

Density Estimation Using Camera Traps: What is Possible?

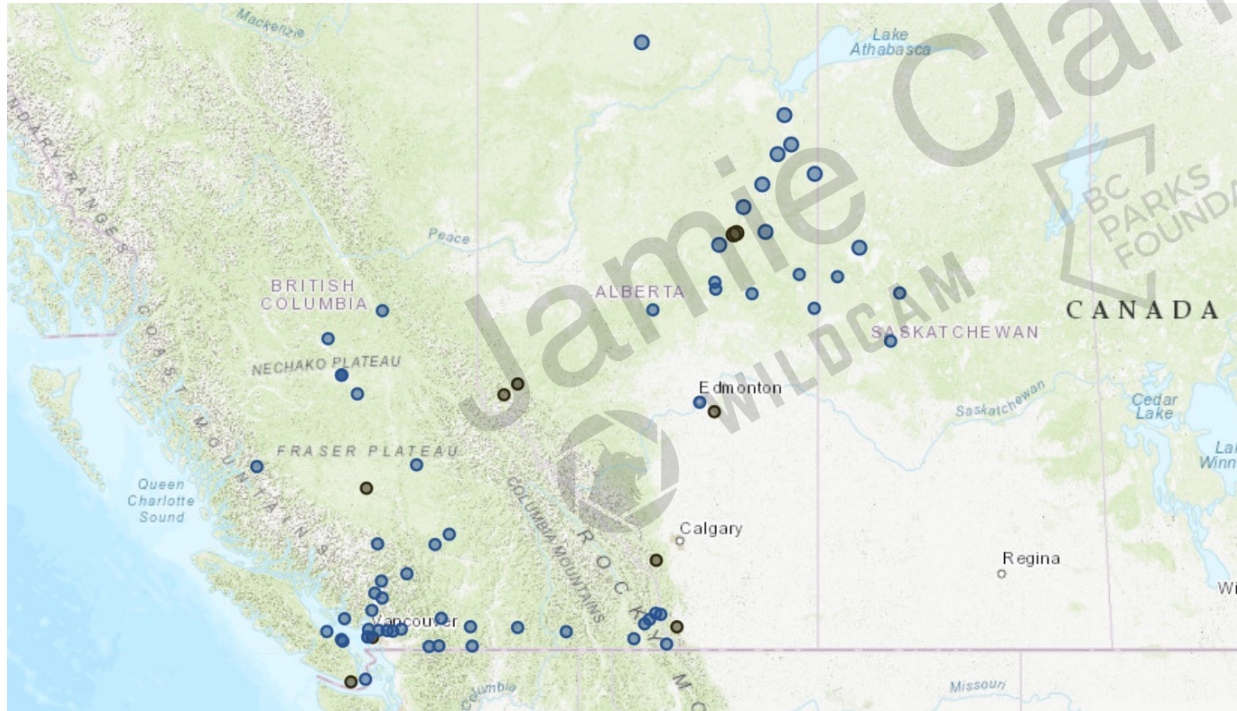
Jamie Clarke¹, Holger Bohm², Cole Burton³ and Alexia Constantinou^{1,4}

¹WildCAM, BC Parks Foundation; ²BC Ministry of Forests; ³UBC Faculty of Forestry; ⁴BCIT School of Construction and the Environment

This research took place on the traditional, ancestral, and unceded territories of the **Coast Salish Peoples** – the **Sk̓wx̓wú7mesh** (Squamish), **Stó:lō** and **Səlílwətaʔ/Selilwitulh** (Tsleil-Waututh) and **xʷməθkʷəy̓əm** (Musqueam) Nations – and the **sngaytskstx** (Sinixt) People.



What is WildCAM?



WILDCAM

is a network of
camera trappers, for
camera trappers, that
supports effective
wildlife stewardship
by fostering
coordination +
collaboration and
sharing **best practices**

Who is WildCAM?

Our Advisory Committee:

- Dr. Cole Burton, University of British Columbia
- Dr. Jason Fisher, University of Victoria
- Dr. Joanna Burgar, BC Ministry of Water, Land and Resource Stewardship
- Dr. Dan Farr, Alberta Resource Stewardship Division
- Dr. Anne Hubbs, Alberta Environment and Parks
- Dr. Kaitlyn Gaynor, University of British Columbia
- Dr. Tyler Muhly, Ministry of Forests
- Melanie Percy, BC Parks



Ministry of
Forests, Lands, Natural
Resource Operations
and Rural Development



WildCo



WildCAM + the BC Parks Foundation



WildCAM is administered
by the



– which protects,
enhances and sustains
BC's parks, while
inspiring and connecting
people to them

WildCAM Coordinator



Jamie Clarke

So You Know...

Material covered today is
also available in the
handbook

**Using Camera Traps to Estimate Medium and Large Mammal
Density:**

**Comparison of Methods and Recommendations for Wildlife
Managers**

Prepared by

Jamie Clarke, WildCAM

In collaboration with

Holger Bohm, Provincial Ungulate Specialist – British Columbia

Dr. Cole Burton, Principal Investigator – Wildlife Coexistence Lab

Alexia Constantinou, WildCAM

Nov 30, 2022

① Background

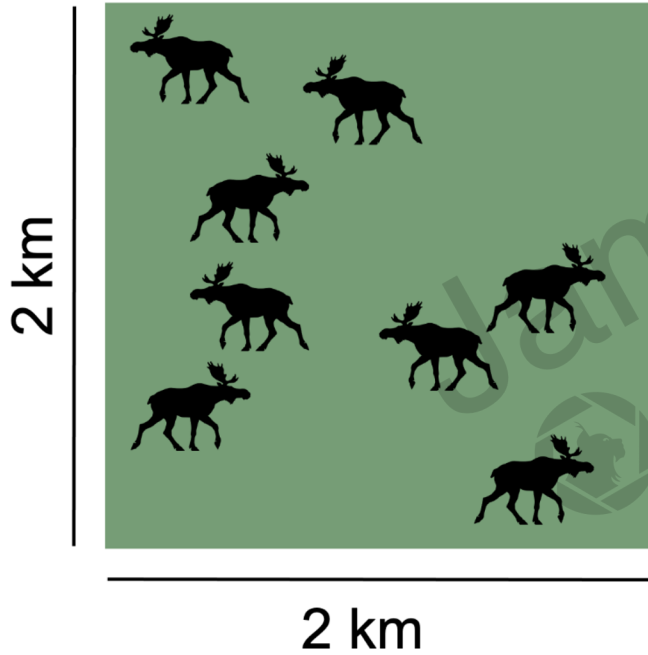
What is Density?

$$\frac{\# \text{ animals}}{\text{area}}$$

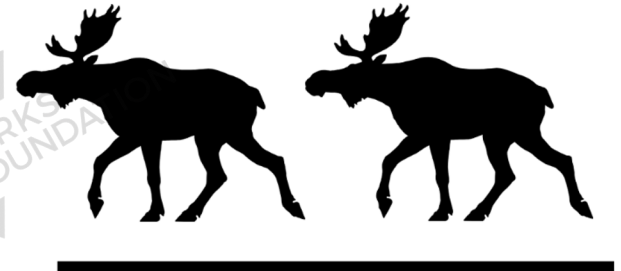
→ population size

→ total area sampled

What is Density?



=

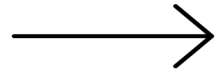


Two black silhouettes of moose are shown above a horizontal line. Below the line, the unit km^2 is written.

$$\frac{\text{Number of moose}}{\text{km}^2}$$

Why is Density Useful?

monitor



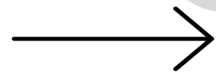
populations trends: increases? declines?
(Morin et al. 2022)

manage



animals that can be sustainably hunted?
(2020-2022 Hunting and Trapping Regulations Synopsis)

assess



impacts of management actions?
(Sun et al. 2022)

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Estimates of Density are Critical for Wildlife Stewardship

standardized
comparisons
across...

(Morin et al. 2022)



space



species



time



vs



vs

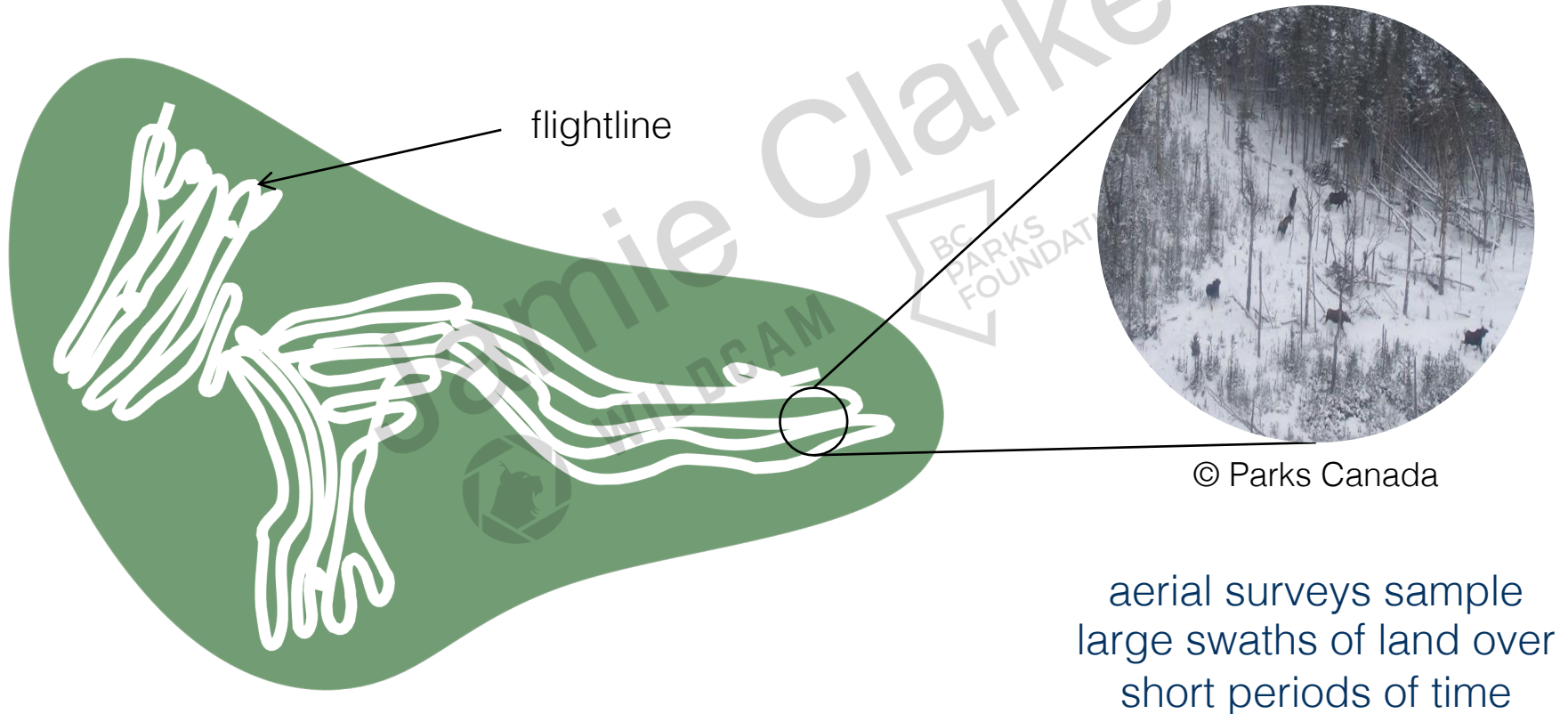


t_1

vs

t_2

In BC: Often Estimate Density via Aerial Survey





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Aerial Surveys Are...

Expensive



- flown infrequently
- few wildlife management units surveyed/year (Boyce et al. 2012)

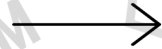


sporadic, spotty coverage

Dangerous



- injury + death to biologists
- disturbance to wildlife
(Côté et al. 2013, Crupi et al. 2020, Frid 2003)

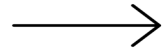


most dangerous part of a
wildlife biologist's job
(Sasse 2003)

Limited in Scope



- big animals
- open, snowy areas
(BC Ministry of SRM 2002)
- poor density estimate
(Davis et al. 2022)



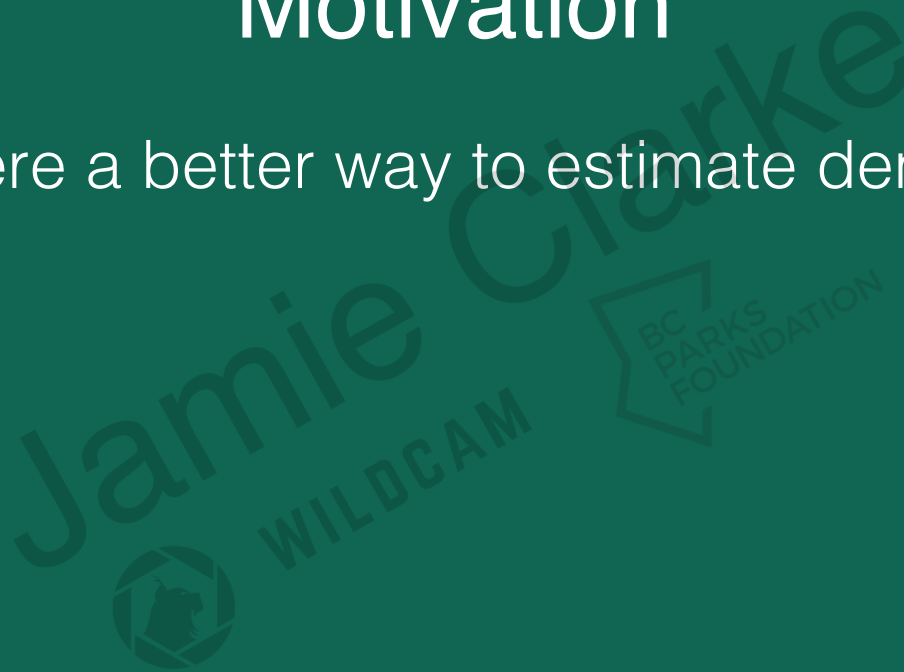
species-, landscape- and
season-limited

Motivation



Motivation

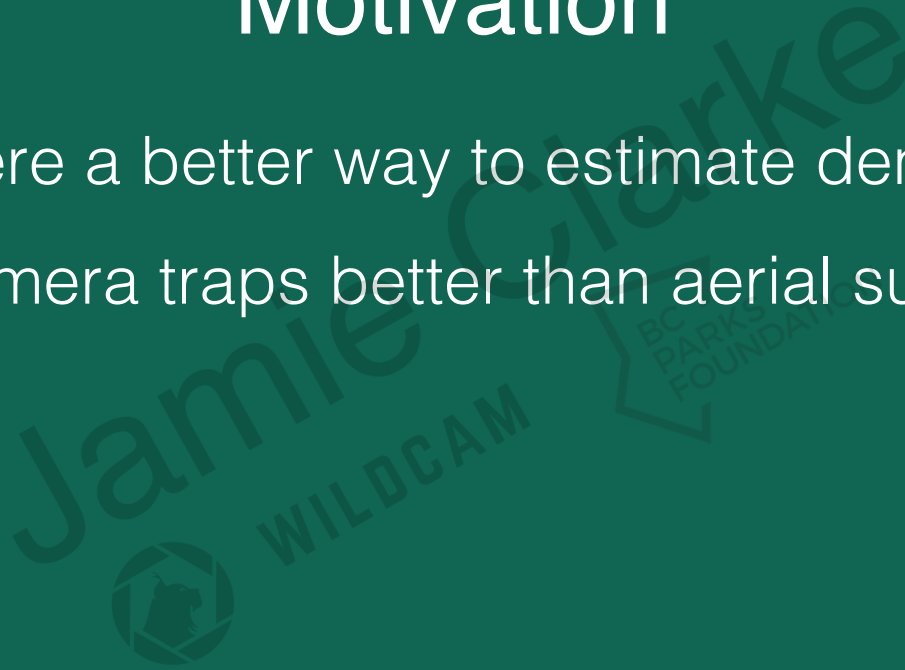
Is there a better way to estimate density?



Motivation

Is there a better way to estimate density?

Are camera traps better than aerial surveys?



Motivation

Is there a better way to estimate density?

Are camera traps better than aerial surveys?



first: we need to know...

Motivation

is there a better way to estimate density?

are camera traps better than aerial surveys?



first: we need to know...

How can you estimate population density using camera traps?

Problem

Information about camera trap density models
is all over the place – hundreds of peer-
reviewed papers, grey literature, reports...

② Context



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How Do Camera Traps Work?



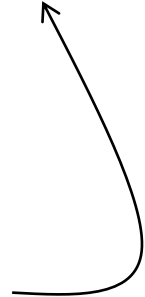
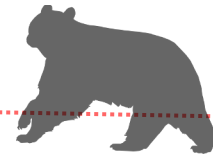
How Do Camera Traps Work?



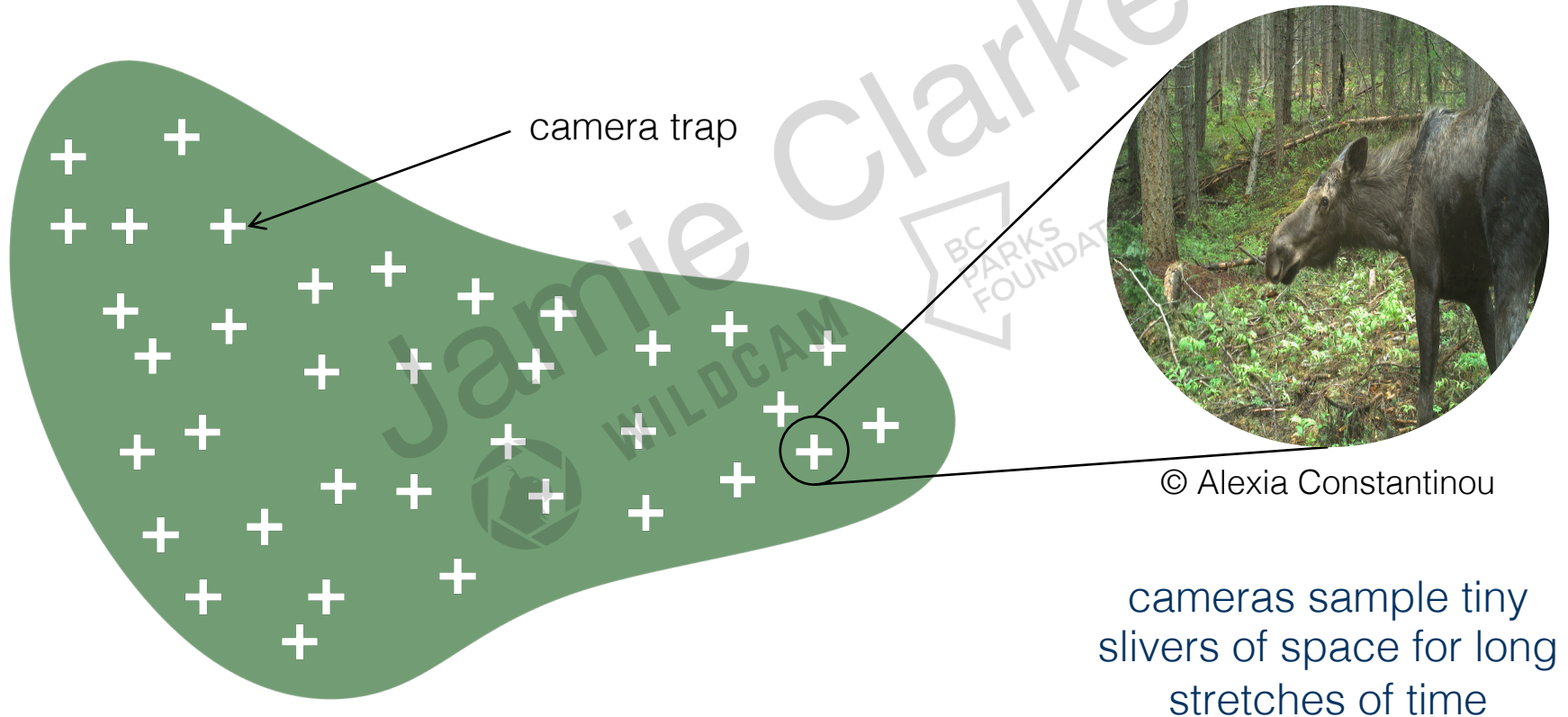
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temperature
difference +
movement
= trigger ⚡

motion
sensor



How Do Camera Traps Sample the Landscape?



③ Camera Trap Density Models



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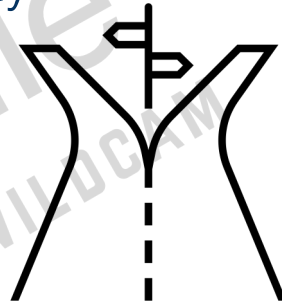


Can use **indices of density**
(relative abundance, occupancy)

Use **density models**
(our focus today)

No – don't need to
know absolute density

Yes – need to know
absolute density



First we need to ask:
are density estimates
needed?

Different Kinds of Camera Trap Density Models



marked models



unmarked models



partially-marked models

So You Know...

- there is ongoing work to **evaluate** these models
- some of this work is highlighted in the **handbook**

Today: going over *how* models work

Marked Models

Animals have
unique natural or
artificial marks =
unique identities



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Conservation

Capture-Recapture

(Karanth and Nichols 1998, Otis et al. 1978)

Data Needed:

- individual detection histories

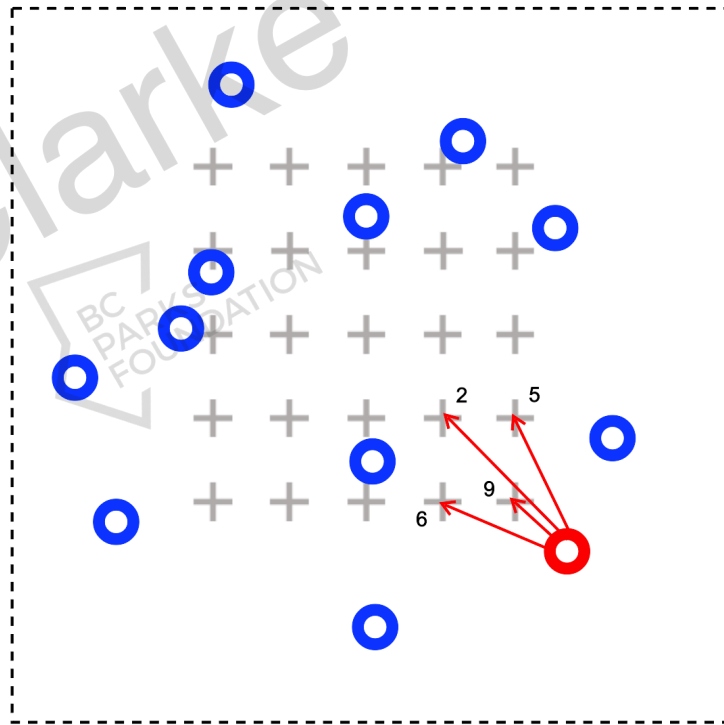
	sampling occasion				
	1	2	3	...	$k = K$
1	0	0	1	...	0
2	0	0	1	...	1
3	0	0	1	...	0
...
$n + 1$	0	0	0	...	0
$n + 2$	0	0	0	...	0
...
N	0	0	0	0	0

Spatial Capture-Recapture

(Borchers and Efford 2008, Royle and Young 2008)

Data Needed:

- ☐ individual detection histories
- ☐ camera trap coordinates



Unmarked Models



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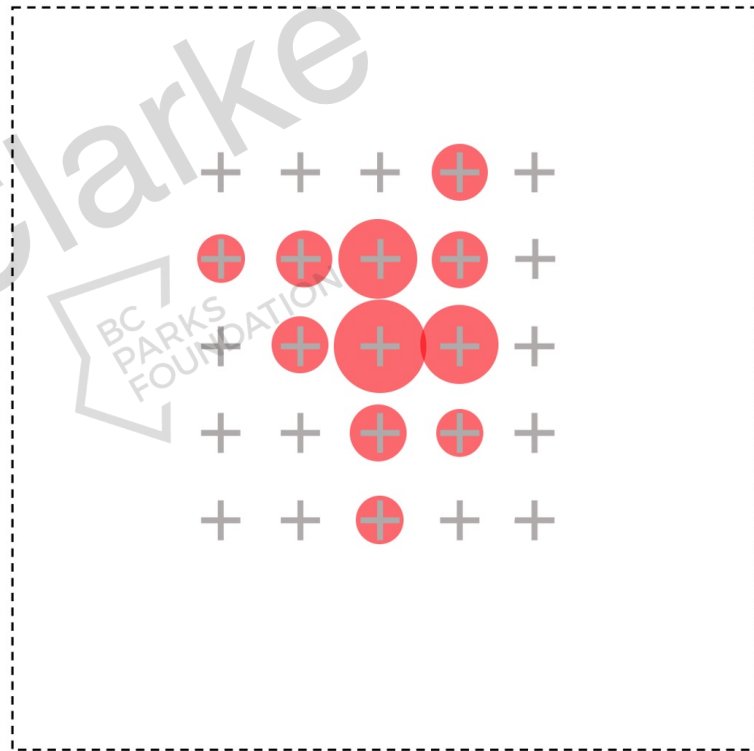
Animals do not have
unique marks =
cannot be individually
identified

Spatial Count

(Chandler and Royle 2013)

Data Needed:

- ☐ camera-specific counts of animals
- ☐ camera trap coordinates

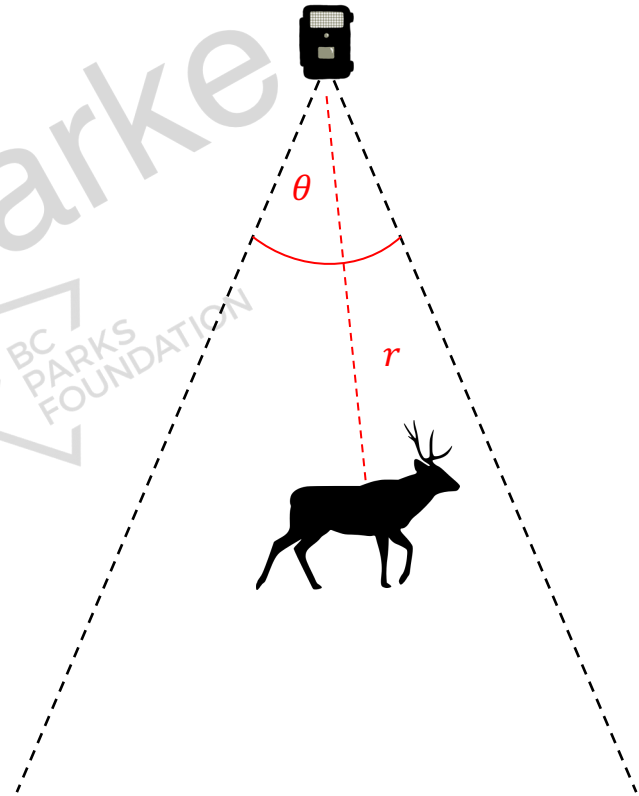


Distance Sampling

(Howe et al. 2017)

Data Needed:

- ☐ number of detections
- ☐ viewshed angle
- ☐ distance between camera and animals' centre

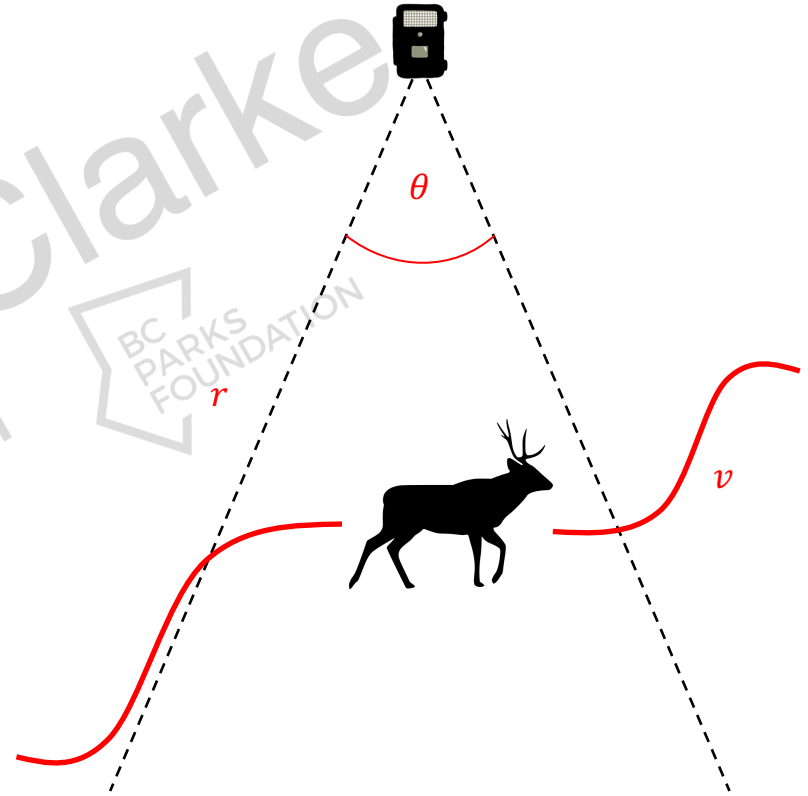


Random Encounter Model

(Rowcliffe et al. 2008)

Data Needed:

- ☐ number of images per unit time
- ☐ animal movement speed
- ☐ radius and angle of detection zone
- ☐ average group size

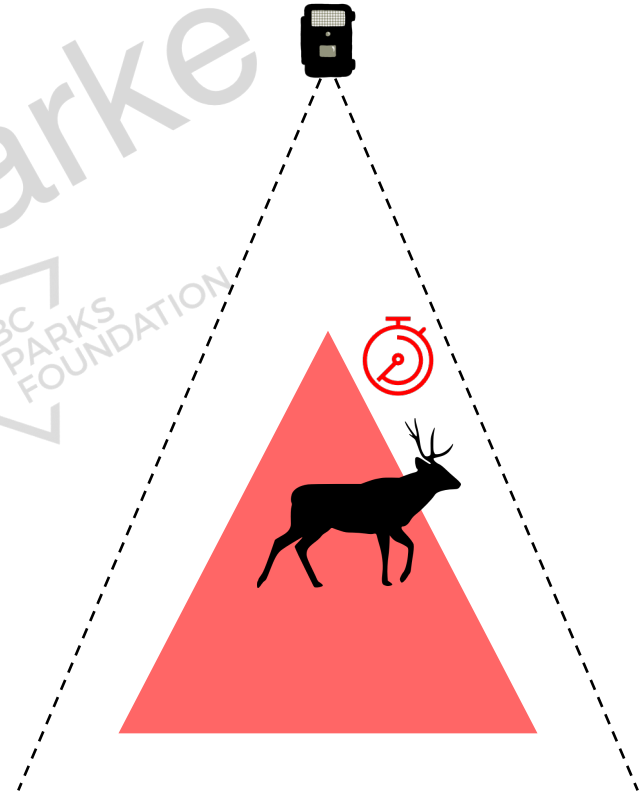


Random Encounter and Staying Time

(Nakashima et al. 2018)

Data Needed:

- ☐ number of detections
- ☐ camera focal area
- ☐ time individuals spend in focal area
- ☐ total sampling time
- ☐ proportion of time animals spend active

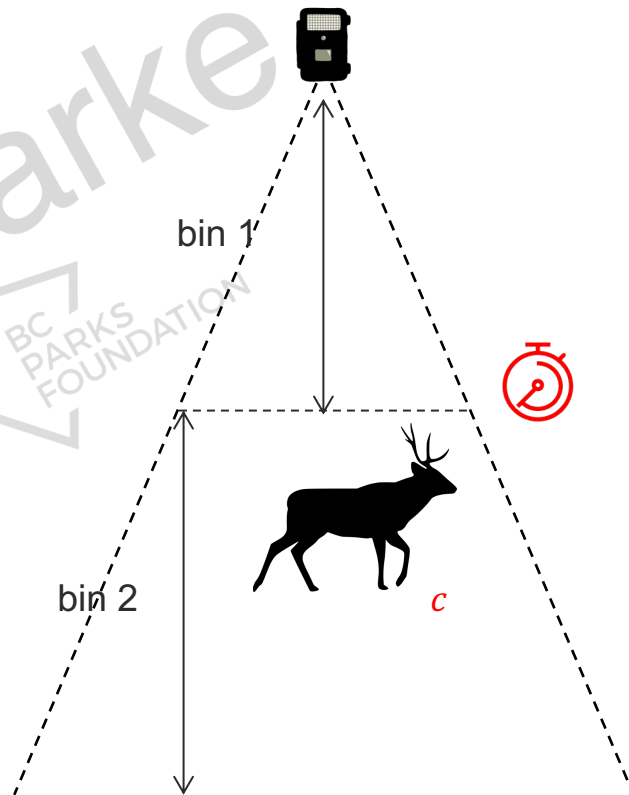


Time in Front of the Camera

(Becker et al. 2022)

Data Needed:

- ☐ counts of individuals in images
- ☐ time individuals spend in viewshed
- ☐ viewshed divided into distance bins
- ☐ total camera operating time

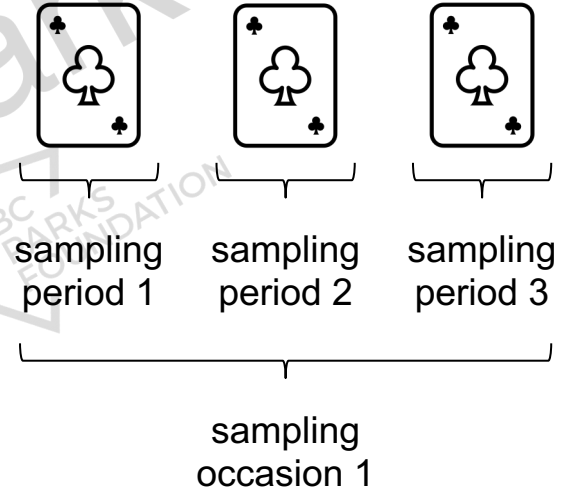


Time-to-Event

(Moeller et al. 2018)

Data Needed:

- ☐ time until individual(s) detected
- ☐ animal movement speed
- ☐ viewshed area



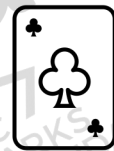
how much time until  drawn?

Space-to-Event

(Moeller et al. 2018)

Data Needed:

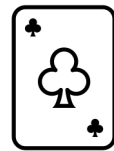
- ☐ number of cameras until individual(s) detected
- ☐ viewshed area



sampling
occasion 1



sampling
occasion 2



sampling
occasion 3

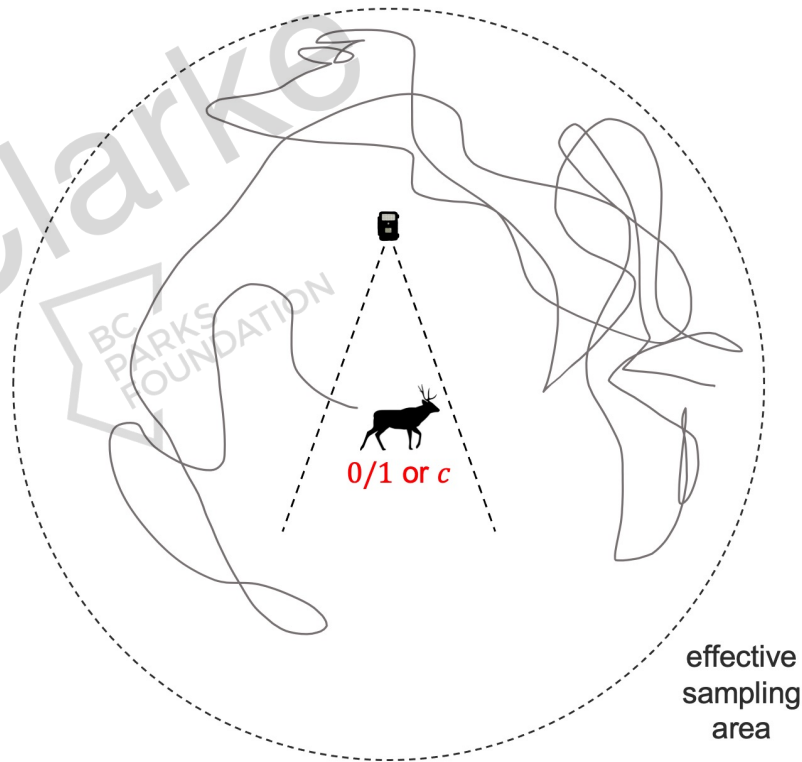
how much area until  drawn?

Site-Structured Models: Royle-Nichols + N-Mixture

(Royle and Nichols 2003, Royle 2004)

Data Needed:

- ☐ detections + non-detections *or* counts of animals during each survey occasion



Partially-Marked Models

Subset of marked
animals in a
population =
populations are
partially-marked



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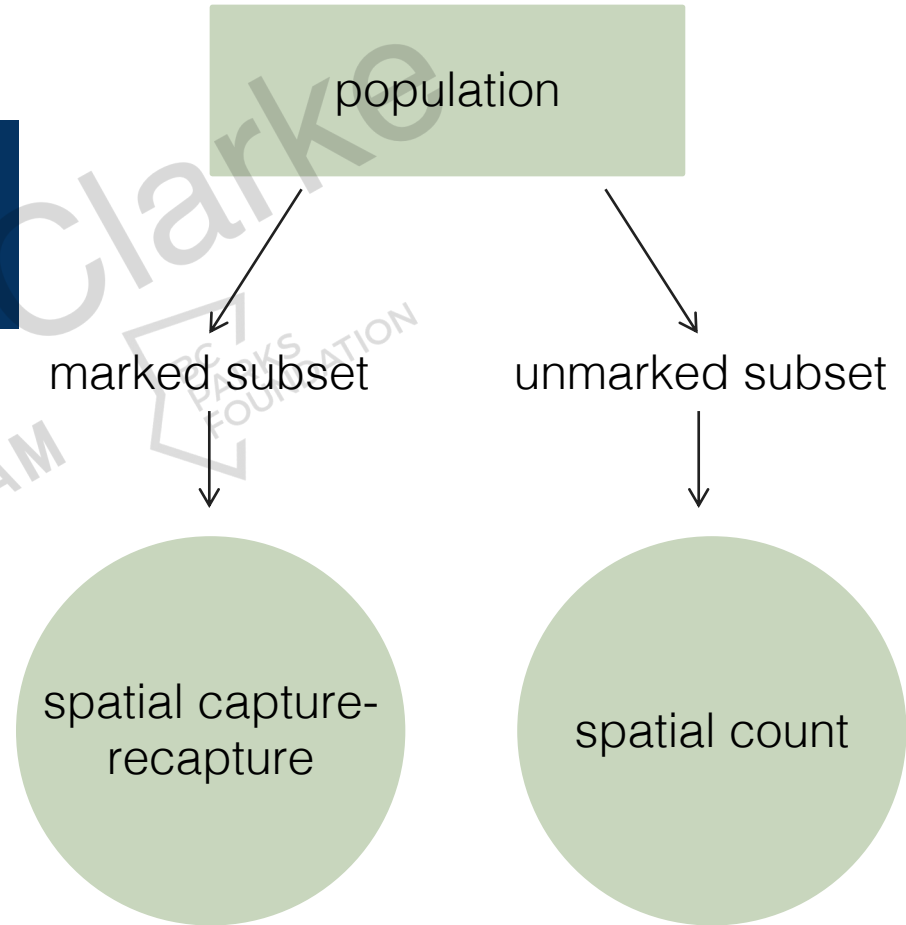
Spatial Mark-Resight

(Chandler and Royle 2013, Sollmann et al. 2013)

Data Needed:

- ☐ individual detection histories
- ☐ camera-specific counts of animals
- ☐ camera trap coordinates

“hybrid model”





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Image sets are
partially-identifying

if capture left +
right flanks
simultaneously:
can assign same
ID to each side

VS

if capture left +
right sides
separately: can
erroneously
assign different
IDs to left + right
flanks



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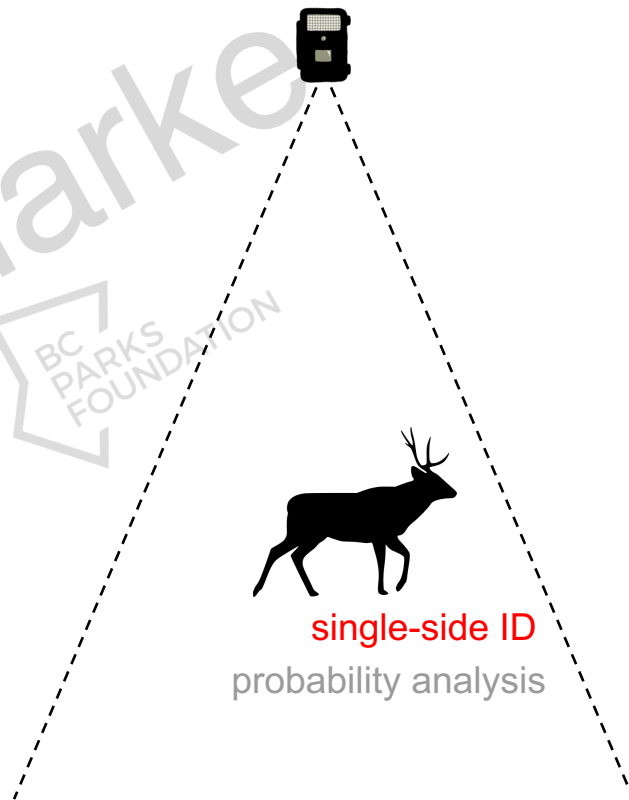
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2-Flank Spatial Partial Identity Model

(Augustine et al. 2018)

Data Needed:

- ☐ individual detection histories
- ☐ camera trap coordinates





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Individual animals
have sets of partially-
identifying traits =
individuals are
partially-marked

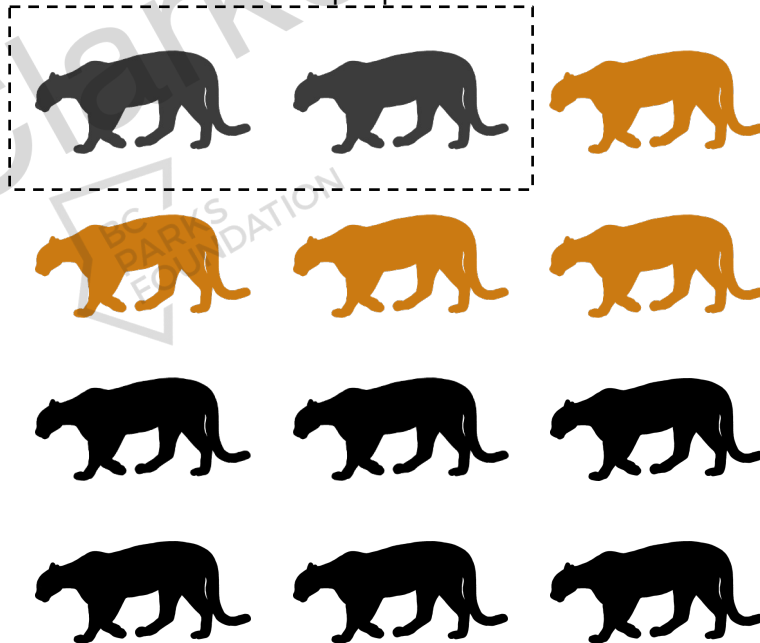
Categorical Spatial Partial Identity Model

(Augustine et al. 2019)

Data Needed:

- ☐ camera-specific counts of animals
- ☐ camera trap coordinates
- ☐ categorical identifiers

perform spatial count on
small subsets of population





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Animals partially-identified using suites of categorical traits

full categorical identity:

♀, adult, collar, 2
antler points

④ Outcomes



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Wrote a Handbook That...

- summarizes + explains *how models work*
- lists model *assumptions* + effects of violations
- lists *advantages* + *limitations*
- discusses *simulations* + *empirical tests*
- **gathers all this info in 1 place!**

Using Camera Traps to Estimate Medium and Large Mammal
Density:

Comparison of Methods and Recommendations for Wildlife
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Nov 30, 2022

Handbook Will Be Available to Read at:

www.wildcams.ca

**WILDCAM**


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WildCAM: A Camera Trap Network for Western Canada Where You Can:

- ▶ Connect with other researchers and projects
- ▶ Share great wildlife images and news
- ▶ Get the supporting resources you need
- ▶ Compare notes on camera-trap methods
- ▶ Contribute to science-based management

Camera Trap Collaborations to Improve Wildlife Management and Conservation

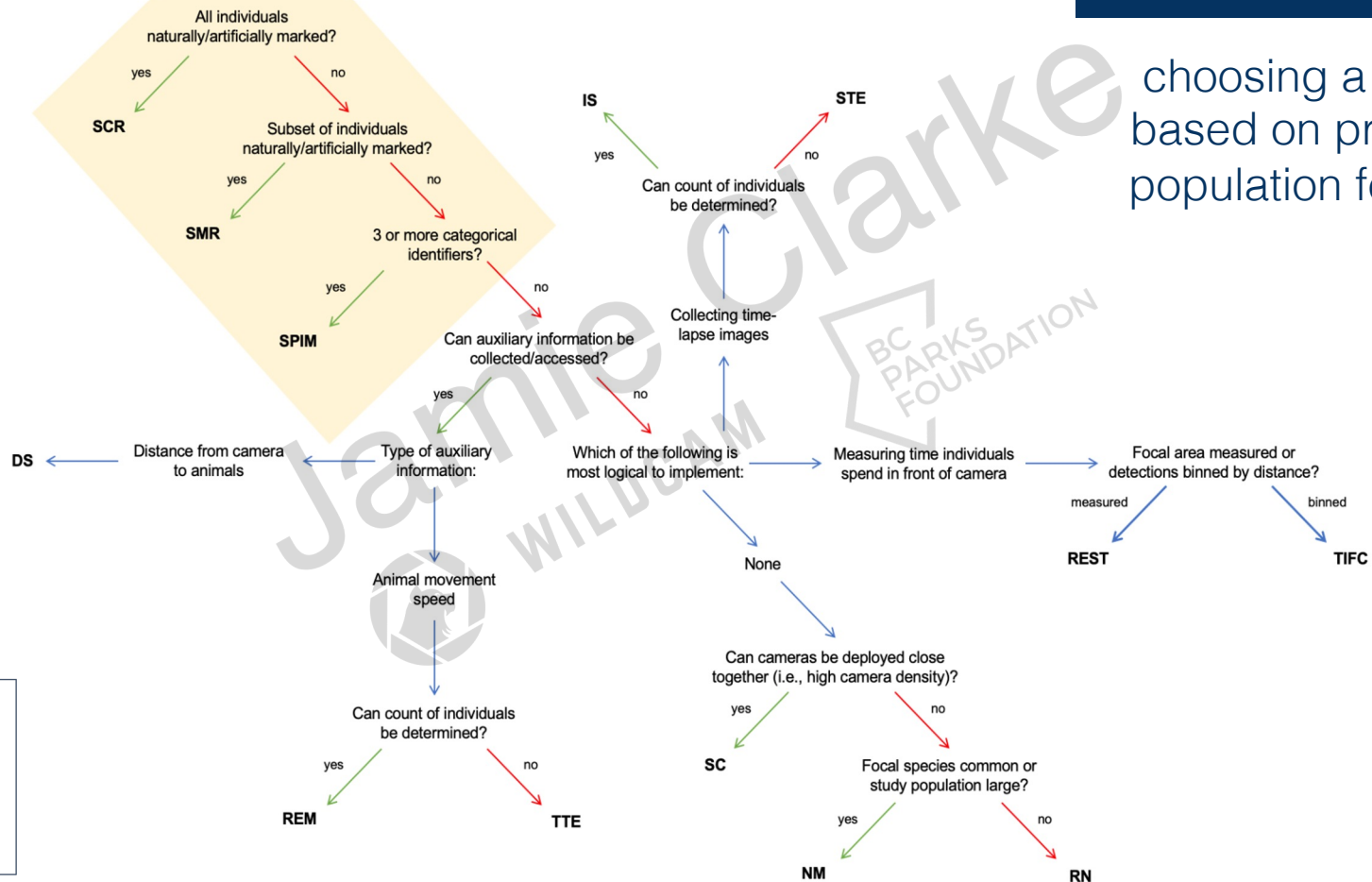

77
Projects


245
Members


6801
Cameras

Decision Tree

choosing a model based on project + population features



⑤ Next Steps



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We Know What's Possible – Now, *What's Best?*

Proposed *field-testing* select camera trap models on ungulates in BC + *comparing* to concurrent aerial surveys

How *accurate, precise + consistent* are camera trap vs aerial survey-derived density estimates?

How *robust* are camera trap density models to *assumption violations*? Different *sampling designs*?

We Know What's Possible – Now, *What's Best?*

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make
guidelines
for
practitioners



We gratefully acknowledge the financial support of the **Province of British Columbia** through the **Ministry of Forests, Lands, Natural Resource Operations and Rural Development**.

Questions?



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Augustine, Ben C., J. Andrew Royle, Marcella J. Kelly, Christopher B. Satter, Robert S. Alonso, Erin E. Boydston, and Kevin R. Crooks. "Spatial Capture–Recapture with Partial Identity: An Application to Camera Traps." *The Annals of Applied Statistics* 12, no. 1 (2018). <https://doi.org/10.1214/17-AOAS1091>.

Augustine, Ben C., J. Andrew Royle, Sean M. Murphy, Richard B. Chandler, John J. Cox, and Marcella J. Kelly. "Spatial Capture–Recapture for Categorically Marked Populations with an Application to Genetic Capture–Recapture." *Ecosphere* (Washington, D.C) 10, no. 4 (2019): e02627-n/a. <https://doi.org/10.1002/ecs2.2627>.

Becker, Marcus, David J. Huggard, Melanie Dickie, Camille Warbington, Jim Schleck, Emily Herdman, Robert Serrouya, and Stan Boutin. "Applying and Testing a Novel Method to Estimate Animal Density from Motion-triggered Cameras." *Ecosphere* (Washington, D.C) 13, no. 4 (2022): n/a-n/a. <https://doi.org/10.1002/ecs2.4005>.

Borchers, D. L., and M. G. Efford. "Spatially Explicit Maximum Likelihood Methods for Capture–Recapture Studies." *Biometrics* 64, no. 2 (2008): 377–85. <https://doi.org/10.1111/j.1541-0420.2007.00927.x>.

Boyce, Mark S., Peter W. J. Baxter, and Hugh P. Possingham. "Managing Moose Harvests by the Seat of Your Pants." *Theoretical Population Biology* 82, no. 4 (2012): 340–47. <https://doi.org/10.1016/j.tpb.2012.03.002>.

British Columbia Ministry of Sustainable Resource Management. Aerial-Based Inventory Techniques for Selected Ungulates: Bison, Mountain Goat, Mountain Sheep, Moose, Elk, Deer and Caribou. Version 2.0--.. Vol. no. 32.;no. 32; Book, Whole. Victoria, B.C.: Resources Inventory Committee, 2002. <https://go.exlibris.link/L4htVzB3>.

Chandler, Richard B., and J. Andrew Royle. "Spatially Explicit Models for Inference about Density in Unmarked or Partially Marked Populations." *The Annals of Applied Statistics* 7, no. 2 (2011–2013): 936–54. <https://doi.org/10.1214/12-AOAS610>.

Côté, Steeve D., Sandra Hamel, Antoine St-Louis, and Julien Mainguy. "Do Mountain Goats Habituate to Helicopter Disturbance?" *The Journal of Wildlife Management* 77, no. 6 (2013): 1244–1244. <https://doi.org/10.1002/jwmg.565>.

Crupi, Anthony P., David P. Gregovich, and Kevin S. White. "Steep and Deep: Terrain and Climate Factors Explain Brown Bear (*Ursus Arctos*) Alpine Den Site Selection to Guide Heli-Skiing Management." *PloS One* 15, no. 9 (2020): e0238711–e0238711. <https://doi.org/10.1371/journal.pone.0238711>.

Davis, Kayla L., Emily D. Silverman, Allison L. Sussman, R. Randy Wilson, and Elise F. Zipkin. "Errors in Aerial Survey Count Data: Identifying Pitfalls and Solutions." *Ecology and Evolution* 12, no. 3 (2022): e8733-n/a. <https://doi.org/10.1002/ece3.8733>.

Frid, Alejandro. "Dall's Sheep Responses to Overflights by Helicopter and Fixed-Wing Aircraft." *Biological Conservation* 110, no. 3 (2003): 387–99. [https://doi.org/10.1016/S0006-3207\(02\)00236-7](https://doi.org/10.1016/S0006-3207(02)00236-7).

Government of British Columbia. "2020-2022 Hunting and Trapping Regulations Synopsis." 2020. <https://www2.gov.bc.ca/assets/gov/sports-recreation-arts-and-culture/outdoor-recreation/fishing-and-hunting/hunting/regulations/2020-2022/hunting-trapping-synopsis-2020-2022.pdf>.

Howe, Eric J., Stephen T. Buckland, Marie-Lyne Després-Einspinner, Hjalmar S. Kühl, and Jason Matthiopoulos. "Distance Sampling with Camera Traps." Edited by Jason Matthiopoulos. *Methods in Ecology and Evolution* 8, no. 11 (2017): 1558–65. <https://doi.org/10.1111/2041-210X.12790>.

Karanth, K. Ullas, and James D. Nichols. "Estimation of Tiger Densities in India Using Photographic Captures and Recaptures." *Ecology* (Durham) 79, no. 8 (1998): 2852–62. [https://doi.org/10.1890/0012-9658\(1998\)079\[2852:EOTDII\]2.0.CO;2](https://doi.org/10.1890/0012-9658(1998)079[2852:EOTDII]2.0.CO;2).

Moeller, Anna K., Paul M. Lukacs, and Jon S. Horne. "Three Novel Methods to Estimate Abundance of Unmarked Animals Using Remote Cameras." *Ecosphere* (Washington, D.C) 9, no. 8 (2018): e02331-n/a. <https://doi.org/10.1002/ecs2.2331>.

Morin, Dana J., John Boulanger, Richard Bischof, David C. Lee, Dusit Ngoprasert, Angela K. Fuller, Bruce McLellan, et al. "Comparison of Methods for Estimating Density and Population Trends for Low-Density Asian Bears." *Global Ecology and Conservation*, no. Journal Article (2022). <https://doi.org/10.1016/j.gecco.2022.e02058>.

Nakashima, Yoshihiro, Keita Fukasawa, Hiromitsu Samejima, and Philip Stephens. "Estimating Animal Density without Individual Recognition Using Information Derivable Exclusively from Camera Traps." Edited by Philip Stephens. *The Journal of Applied Ecology* 55, no. 2 (2018): 735–44. <https://doi.org/10.1111/1365-2664.13059>.

Otis, David L., Kenneth P. Burnham, Gary C. White, and David R. Anderson. "Statistical Inference from Capture Data on Closed Animal Populations." *Wildlife Monographs*, no. 62 (1978): 3–135.

Rowcliffe, J. Marcus, Juliet Field, Samuel T. Turvey, and Chris Carbone. "Estimating Animal Density Using Camera Traps without the Need for Individual Recognition." *The Journal of Applied Ecology* 45, no. 4 (2008): 1228–36. <https://doi.org/10.1111/j.1365-2664.2008.01473.x>.

Royle, J. Andrew. "N-Mixture Models for Estimating Population Size from Spatially Replicated Counts." *Biometrics* 60, no. 1 (2004): 108–15. <https://doi.org/10.1111/j.0006-341X.2004.00142.x>.

Royle, J. Andrew, and Robert M. Dorazio. *Hierarchical Modeling and Inference in Ecology: The Analysis of Data from Populations, Metapopulations and Communities*. 1st ed. Book, Whole. Amsterdam;Boston; Academic, 2008.

Royle, J. Andrew, and James D. Nichols. "Estimating Abundance from Repeated Presence–Absence Data or Point Counts." *Ecology* (Durham) 84, no. 3 (2003): 777–90. [https://doi.org/10.1890/0012-9658\(2003\)084\[0777:FAFBPA\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2003)084[0777:FAFBPA]2.0.CO;2).

Sasse, D. Blake. "Job-Related Mortality of Wildlife Workers in the United States, 1937–2000." *Wildlife Society Bulletin* 31, no. 4 (2003): 1015–20.

Sollmann, Rahel, Beth Gardner, Arielle W. Parsons, Jessica J. Stocking, Brett T. McClintock, Theodore R. Simons, Kenneth H. Pollock, and Allan F. O'Connell. "A Spatial Mark–Resight Model Augmented with Telemetry Data." *Ecology* (Durham) 94, no. 3 (2013): 553–59. <https://doi.org/10.1890/12-1256.1>.

Sun, Catherine, Joanna M. Bugar, Jason T. Fisher, and A. Cole Burton. "A Cautionary Tale Comparing Spatial Count and Partial Identity Models for Estimating Densities of Threatened and Unmarked Populations." *Global Ecology and Conservation* 38, no. Journal Article (2022): e02268.