Evaluating Density-Weighted Connectivity of Black Bears (*Ursus americanus*) in Glacier National Park with Spatial Capture-Recapture Models

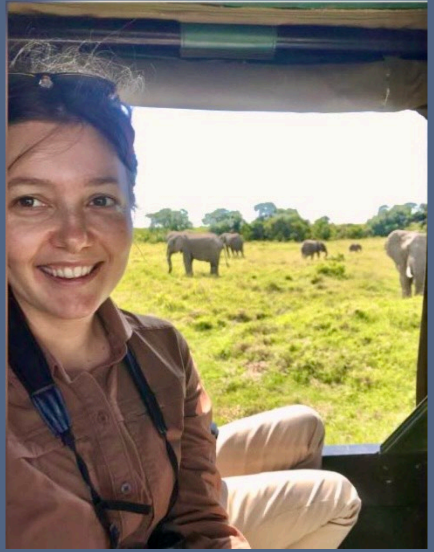


Photo Credit: Sarah Carroll

Carroll et al. 2024 - Movement Ecology

Tabitha Graves[1], Sarah Carroll[2], Greta Schmidt[3], John Waller[4]
[1]U.S. Geological Survey, Northern Rocky Mountain Science Center
[2]Colorado State University
[3]San Diego State University
[4]Glacier National Park

Source: IconFinder

U.S. Department of the Interior
U.S. Geological Survey

Motivation

The Crown of the Continent Ecosystem

Conservation threats*

- US2- BNSF railroad transportation corridor
- Subdivision & development
- Soaring visitation in Glacier ~ 3 million annual visitors
- Priority transportation corridor in MT FWP assessment

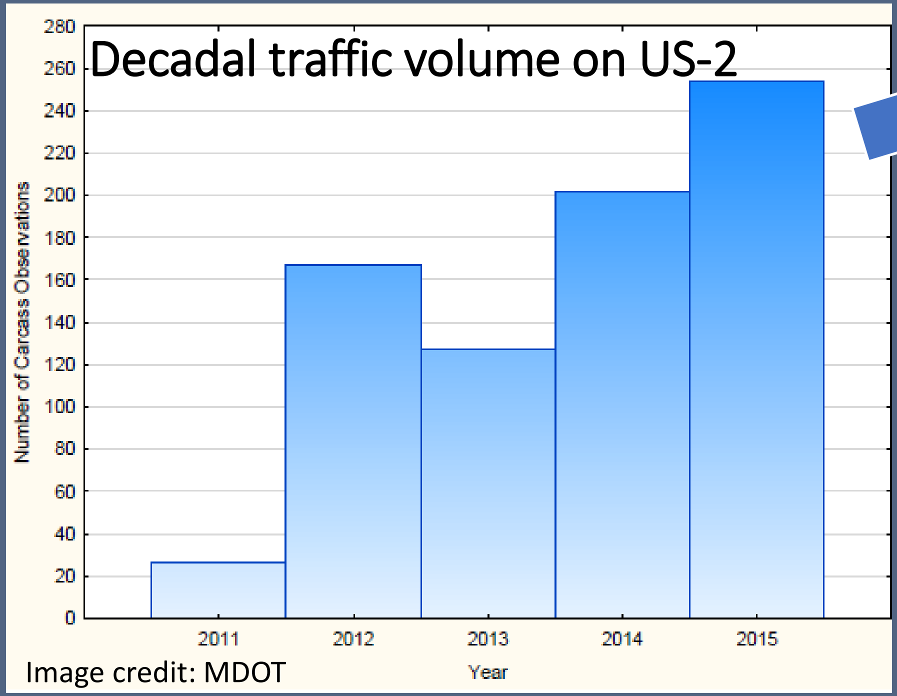
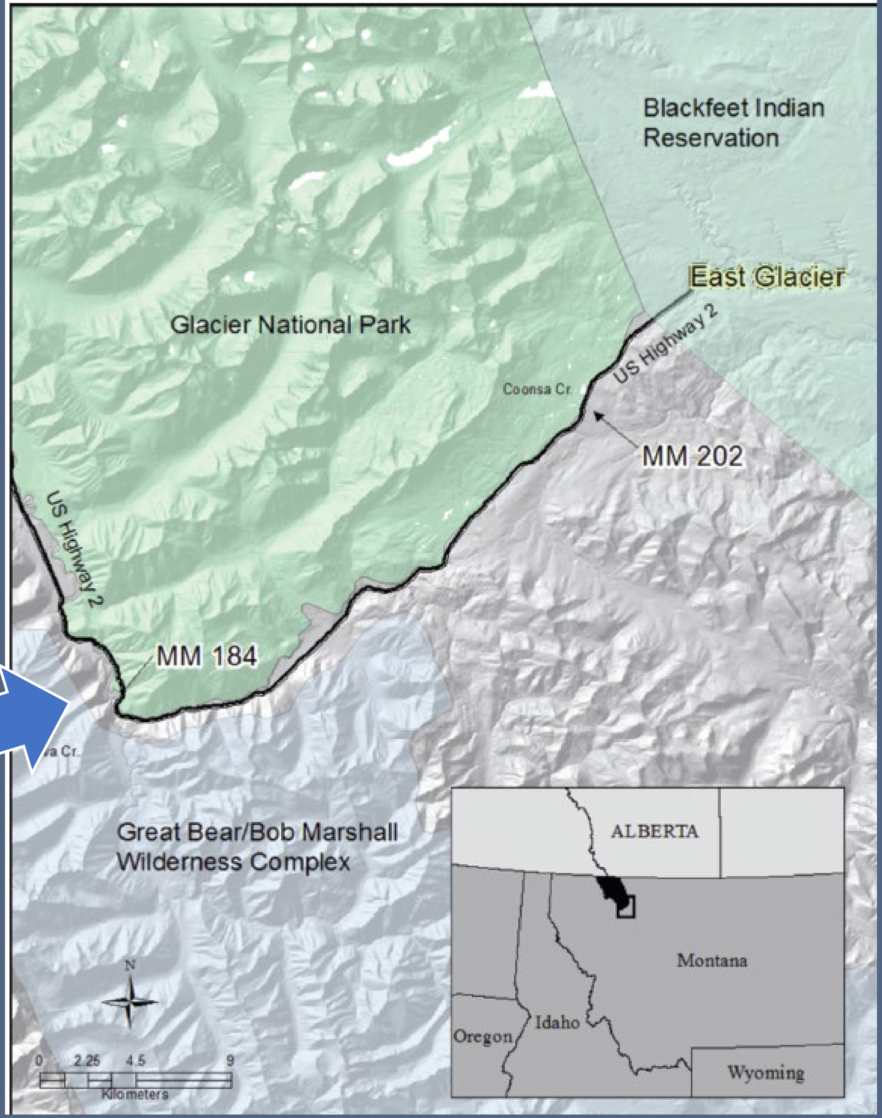


Image credit: MDOT



USGS
science for a changing world

*Waller & Miller 2015; Michaels 2016; Headwaters Economics 2018;Waller and Graves 2018

Questions

1. How many black bears are in GNP?
2. What influences black bear distribution?
3. What influences black bear movement?
   - Does US2 and railroad limit movement?

Photo Credit: USGS, Graves

USGS science for a changing world

What is *density-weighted connectivity*?

- The ability of individual animals to move through a landscape given the spatial distribution of individuals across the landscape

Spatial-capture recapture models

Spatial encounter history data

Detection probability model

Density model (Spatially explicit point process)

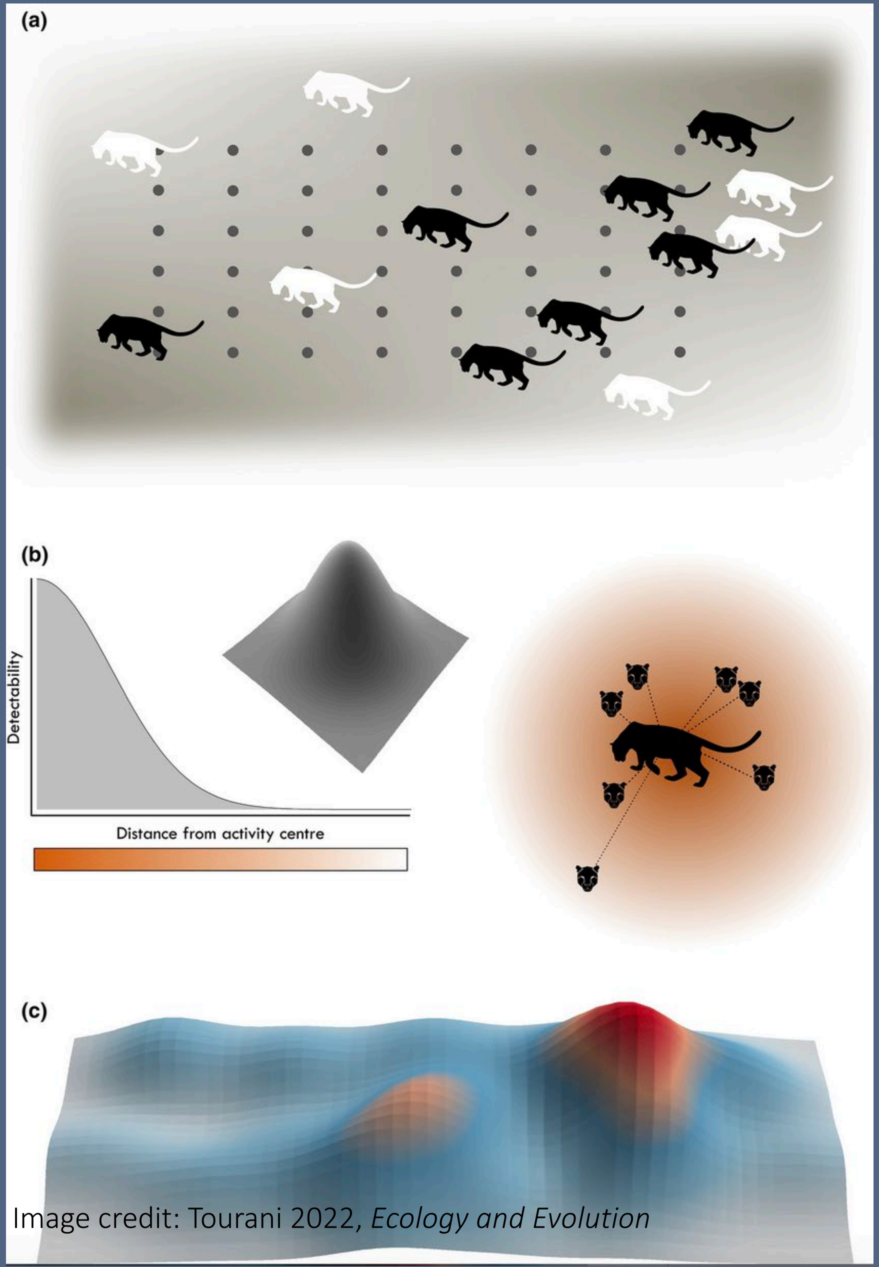


Image credit: Tourani 2022, *Ecology and Evolution*

USGS
science for a changing world

Spatial-capture recapture *connectivity* models (Royle et al. 2013)

Typical detection probability: Euclidean distance between latent activity center and traps

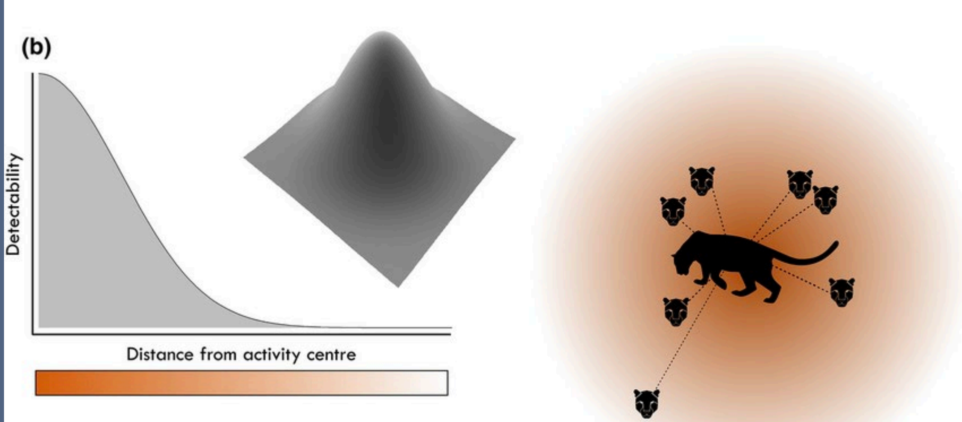


Image credit: Tourani 2022, *Ecology and Evolution*

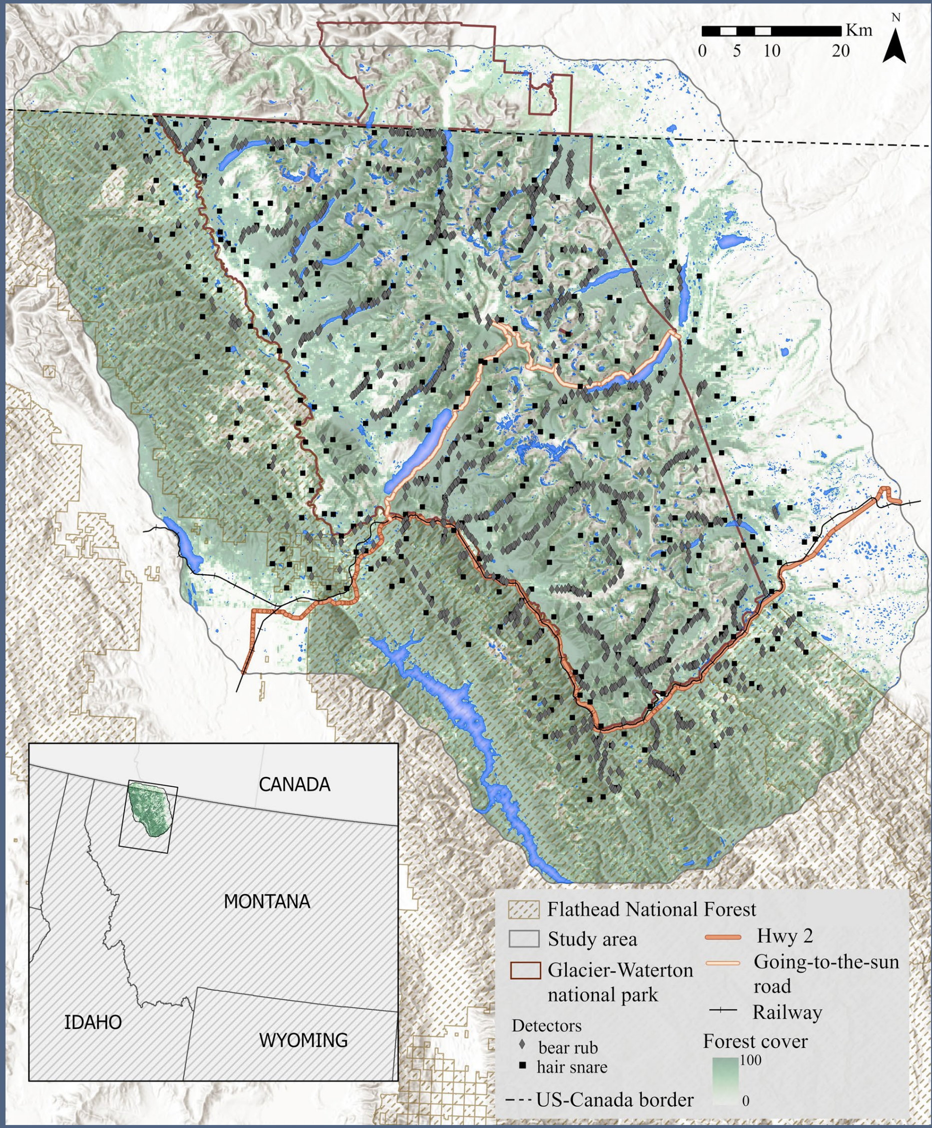
Assumption about movement

SCR data from bear hair genetics

- Collected from **1,914** detectors, summer 2004
- Scent lured hair snares & bear rubs

(Wildlife Genetics International; Stetz et al. 2014)

	Individuals Detected	Detections
Females	303	430
Males	295	494
Total	**598**	**924**



Carroll et al. 2024, *Movement Ecology*

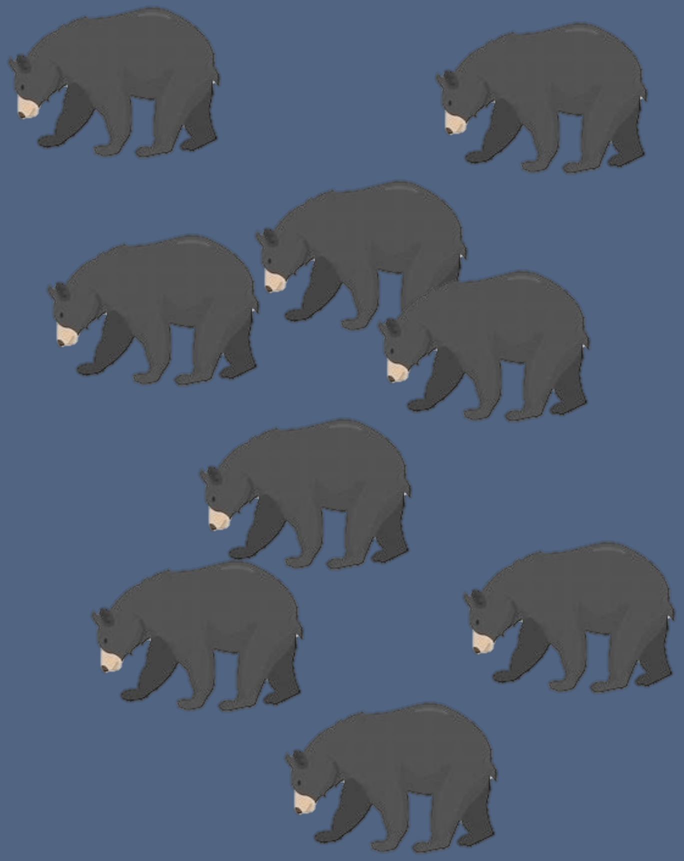
How many black bears are in GNP?

	N
Females	674
Males	323
Total bears	997

What influences black bear distribution?

Forest cover

Grizzly bear density (males)

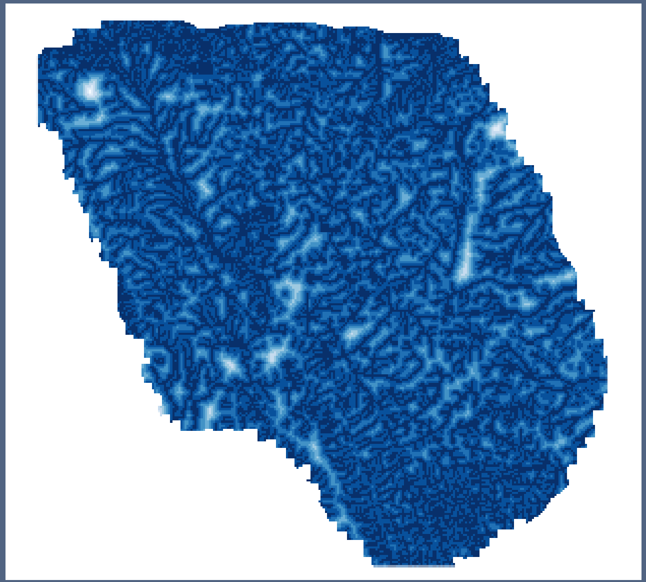


Source: IconFinder

USGS science for a changing world

Carroll et al. 2024, *Movement Ecology*

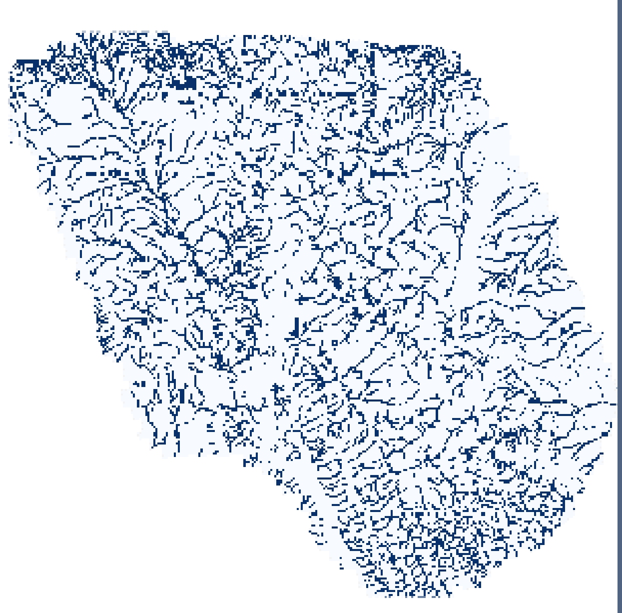
What influences black bear movement? Cost of movement (δ)



Drainages facilitate movement

Distance from drainages

Increased cost with distance
(males, δ = 1.50, 95% CI [0.62 to 2.39])

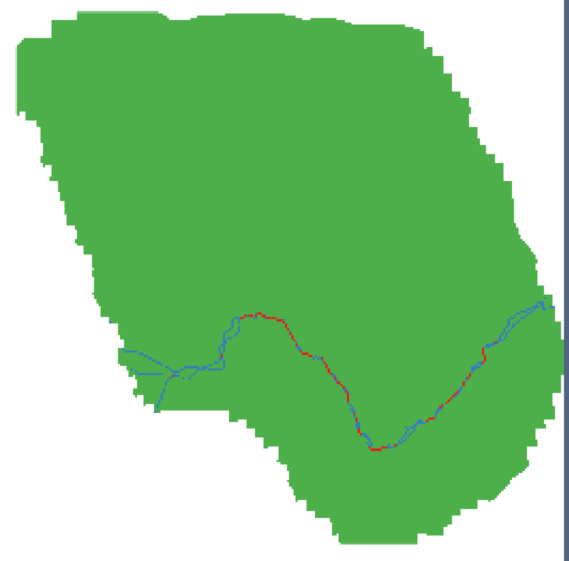


Drainage presence decreased cost
(females, δ = -0.53, 95% CI [-0.23 to -0.83])

USGS
science for a changing world

Carroll et al. 2024, *Movement Ecology*

What influences black bear movement? Cost of movement (δ)

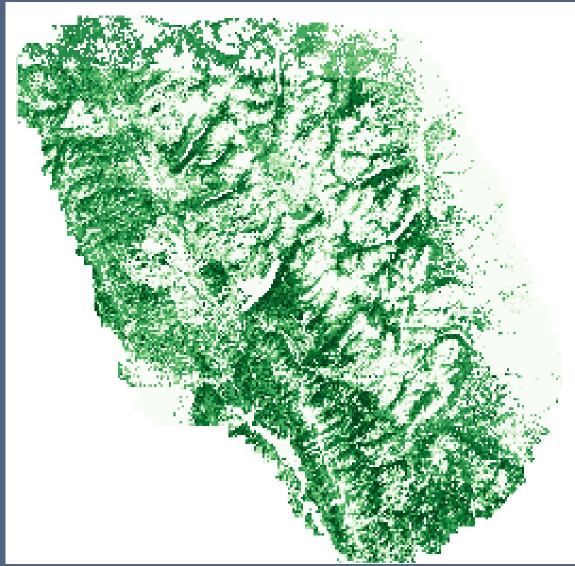


Hwy-2 & BNSF Railway (males)

Increased cost where present

(δ = 2.20, 95% CI [1.61 to 2.79])

800% higher where both present vs 1



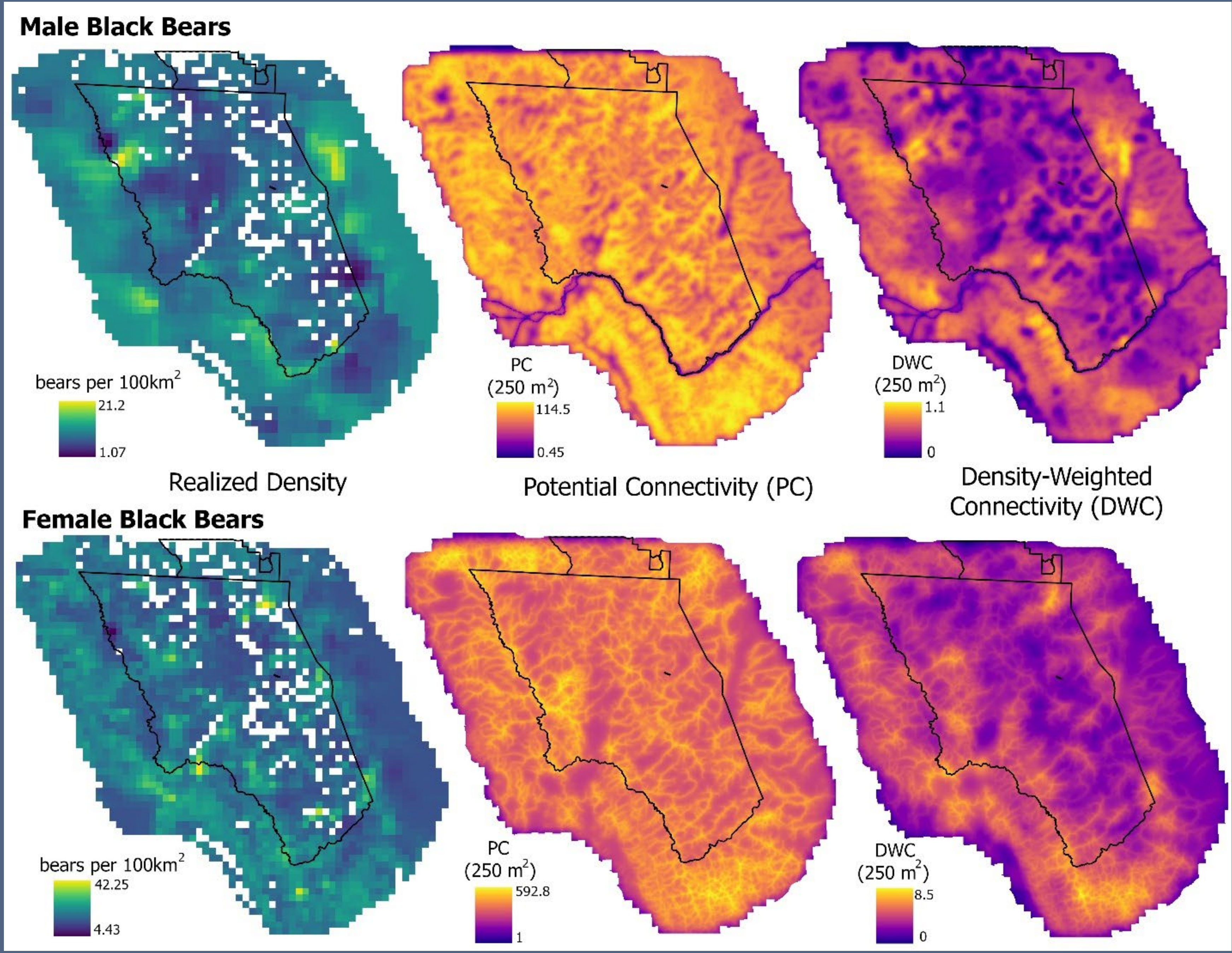
Forest cover (%) (males)

Decreased cost as forest cover increases

(δ = -0.85, 95% CI [-1.41 to -0.29])

science for a changing world

Carroll et al. 2024, *Movement Ecology*



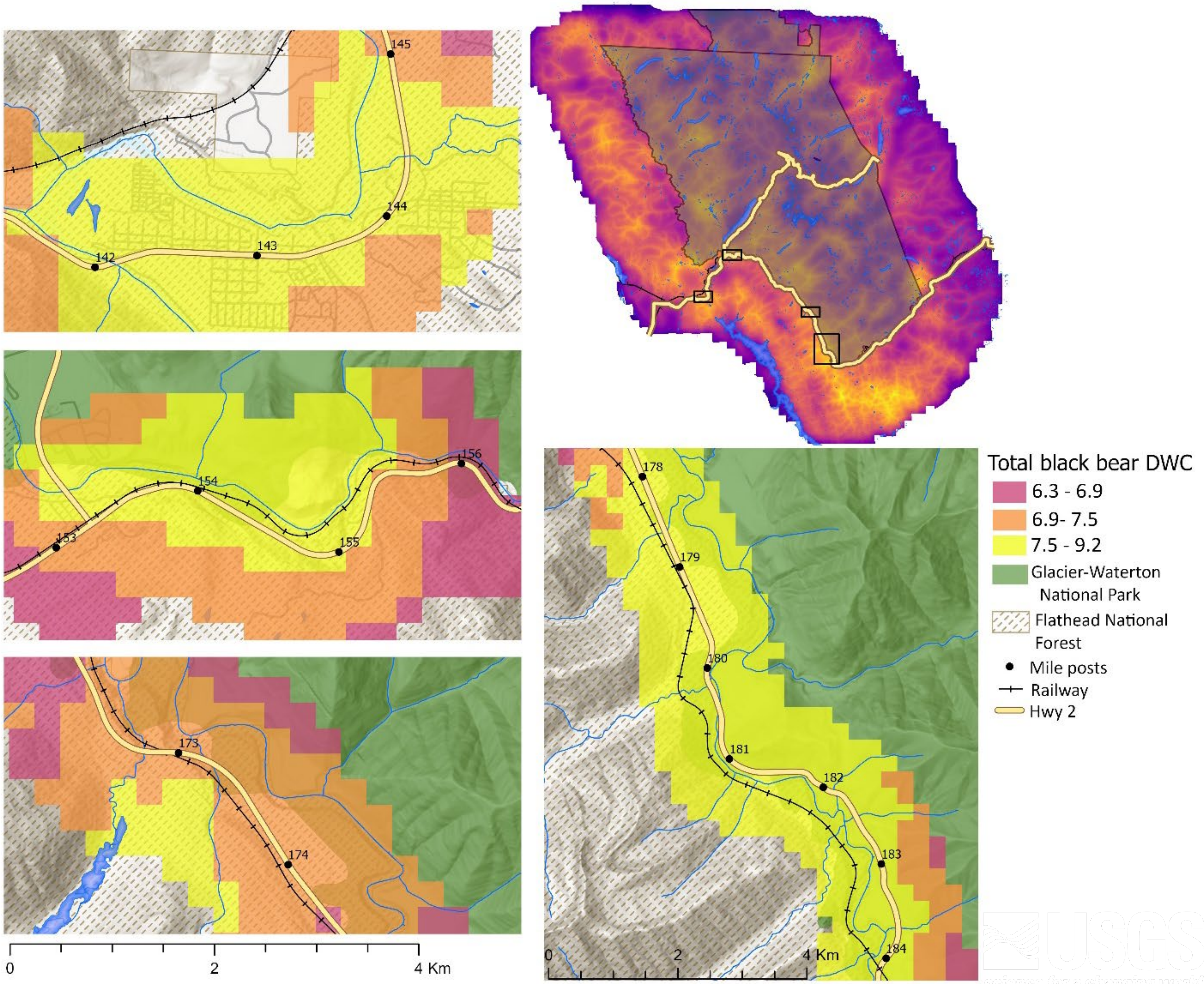
Carroll et al. 2024, *Movement Ecology*

USGS
science for a changing world

Total density-weighted connectivity
&

potential priority mitigation zone based on areas with the greatest number of bears

Carroll et al. 2024, *Movement Ecology*



USGS
science for a changing world

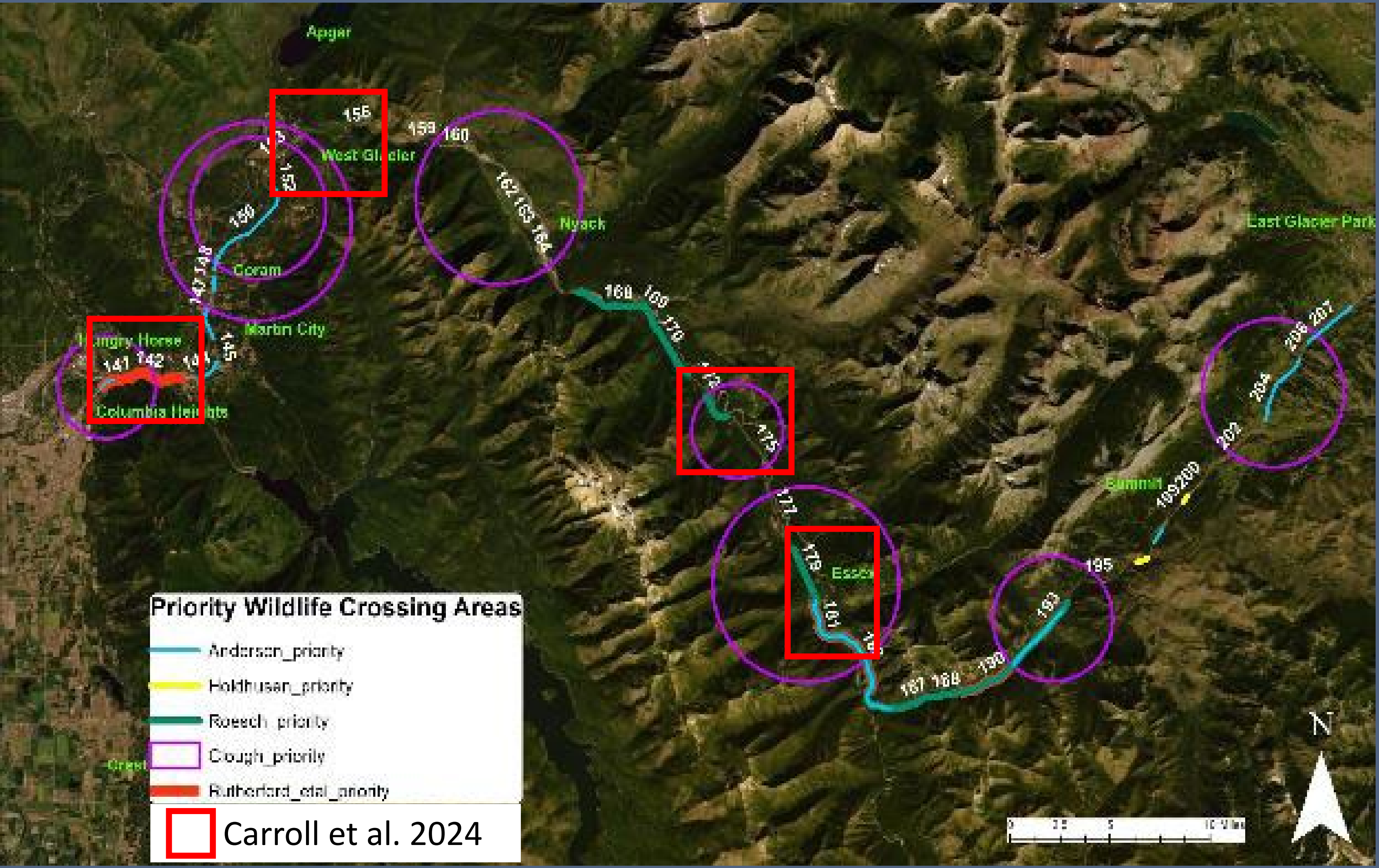


Figure 23. Priority wildlife crossing areas compiled from the work of Rich Clough, Becca Holdhusen, Michael Roesch, Rutherford et al., and Brad Anderson.

Waller et al. 2020
Waller & Graves 2018

Large collaboration of state, federal, tribal and university partners.

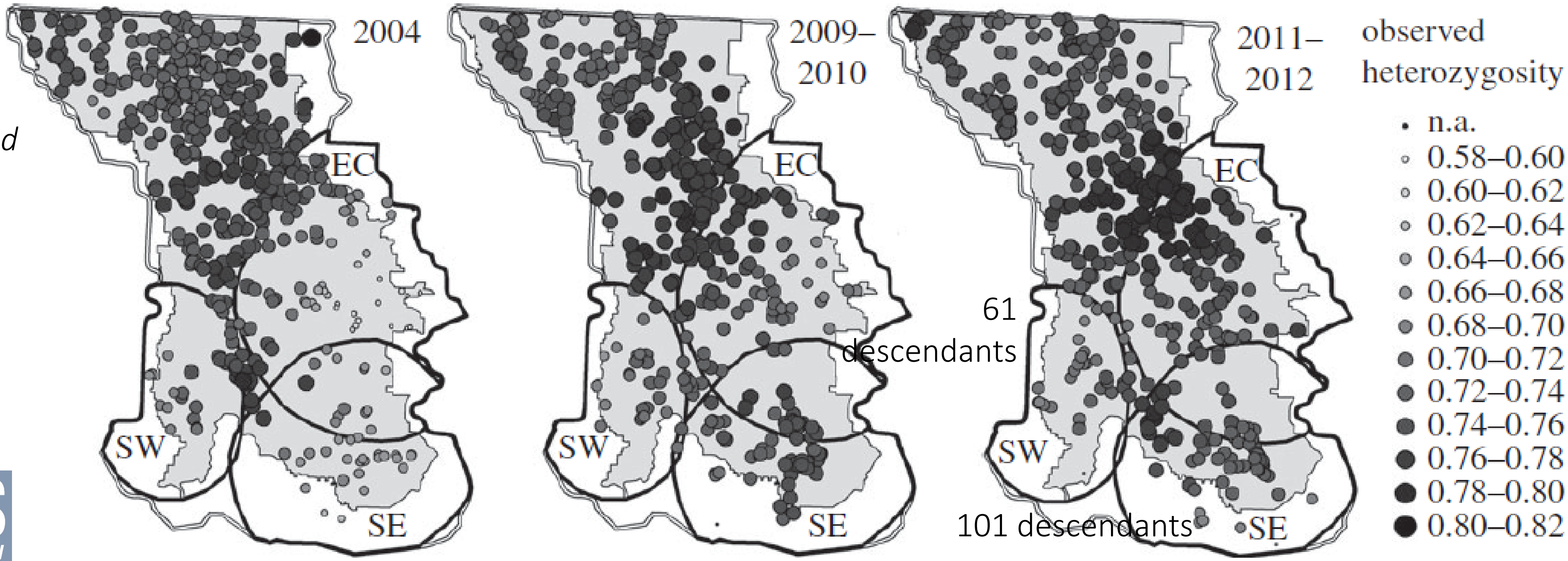
Demographic mechanisms underpinning genetic assimilation of remnant groups of a large carnivore

Nate Mikle[1], Tabitha A. Graves[1], Ryan Kovach[1], Katherine C. Kendall[1] and Amy C. Macleod[2]

Prior work on grizzly bears

Proc B 2016

1115 individuals
~1287 assigned
>400 triads
>600 M-O



Carroll et al. 2024, *Movement Ecology*

Funded by:
NSF, USGS, USFS, NPS

Thanks also to multi-entity partnership working on US2:
MDOT
MTFWP
USFS
USFWS
UM
Blackfeet Nation
CSKT
More!

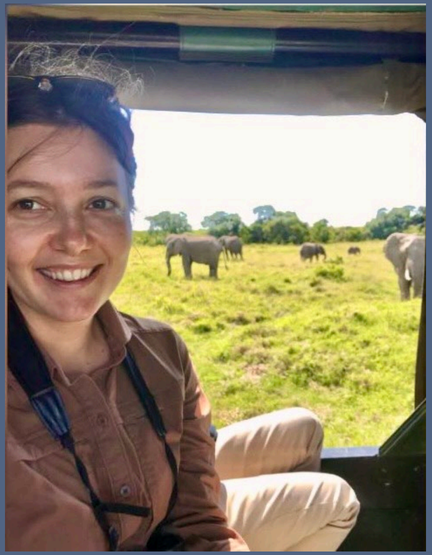
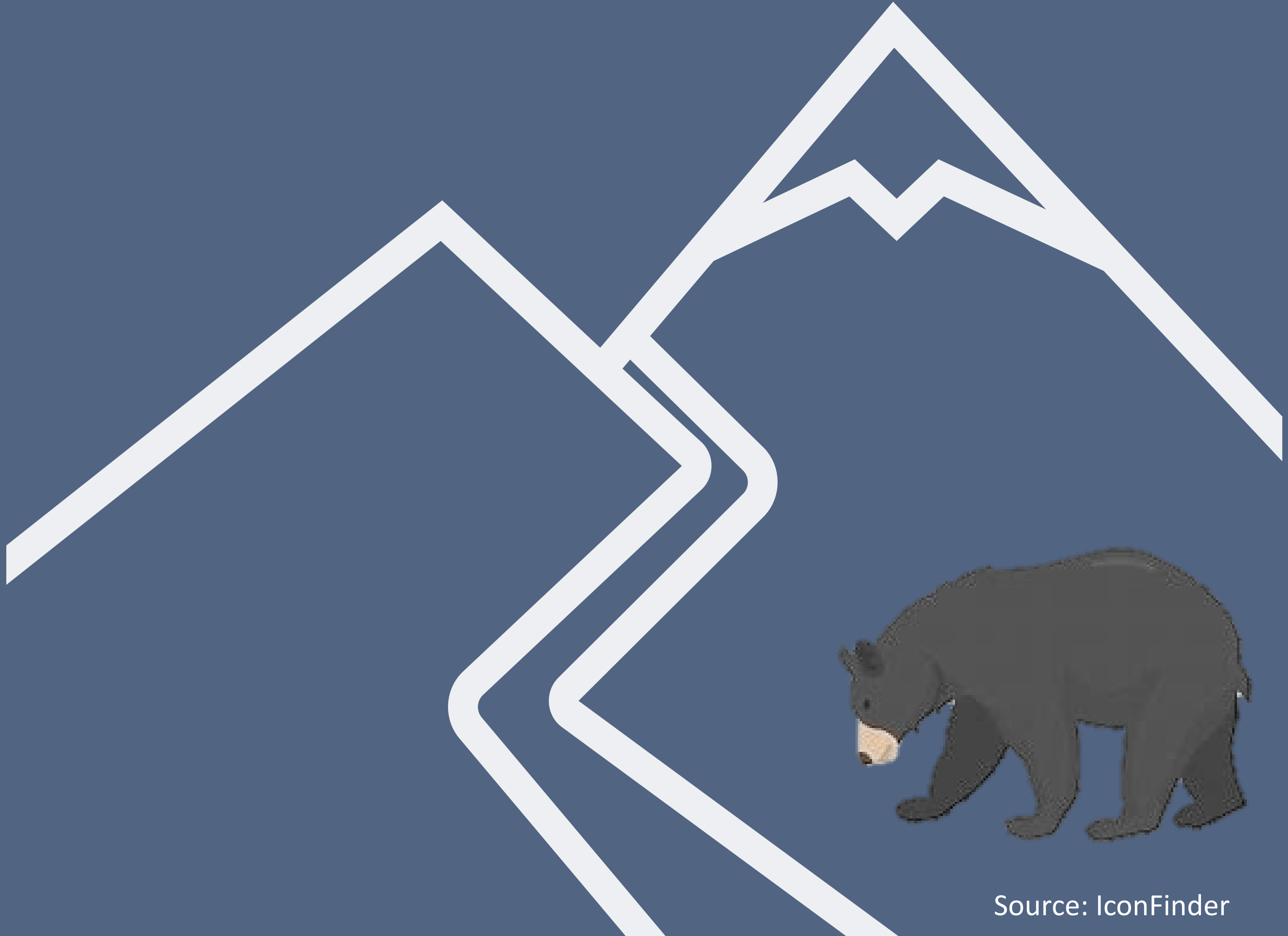


Photo Credit: Sarah Carroll

THANK YOU!

QUESTIONS?



Source: IconFinder

USGS
science for a changing world

SCR Analyses

- *oSCR* package in R (Sutherland et al.2019)

- **Separate models for males and females**

State space (estimating density)

- 2km^2
- 12km from traps
- Masked non-habitat (lakes,snowfields)

Connectivity space (estimating resistance)

- Resolution of 0.25km^2
- All pixels are available for movement

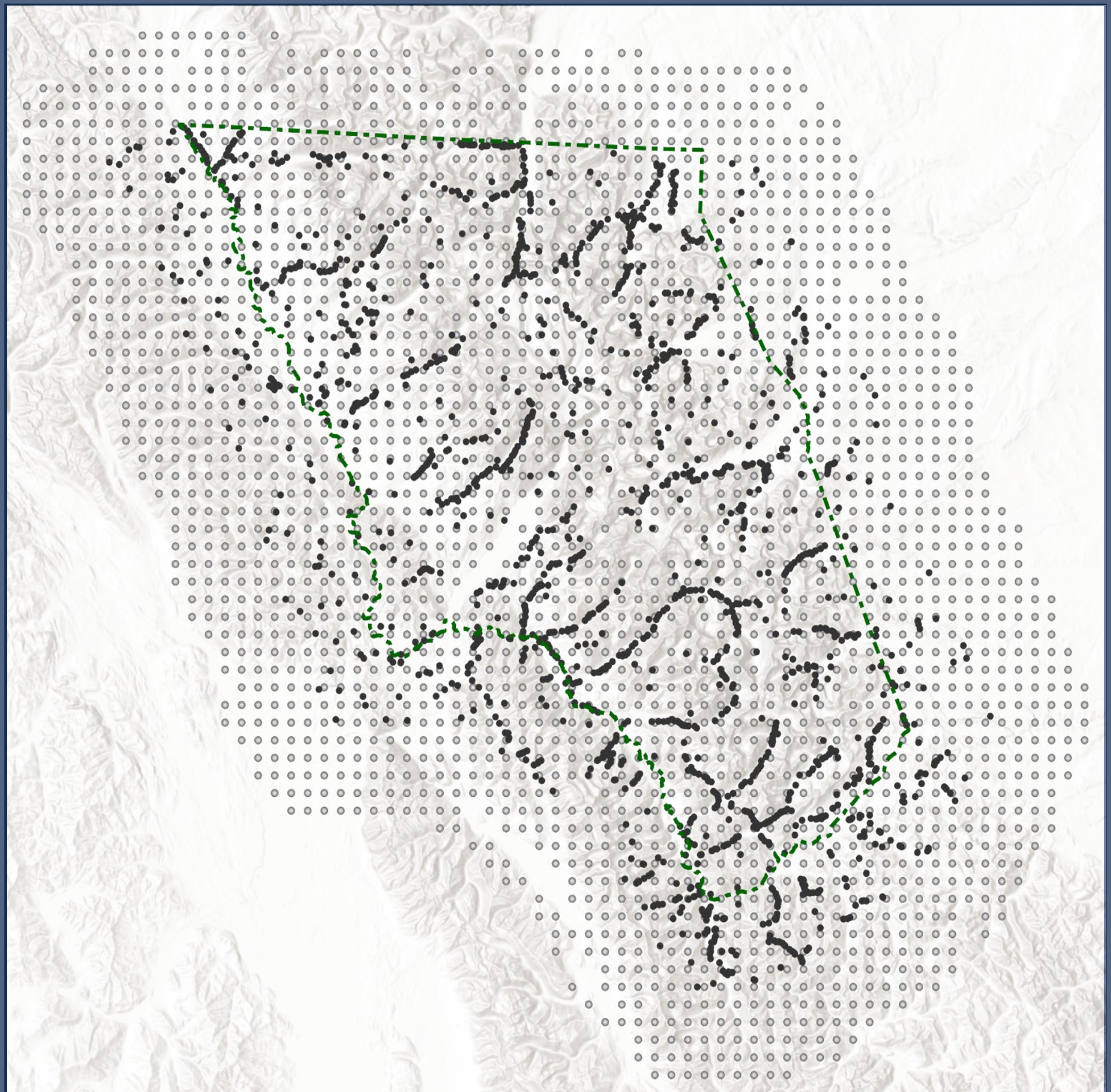


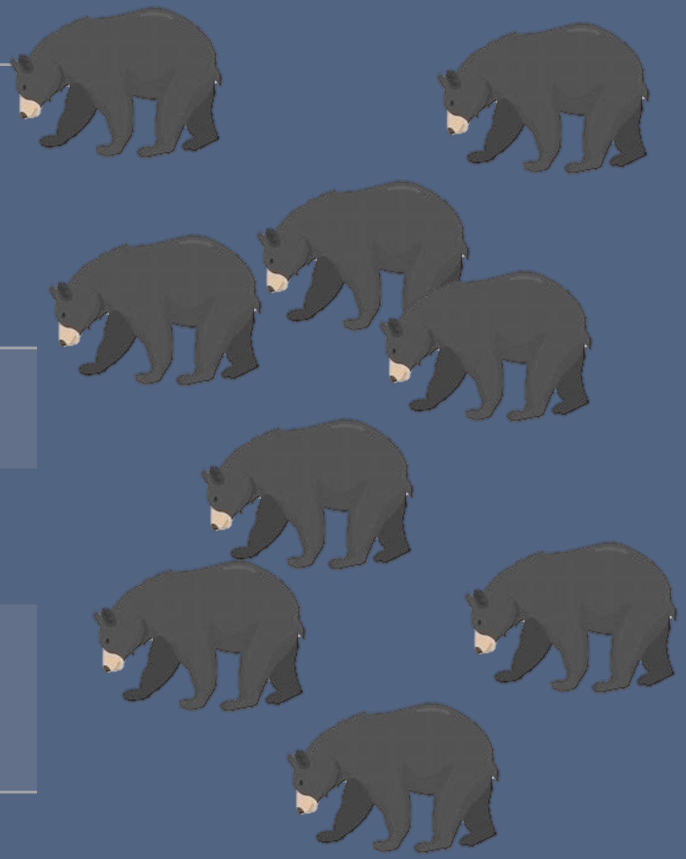
Image credit: Sarah Carroll

USGS
science for a changing world

Appendices

Population estimates based on final models

Glacier National Park & Waterton	Density
Females	16.3 bears /100km^2
Males	7.8 bears /100km^2
Total average (female + male)	24.1 / 100km^2



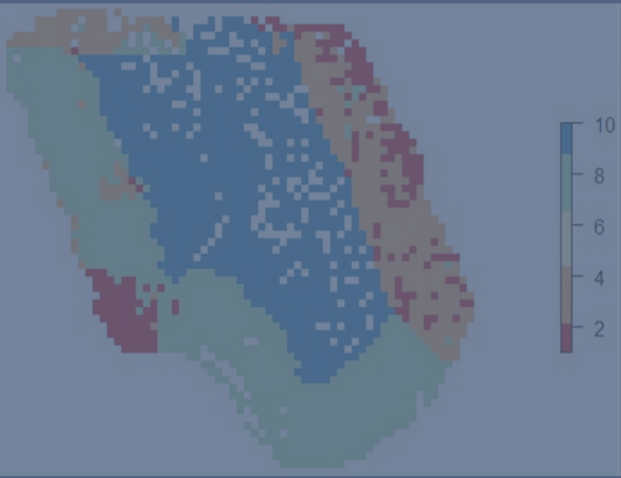
Source: IconFinder

USGS science for a changing world

Carroll et al. 2024, *Movement Ecology*

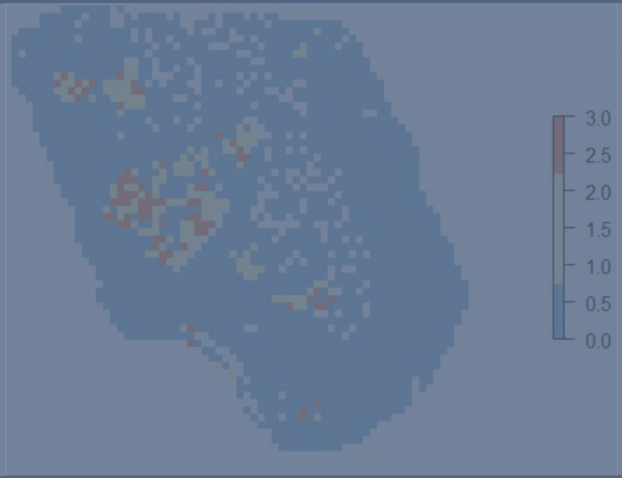
Density (d0)

Security level



Phenology

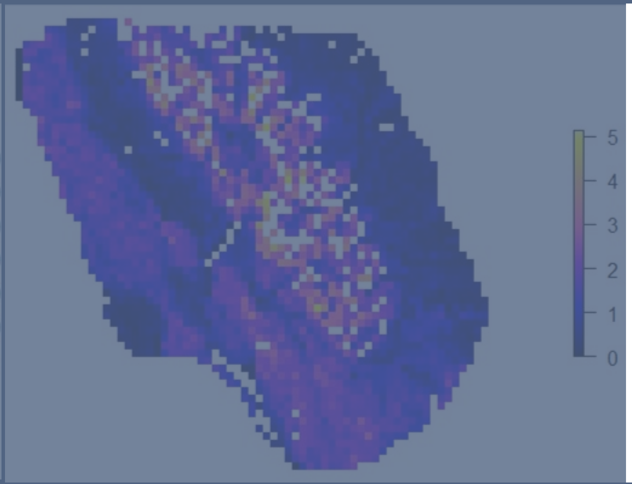
Fires



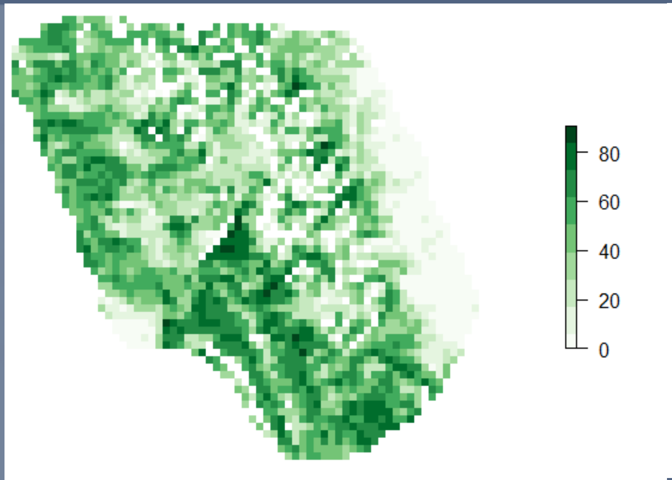
Paved road density

Developed land cover (%)

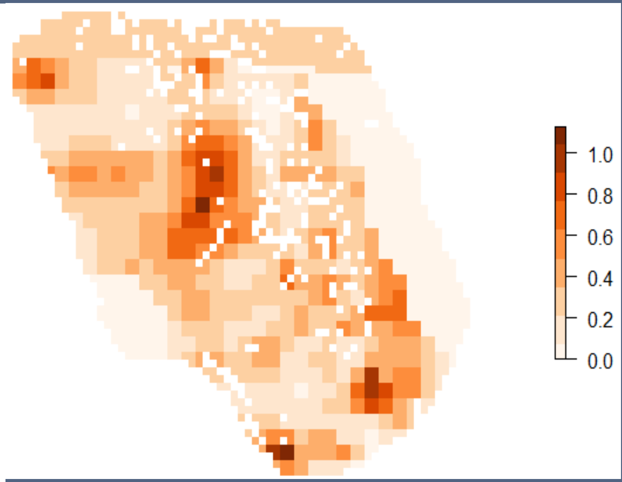
Terrain curvature (std)



Forest cover (%)



Grizzly density 2004



USGS
science for a changing world

Carroll et al. 2024, *Movement Ecology*

Spatial-capture recapture *connectivity* models (Royle et al. 2013)

Detection probability: *least-cost path* distance between latent activity center and traps

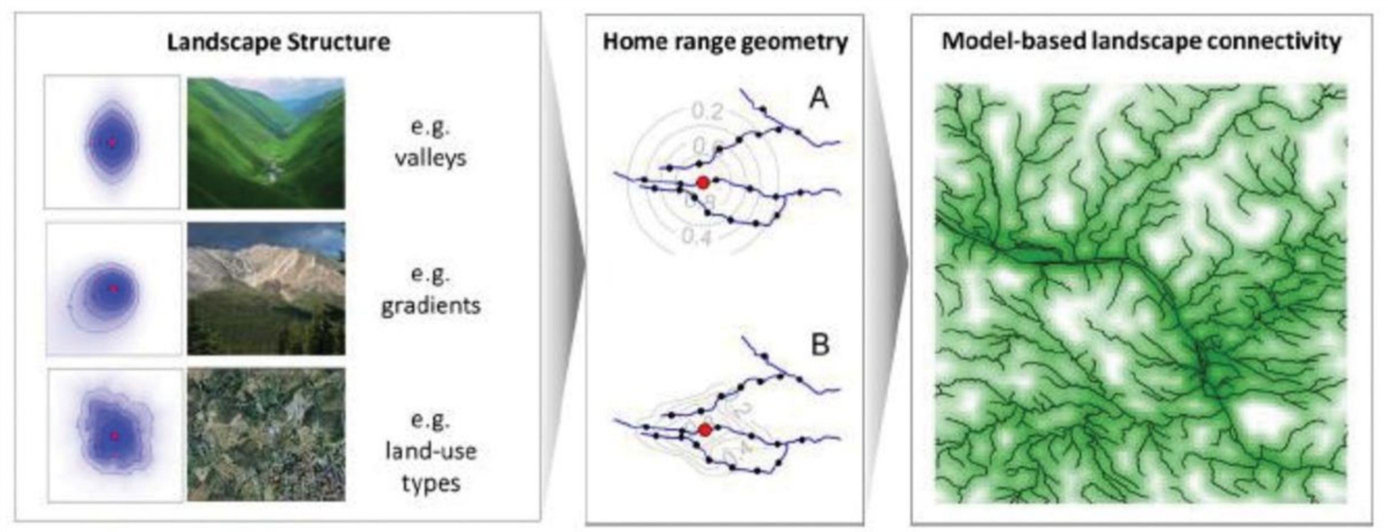
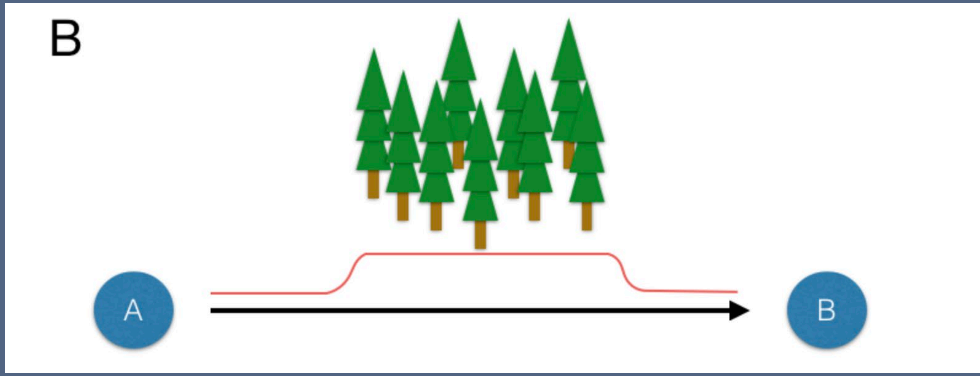


Image credit: Royle et al. *Ecography* 2017

Assumption about movement



Variable resistance based on landscape

Estimate additional cost of movement parameter

Objective 1: **Evaluate** density-weighted connectivity

- Use the coefficients from the most supported model to create a model-estimated resistance surface for the entire study-area
- Assume that connectivity is the inverse of resistance
- Pixel-wise calculations of *potential connectivity*:

$$PC(s_u) = \sum_{Si \in \boldsymbol{S}} \exp\left(-\frac{1}{2\sigma^2} * dist^2{}_{ecol}[s_{u,} s_i]\right)$$

the expected probability of movement to each pixel from any other pixel when each cell in $\boldsymbol{S}$ contains a single activity center (homogenous density)

USGS science for a changing world

Carroll et al. 2024, *Movement Ecology*

Calculating population connectivity surfaces

- Use the coefficients from the most supported model to create a model-estimated resistance surface for the entire study-area

- Assume that connectivity is the inverse of resistance

- Pixel-wise calculations of *potential connectivity*:

$$PC(s_u) = \sum_{Si \in \boldsymbol{S}} \exp\left(-\frac{1}{2\sigma^2} * dist^2{}_{ecol}[s_{u,} s_i]\right)$$

the estimated use of each cell from any other cell when each cell in ***S*** contains a single activity center (homogenous density)

- *Density-weighted connectivity*:

$$DWC(s_u) = \sum_{Si \in \boldsymbol{S}} \exp\left(-\frac{1}{2\sigma^2} * dist^2{}_{ecol}[s_{u,} s_i]\right) * D(s_i)$$

The estimated number of bears using each cell in the landscape based on realized density estimates

USGS
science for a changing world

Carroll et al. 2024, *Movement Ecology*

Parameter and coefficient description		MLE	SE	95% CI	MLE	SE	95% CI
		Females			Males		
p0 (baseline detection probability)	intercept (rub tree)	-6.20	0.30	(-6.8 – -5.61)	-7.77	0.29	(-8.37 – 7.17)
	β rub behavior	0.99	0.10	(0.79 – 1.20)	1.35	0.09	(1.16 – 1.54)
	β rub tree effort	-0.04	0.09	(-0.03 – 0.33)	0.16	0.07	(0.02 – 0.29)
	β hair snare	0.73	0.37	(0.01–1.46)	-0.05	0.30	(-0.64 – 0.53)
	β hair snare effort	2.47	0.34	(1.79 – 3.14)	3.63	0.31	(3.02 – 4.24)
	β forest cover	0.15	0.08	(0.01 – 0.30)	0.09	0.07	(-0.03 – 0.23)
	β Julian day	0.25	0.09	(0.07 – 0.42)	5.05	0.49	(4.09 – 6.01)
	β std. of terrain curvature	-0.09	0.06	(-0.22 – 0.02)	-0.22	0.06	(-0.33 – -0.10)
	β Julian day quadratic effect				-1.95	0.21	(-2.36 – -1.53)
σ (spatial scaling)	intercept	0.55	0.09	(0.36 – 0.74)	1.04	0.21	(0.63 – 1.45)
(δ) (resistance or cost of movement)	β drains binary	-0.53	0.15	(-0.83 – -0.23)			
	β forest cover				-0.85	0.29	(-1.41 – -0.29)
	β distance to drains				1.50	0.45	(0.62 – 2.39)
	β transportation corridor				2.20	0.30	(1.61 – 2.79)
Density (bears per 4km² pixel)	Intercept (D_0)	-0.44	0.13	(-0.69 – -0.19)	-0.99	0.09	(-1.81 – -0.81)
	β forest cover	0.22	0.11	(0.00 – 0.44)	0.04	0.19	(-0.33 –0.42)
	β grizzly density				-0.18	0.09	(-0.35 – -0.01)

USGS science for a changing world

Carroll et al. 2024, *Movement Ecology*

Detection & density sub-model results: females

Model[a]	D	p0	K	AIC	△AIC	Weight	CumWt
3	~forest cover	~Hair + BE + Cover + Jul + ER + EH + Curv	11	2159.83	0.00	0.21	0.21
5	~forest cover	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	12	2160.10	0.27	0.19	0.40
9	~1	~Hair + BE + Cover + Jul + ER + EH + Curv	10	2161.31	1.48	0.10	0.50
1	~forest cover	~Hair + BE + Cover + Jul + Jul2 + ER + EH	11	2161.39	1.57	0.10	0.60
11	~1	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	11	2161.57	1.75	0.09	0.68
7	~1	~Hair + BE + Cover + Jul + Jul2 + ER + EH	10	2161.99	2.16	0.07	0.76
6	~forest cover	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv + Snow	13	2162.03	2.20	0.07	0.83
2	~forest cover	~Hair + BE + Cover + Jul + ER + EH + Snow	11	2163.08	3.25	0.04	0.87
4	~forest cover	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Snow	12	2163.30	3.47	0.04	0.91
12	~1	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv + Snow	12	2163.50	3.67	0.03	0.94
8	~1	~Hair + BE + Cover + Jul + ER + EH + Snow	10	2163.67	3.85	0.03	0.97
10	~1	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Snow	11	2163.89	4.06	0.03	1.00

[a] Model Notation:

Hair trap type is or is not hair snare
BE rub behavior effect
Cover percent forest cover (0-100%)
Jul Julian day; linear effect of season
Jul2 Julian day squared; quadratic effect of season
EH trap effort: # of days trap open during each occasion
ER Effort rub traps
Curv standard deviation of terrain curvature
Snow ground snow cover presence/absence

USGS science for a changing world

Carroll et al. 2024, *Movement Ecology*

Detection & density sub-model results : males

Model[a]	D	*p0*	K	AIC	△AIC	Weight	CumWt
29	~forest cover + griz density	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	13	3027.47	0.00	0.26	0.26
5	~forest cover	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	12	3028.36	0.89	0.16	0.42
23	~forest cover + curv + griz density	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	14	3028.68	1.21	0.14	0.56
30	~forest cover + griz density	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv + Snow	14	3029.31	1.83	0.10	0.66
17	~forest cover + curv	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	13	3029.65	2.17	0.09	0.75
6	~forest cover	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv + Snow	13	3030.16	2.68	0.07	0.82
24	~forest cover + curv + griz density	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv + Snow	15	3030.52	3.05	0.06	0.87
18	~forest cover + curv	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv + Snow	14	3031.45	3.97	0.04	0.91
35	~griz density	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	12	3031.54	4.07	0.03	0.94
41	~griz density + curv	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv	13	3032.48	5.01	0.02	0.96
36	~griz density	~Hair + BE + Cover + Jul + Jul2 + ER + EH + Curv + Snow	13	3033.40	5.93	0.01	0.98

Carroll et al. 2024, *Movement Ecology*

Final candidate model selection table for ecological distance models (resistance to movement parameter; δ) for **male** black bears.

Model (males)	*D*	*p*0	asu (δ)	LogL	K	AIC	Δ AIC	Weight (wi)	CumWt
4	~forest cover + griz density	~ best	~ distance to drain + transport corridor + forest cover	1485.69	16	3003.38	0.00	0.33	0.33
5	~forest cover + griz density	~ best	~ distance to drain + transport corridor + riparian	1485.78	16	3003.56	0.18	0.30	0.64
2	~forest cover + griz density	~ best	~ distance to drain + transport corridor	1487.36	15	3004.72	1.34	0.17	0.81
6	~forest cover + griz density	~ best	~ transport corridor + tree cover + riparian	1486.88	16	3005.77	2.38	0.10	0.91
3	~forest cover + griz density	~ best	~ transport corridor + forest cover	1488.01	15	3006.01	2.63	0.09	1.00
1	~forest cover + griz density	~ best	~ distance to drain + forest cover	1494.29	15	3018.59	15.21	0.00	1.00

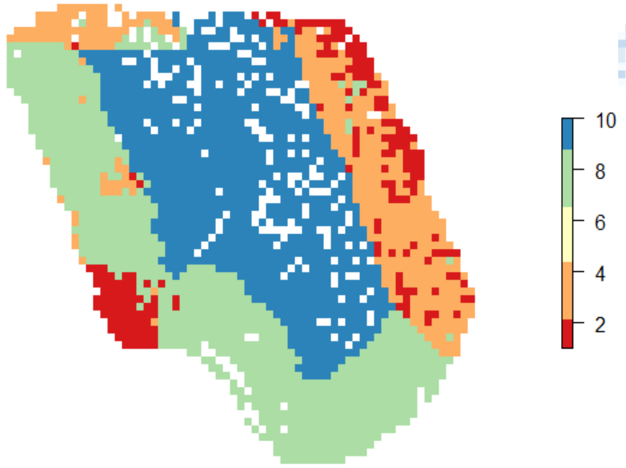
USGS science for a changing world

Carroll et al. 2024, *Movement Ecology*

Density (d0) hypotheses

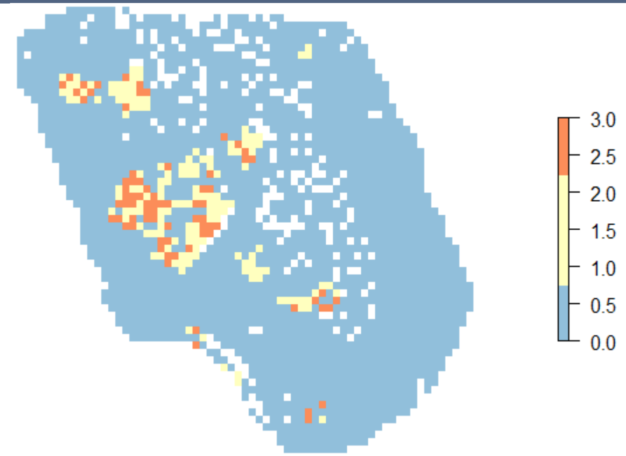
Carroll et al. 2024, *Movement Ecology*

Security level

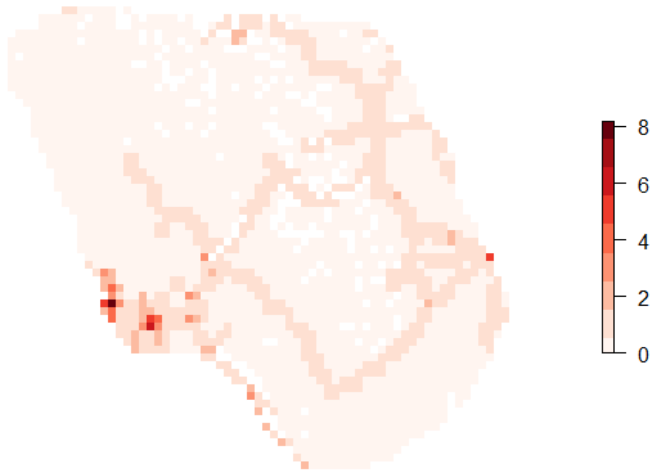


Phenology

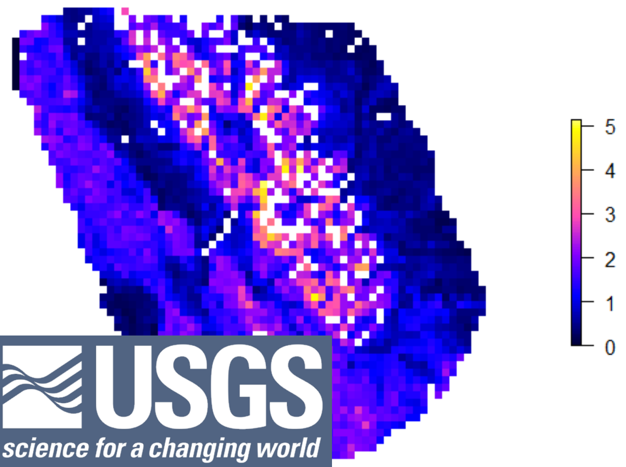
Fires



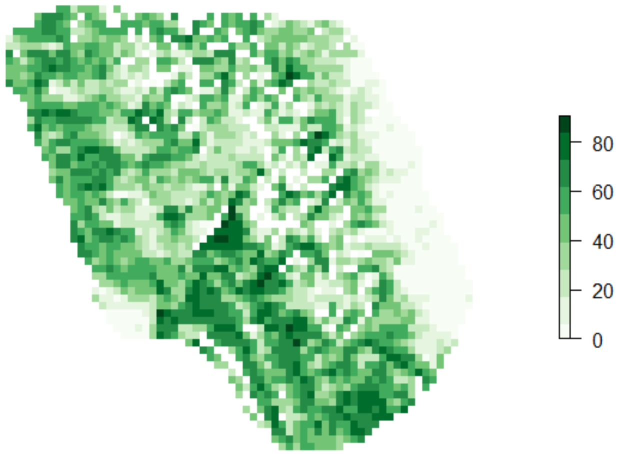
Paved road density



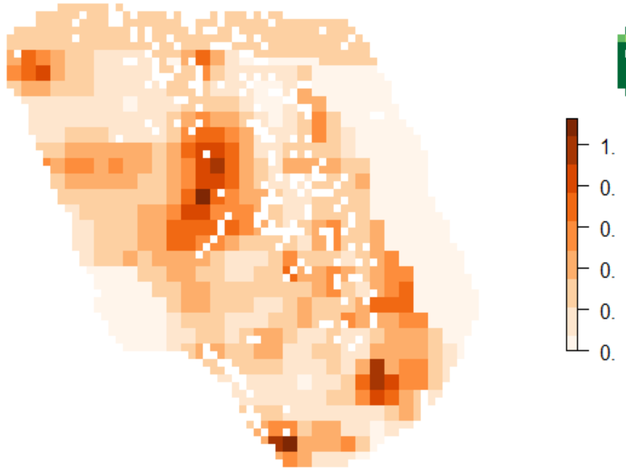
Terrain curvature (std)



Tree cover (%)

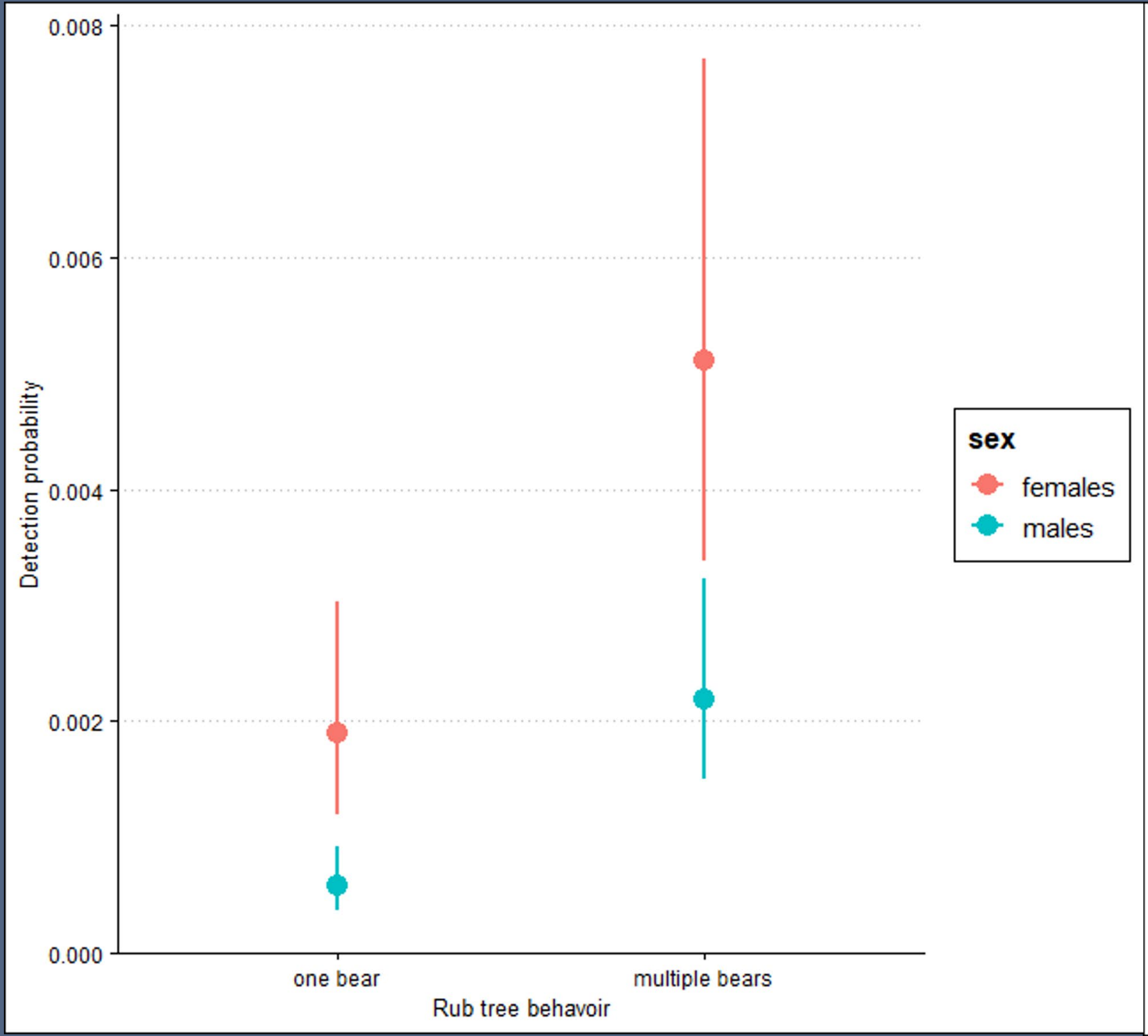


Grizzly density 2004

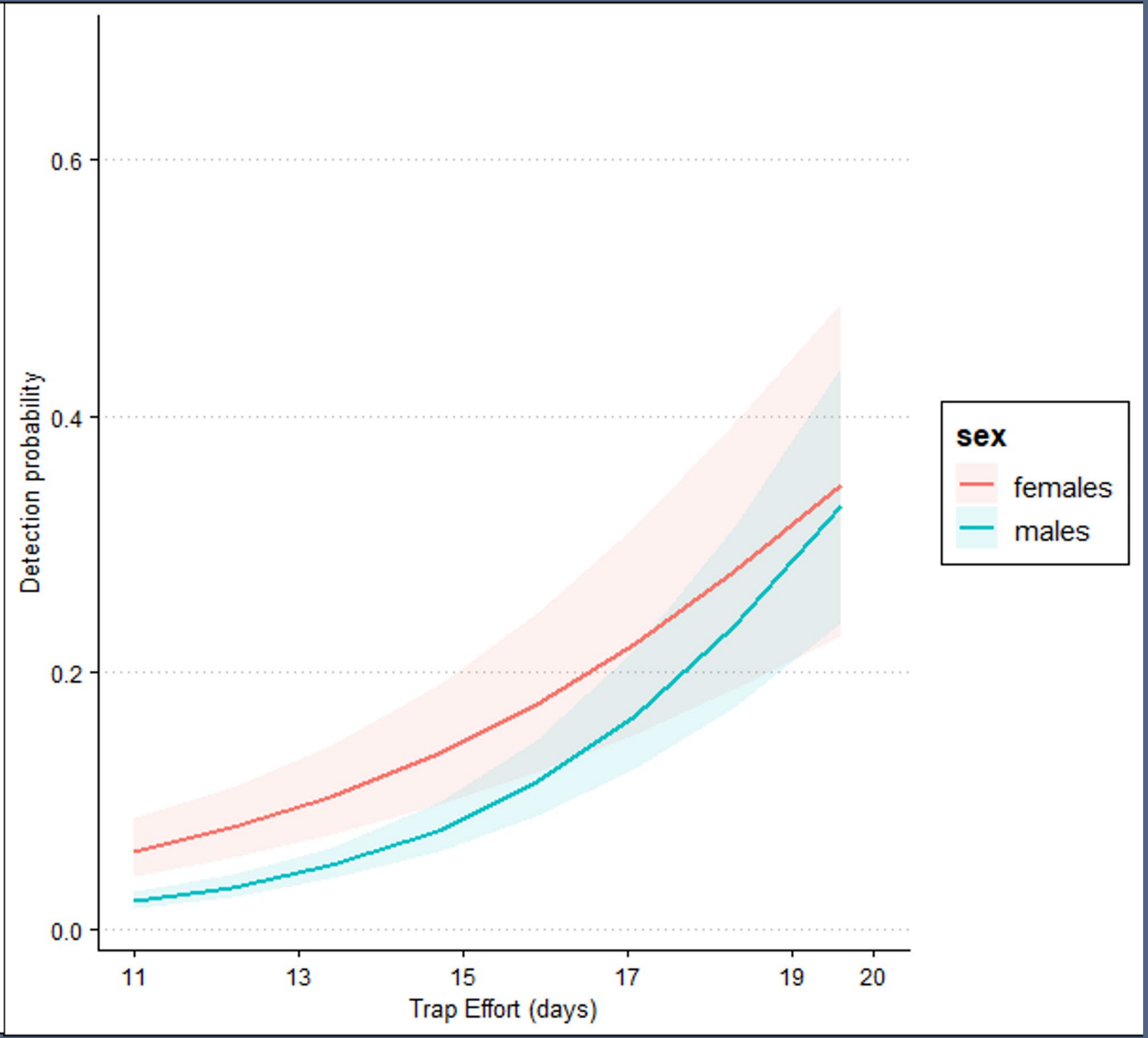


Developed land cover (%)

Rub tree detection probability



Hair snare detection probability



Carroll et al. 2024, *Movement Ecology*

Final candidate model selection table for ecological distance models (resistance to movement parameter; δ) for **female** black bears.

Model (females)	D	p0	asu (δ)	LogL	K	AIC	Δ AIC	Weight (wi)	CumWt
5	~forest cover	~ best	~ drain binary	1065.61	12	2155.22	0.00	0.68	0.68
10	~forest cover	~ best	~ riparian cover	1067.41	12	2158.83	3.60	0.11	0.79
16	~forest cover	~ best	~ null	1068.91	11	2159.83	4.60	0.07	0.86
9	~forest cover	~ best	~ distance to roads	1067.97	12	2159.95	4.72	0.06	0.92
6	~forest cover	~ best	~ distance to drain	1069.16	12	2162.32	7.10	0.02	0.94
14	~forest cover	~ best	~ distance to Hwy	1069.83	12	2163.67	8.44	0.01	0.95
8	~forest cover	~ best	~ GTSR	1070.05	12	2164.11	8.88	0.01	0.96
7	~forest cover	~ best	~ railway	1070.19	12	2164.38	9.16	0.01	0.97
3	~forest cover	~ best	~ aspen cover	1070.27	12	2164.55	9.33	0.01	0.98
4	~forest cover	~ best	~ transport corridor	1070.31	12	2164.63	9.40	0.01	0.98
2	~forest cover	~ best	~ roads binary	1070.33	12	2164.66	9.43	0.01	0.99
1	~forest cover	~ best	~ Hwy 2	1070.34	12	2164.68	9.46	0.01	0.99
15	~forest cover	~ best	~ road density	1070.34	12	2164.69	9.46	0.01	1.00

USGS science for a changing world

Carroll et al. 2024, *Movement Ecology*