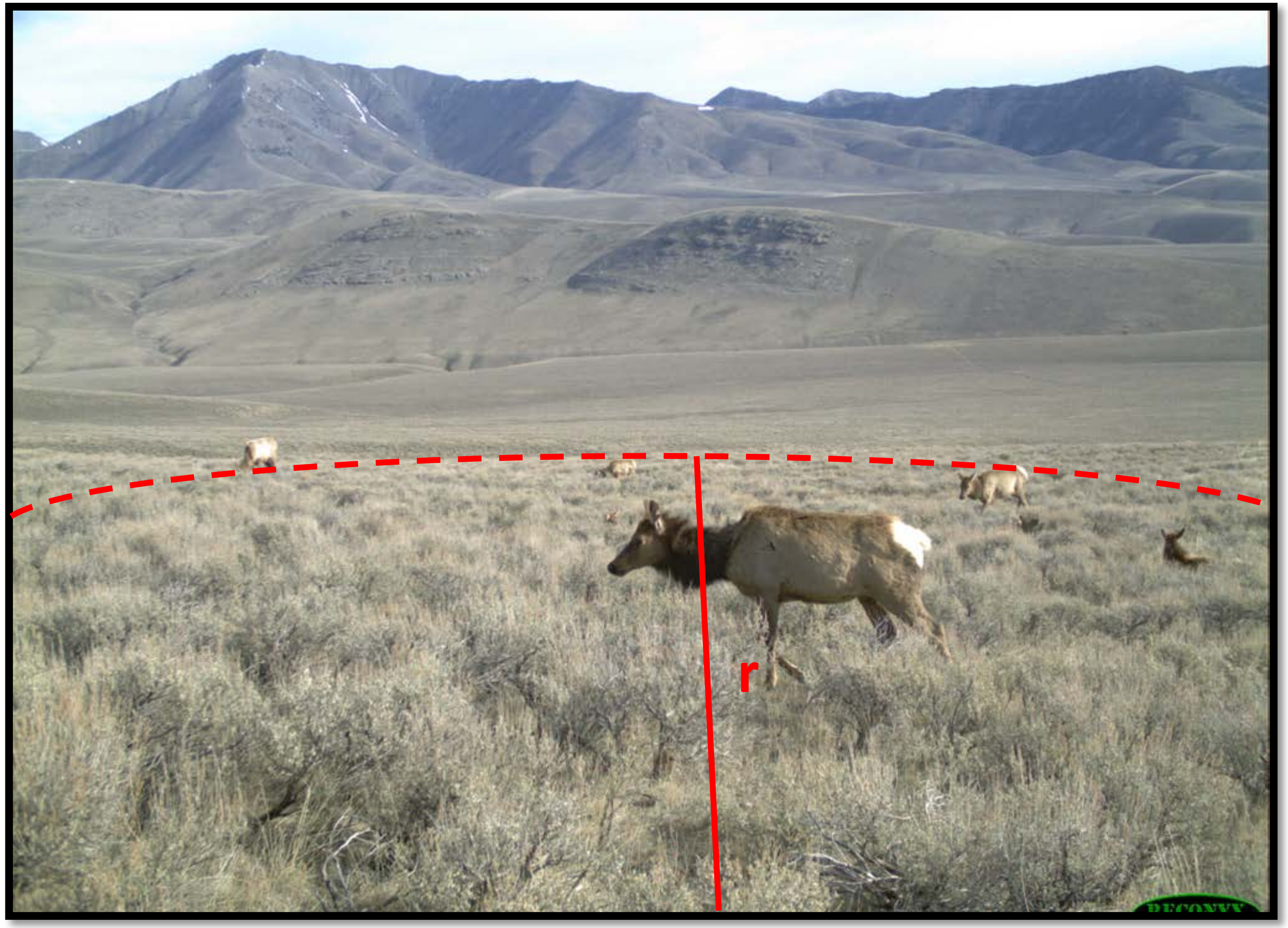
6:00 am



8:00 am



10:00 am



Space-to-Event

6:00 am

Camera 1

Camera 2

Camera 3

Camera 4

Camera 5

Camera 6

Space-to-Event Model

6:00	8:00	10:00	12:00	2:00	4:00
3					

8:00 am

Camera 1

Camera 2

Camera 3

Camera 4

Camera 5

Camera 6

Space-to-Event Model

6:00	8:00	10:00	12:00	2:00	4:00
3	2				

8:00 am

Camera 1

Camera 2

Camera 3

Camera 4

Camera 5

Camera 6

Space-to-Event Model

6:00	8:00	10:00	12:00	2:00	4:00
3	2	5	NA	1	NA

$$\mathcal{L}(\lambda|T_{ij}) = \prod_{j=1}^{J}\prod_{i=1}^{M}\sum_{z=0}^{\infty}\left(I_{(T\leq t)}p(1-p)^z\frac{\lambda_i^{z+1}}{\Gamma(z+1)}T_{ij}^{z}e^{-\lambda_i T_{ij}} + I_{(1-(T\leq t))}p(1-p)^z\int_t^{\infty}\frac{1}{\Gamma(z+1)}\gamma(z+1,\lambda_i T_{ij})d\lambda\right)$$

Time-to-Event Model

8:00 am

Time-to-Event Model

8:00 am

$T = 1$

Time-to-Event Model

8:00 am

$\cancel{T = 1}$

Time-to-Event Model

9:00 am

$\cancel{T = 1}$

$T = 2$

Time-to-Event Model

9:00 am

$\cancel{T = 1}$

$\cancel{T = 2}$

Time-to-Event Model

10:00 am

$\cancel{T = 1}$

$\cancel{T = 2}$

$T = 3$

Time-to-Event Model

10:00 am

$\cancel{T = 1}$

$\cancel{T = 2}$

$\boxed{T = 3}$

Time-to-Event Model

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Cam 1	3					
Cam 2						
Cam 3						
Cam 4						

Time-to-Event Model

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Cam 1	3	1	NA	5	NA	NA
Cam 2	NA	NA	NA	NA	2	NA
Cam 3	NA	5	4	NA	NA	NA
Cam 4	5	NA	NA	NA	NA	4

Time-to-Event Model

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Cam 1	3	1	NA	5	NA	NA
Cam 2	NA	NA	NA	NA	2	NA
Cam 3	NA	5	4	NA	NA	NA
Cam 4	5	NA	NA	NA	NA	4

6:00 am

Camera 1

Camera 2

Camera 3

Camera 4

Camera 5

Camera 6

Space-to-Event Model

6:00	8:00	10:00	12:00	2:00	4:00
3					

8:00 am

Camera 1

Camera 2

Camera 3

Camera 4

Camera 5

Camera 6

Space-to-Event Model

6:00	8:00	10:00	12:00	2:00	4:00
3	2	5	NA	1	NA

$$N \sim \mathrm{Pois}(\lambda)$$
$$S \sim \mathrm{Exp}(\lambda)$$

Abundance ↑ # Photos ↑

Abundance ↑ Time until detection ↓

Want to estimate

“Event”

Observe

“Waiting Time”

Time-to-Event Model

8:00 am

Time-to-Event Model

8:00 am

$T = 1$

Time-to-Event Model

8:00 am

$\cancel{T = 1}$

Time-to-Event Model

9:00 am

$\cancel{T = 1}$

$T = 2$

Time-to-Event Model

9:00 am

$\cancel{T = 1}$

$\cancel{T = 2}$

Time-to-Event Model

10:00
am

$\cancel{T = 1}$

$\cancel{T = 2}$

$T = 3$

Time-to-Event Model

10:00 am

$\cancel{T = 1}$

$\cancel{T = 2}$

$\boxed{T = 3}$

Time-to-Event Model

	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Obs 6
Cam 1	3					
Cam 2						
Cam 3						
Cam 4						

Time-to-Event Model

	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Obs 6
Cam 1	3	1	NA	5	NA	NA
Cam 2	NA	NA	NA	NA	2	NA
Cam 3	NA	5	4	NA	NA	NA
Cam 4	5	NA	NA	NA	NA	4

Time-to-Event Model

	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Obs 6
Cam 1	3	1	NA	5	NA	NA
Cam 2	NA	NA	NA	NA	2	NA
Cam 3	NA	5	4	NA	NA	NA
Cam 4	5	NA	NA	NA	NA	4

$$N \sim \text{Pois}(\lambda)$$
$$T \sim \text{Exp}(\lambda)$$

Three estimators

- Instantaneous
- Space-to-Event
- Time-to-Event

More details…

Space-to-event

- Algorithm
  - Time lapse photos
  - At each photo event
    - List all active cameras
    - Randomize list order
    - Sum area covered by cameras until the first animal of interest is detected
  - Repeat for each time lapse event
  - Fit exponential distribution to the areas
  - Rate parameter is animals per unit area
  - Multiply by total sampling frame area to estimate abundance

Time-to-Event

- Algorithm
  - Motion trigger photos
  - For each camera
    - Measure time steps to next detection
  - Repeat for each camera event
  - Fit exponential distribution to the time steps
  - Rate parameter is animals per unit area
  - Multiply by total sampling frame area to estimate abundance

Instantaneous Estimator

- Algorithm
    - Time lapse photos
    - At each photo event
        - Count animals in each photo
    - Repeat for each time lapse event
    - Fit average animals per unit area
    - Multiply by total sampling frame area to estimate abundance

Assumptions

Sample Size

Potential Problems

- Kenneth

Field logistics

- Camera placement
- Numbers of cameras
- Study duration

Photo storage and processing

Future directions