Integrated Step-Selecion approach (iSSA): combining movement and habitat selection

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Methods in Ecology and Evolution

British Ecological Society

Methods in Ecology and Evolution 2016, **7**, 619–630 doi: 10.1111/2041-210X.12528

Integrated step selection analysis: bridging the gap between resource selection and animal movement

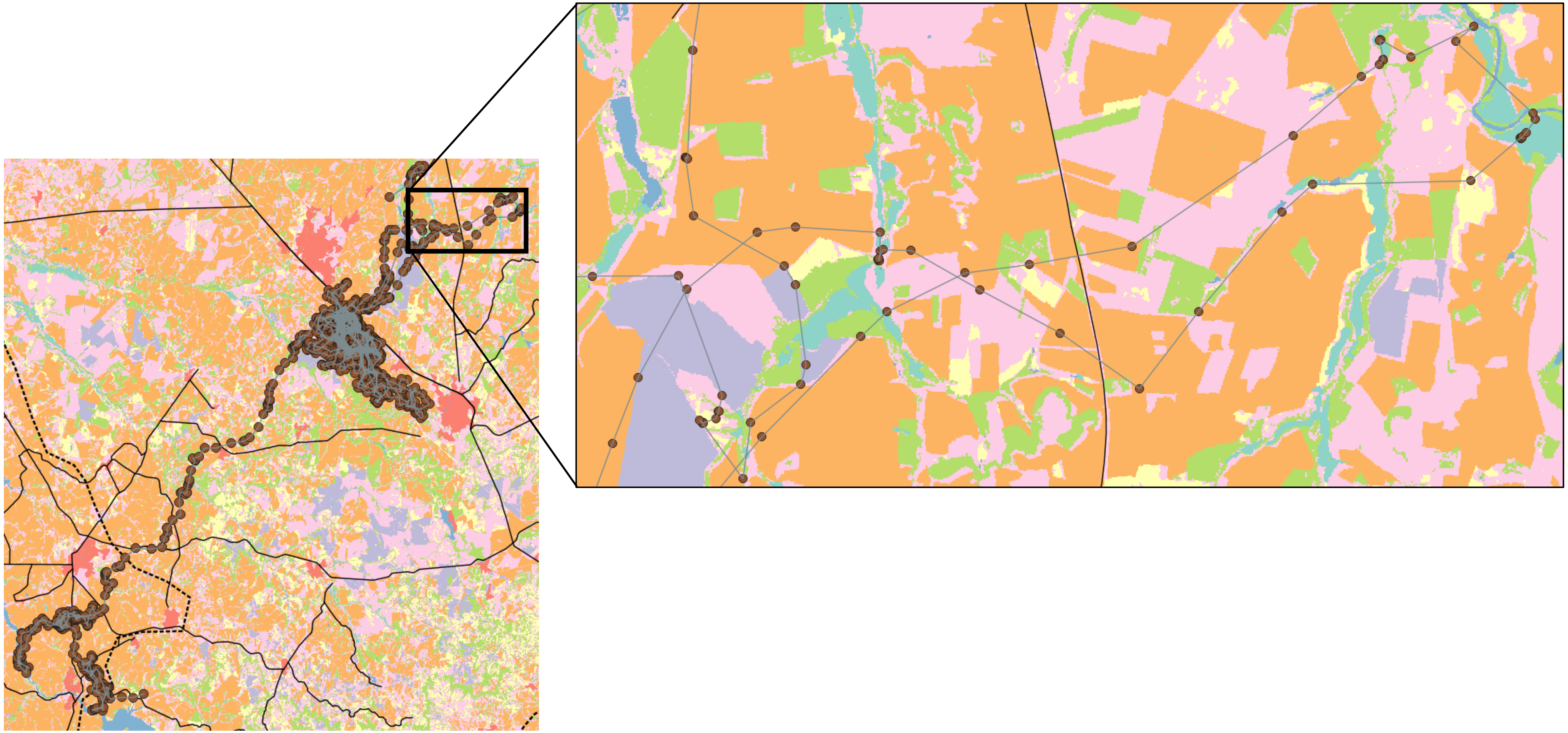
Tal Avgar[1]*, Jonathan R. Potts[2], Mark A. Lewis[1,3] and Mark S. Boyce[1]

Movement processes or patterns

Discrete

Step length ℓ

Turning angle θ



Movement processes or patterns

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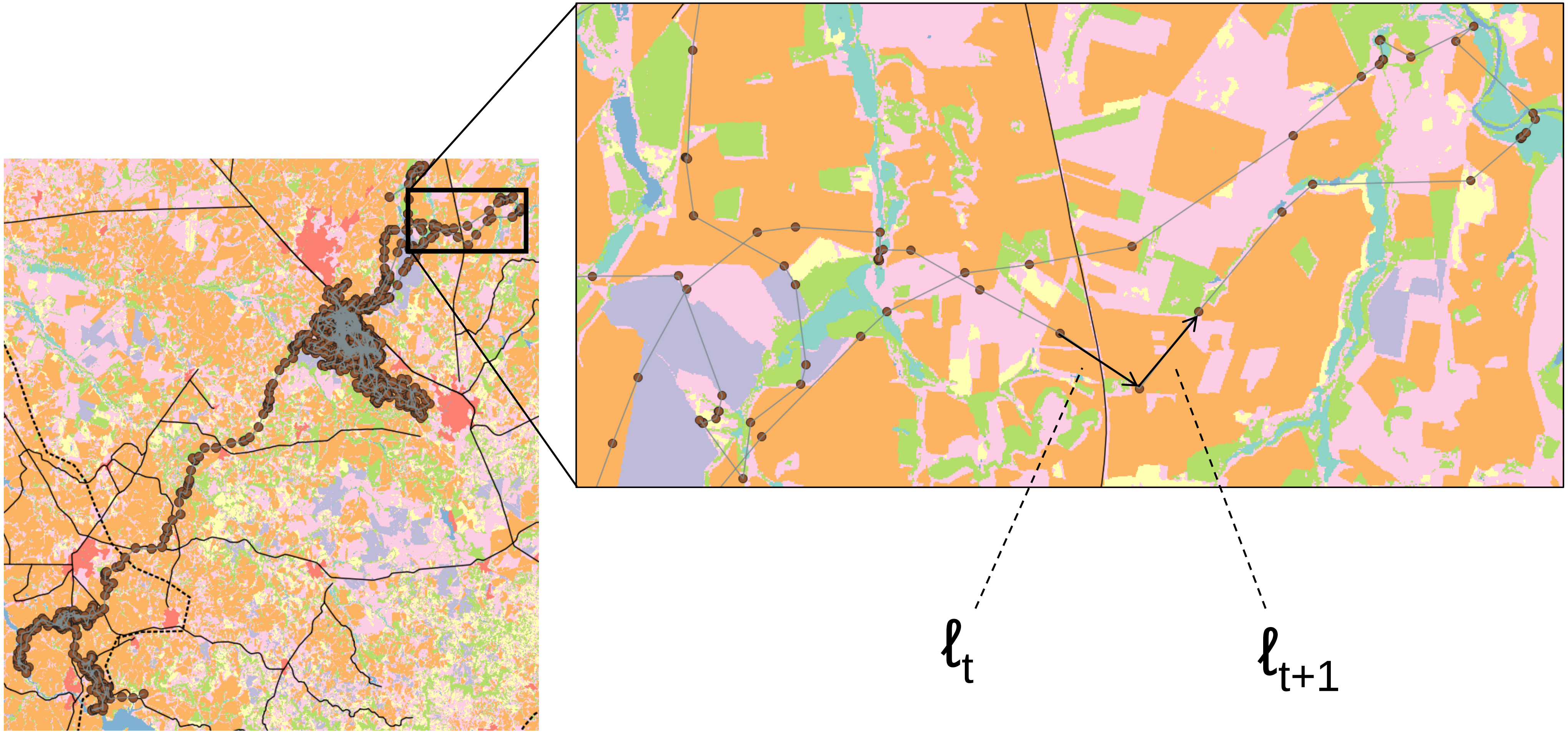

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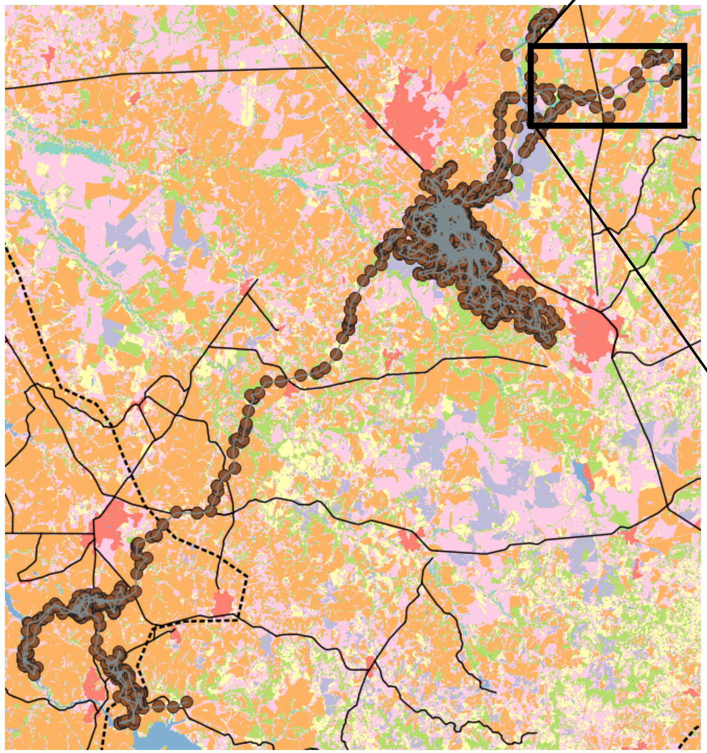
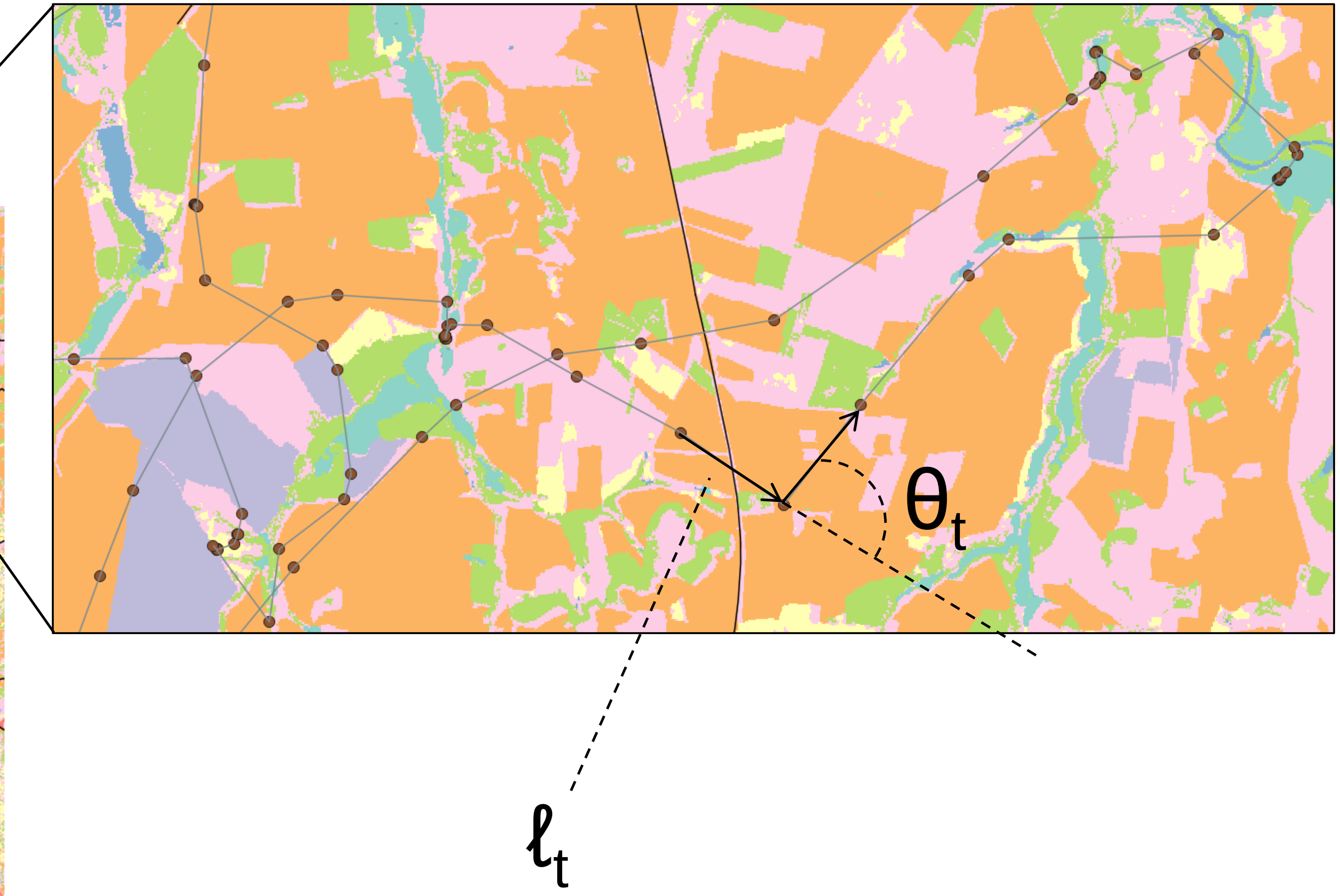
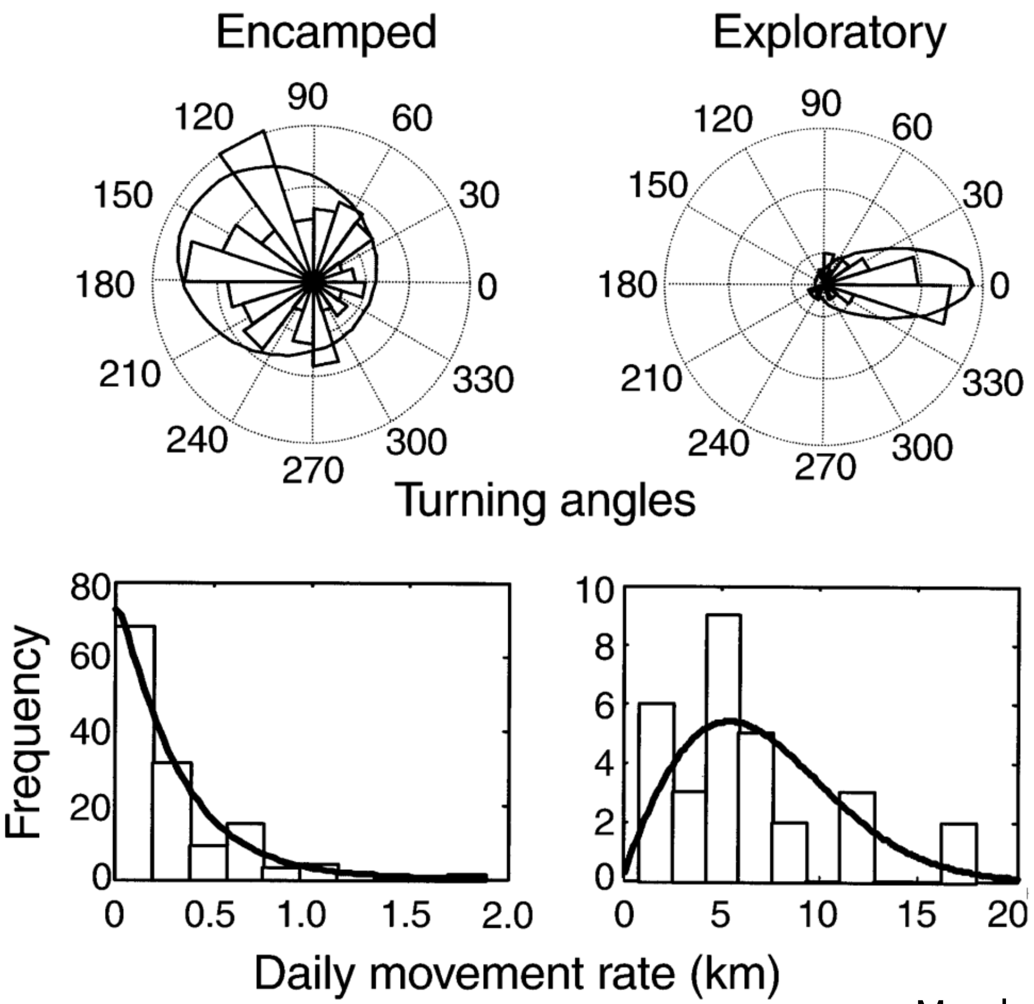
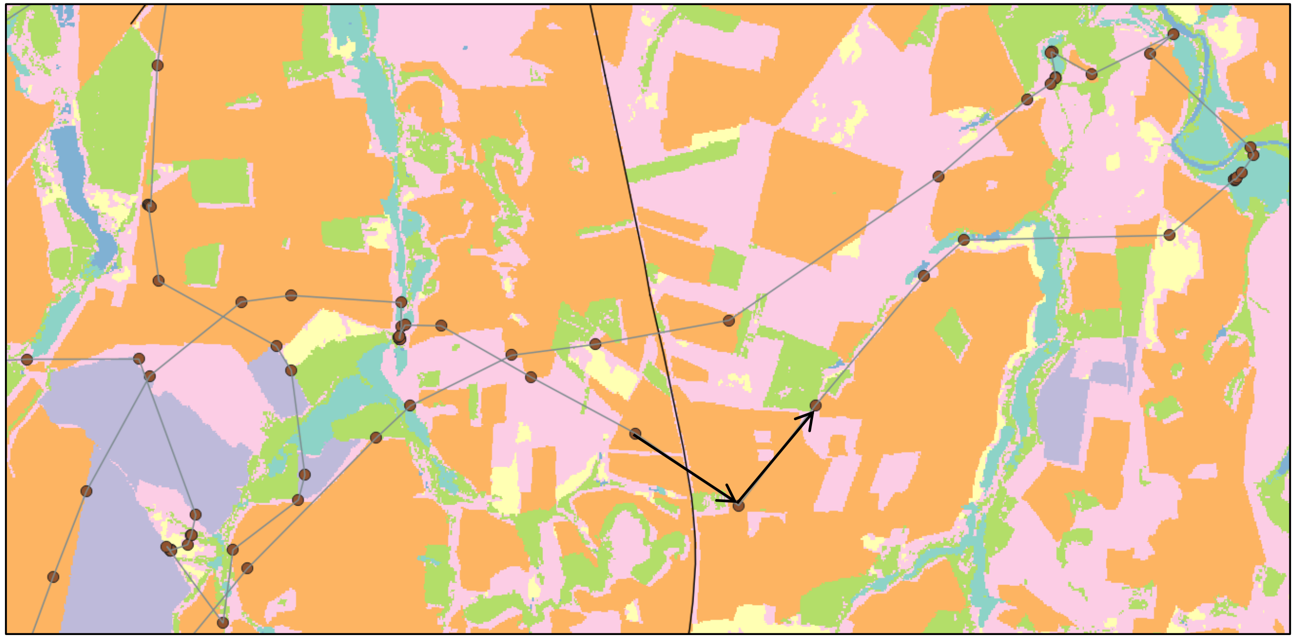




Movement processes or patterns

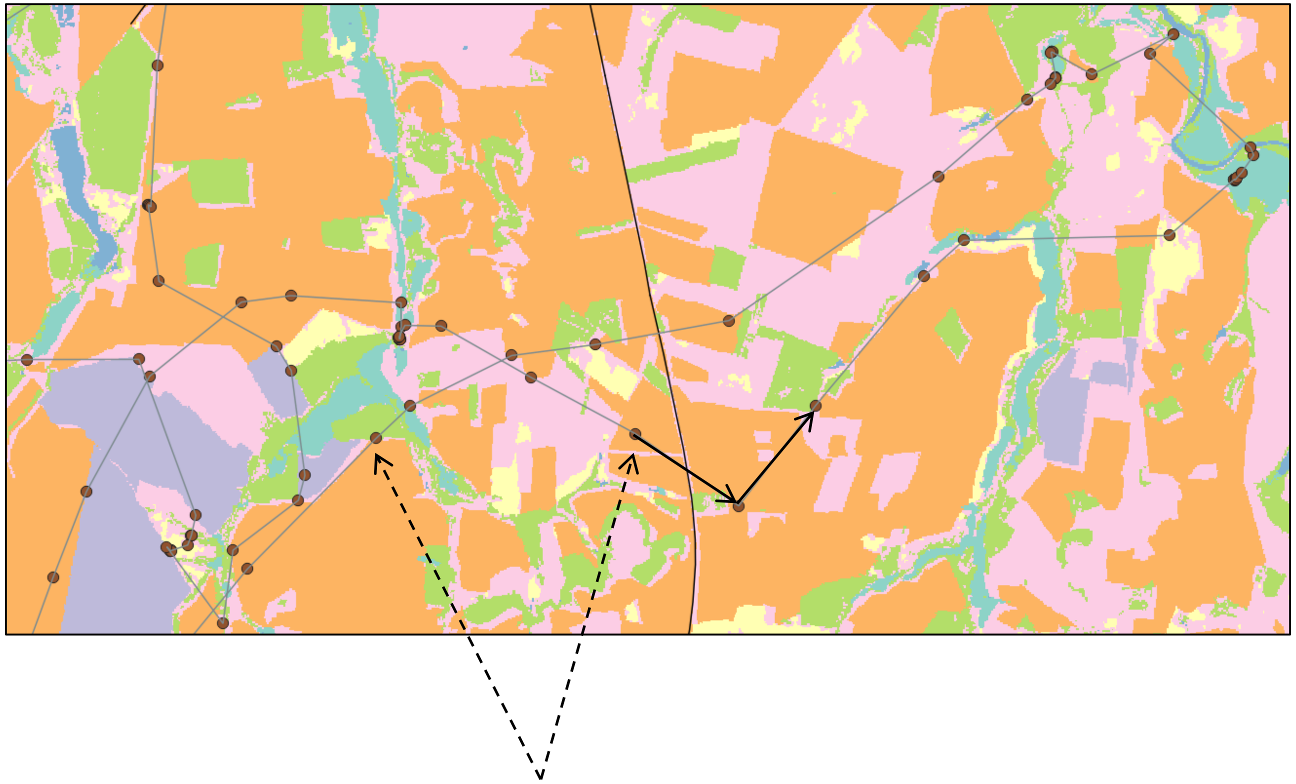




Morales et al. 2004 Ecol.

Movement processes or patterns

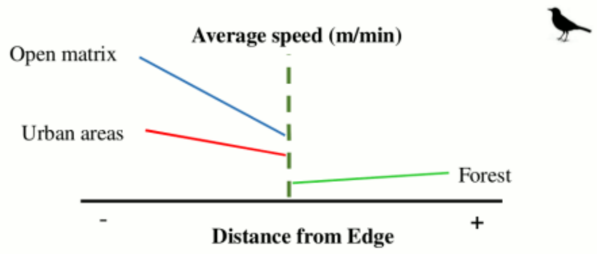
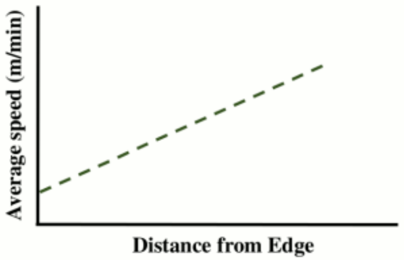
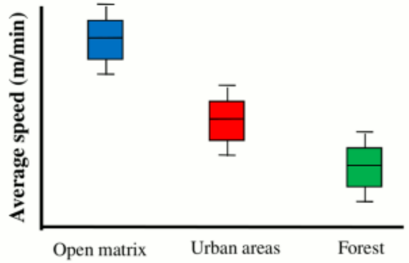
- How the animal’s movement rate changes in different habitats or conditions?
- How does step length changes when close to wind farms or roads?
- How movement rate or directionality changes during different behaviors?



We are generally interested in the conditions at the **start point** of the step

Movement processes or patterns

How do thrushes move in a fragmented tropical forest landscape?

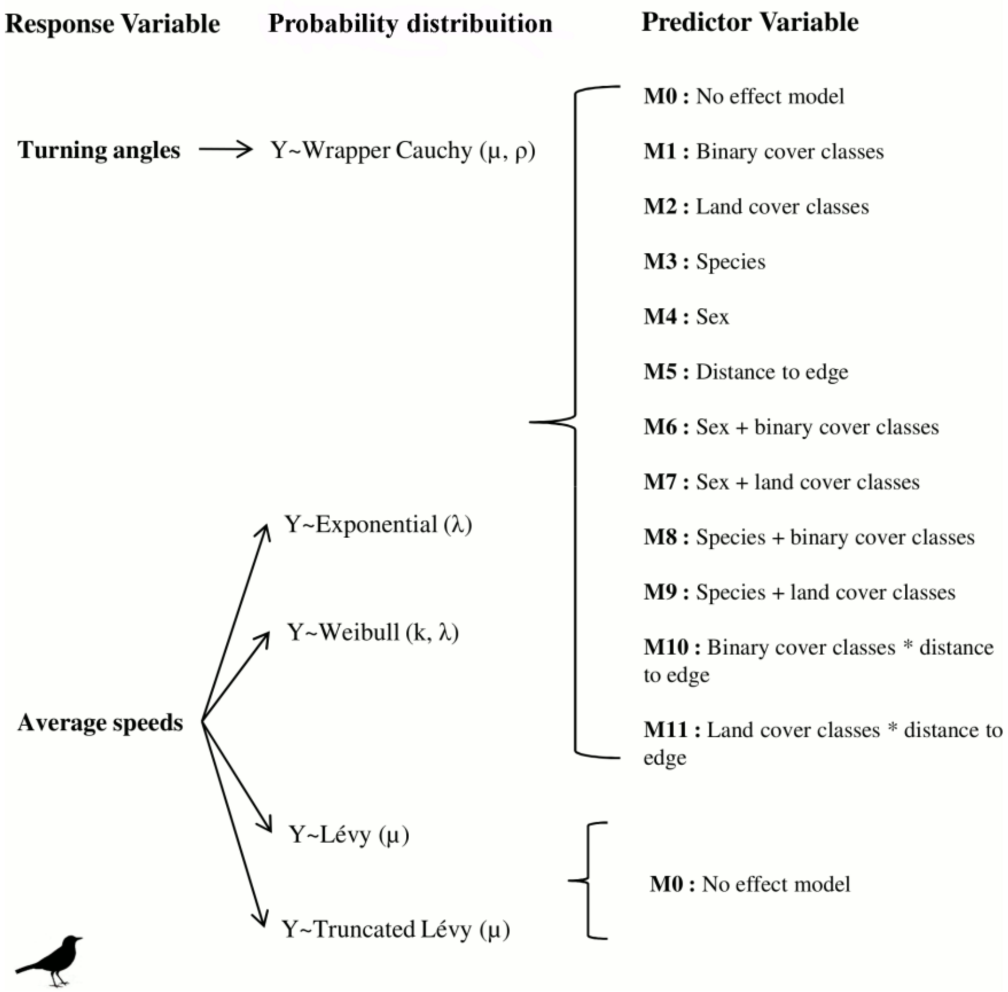
Hypothesis	Description of the expected responses	Sketch of expected responses
H1 Average Speed: Effect of Distance from Edges and Land Cover	We expected average speeds to increase with the distance from forest edges. Also, we expected this increase to be smaller in the forest, intermediate in urban areas and higherin open matrix types (crops and pasture), where resources are scarcer.	
H2 Average Speed: Effect of Distance from Edges	We expected average speeds to increase only with the distance from forest edges, with shorter speeds near edges, one of thrushes' preferred habitats.	
H3 Average Speed: Effect of Land Cover	We expected lower average speeds inside forests, where resources area abundant, moderately speeds in urban areas, and higher movement speeds in open matrix types (crops and pasture), where resources are scarcer.	

Turdus rufiventris

Silveira et al. 2016 PLOS One

Movement processes or patterns

How do thrushes move in a fragmented tropical forest landscape?



Silveira et al. 2016 PLOS One

Movement processes or patterns

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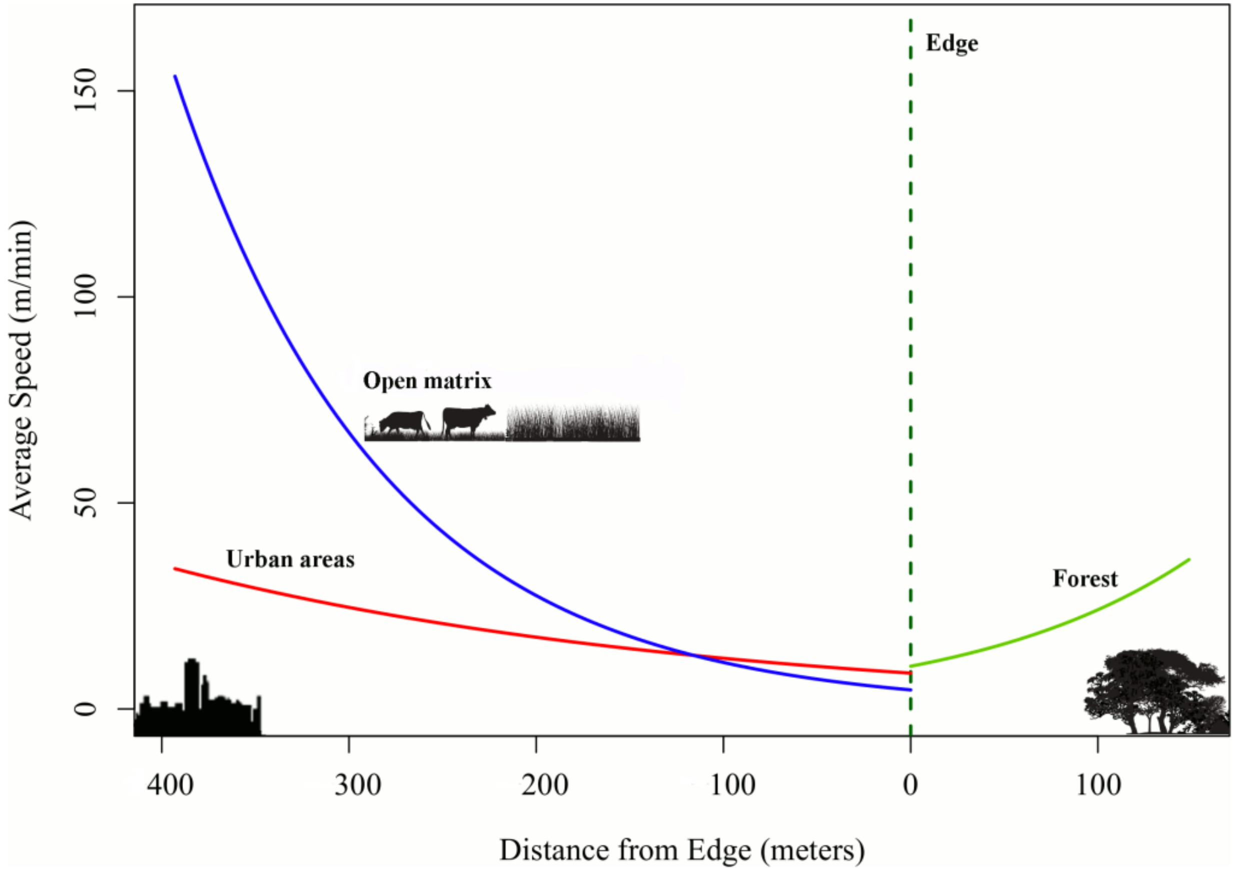
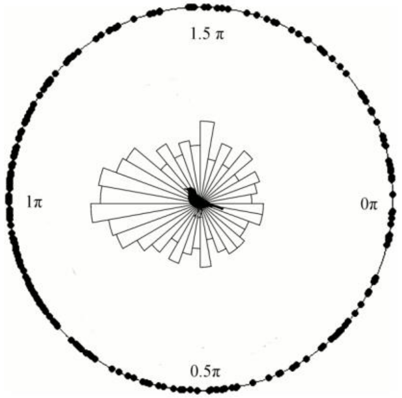


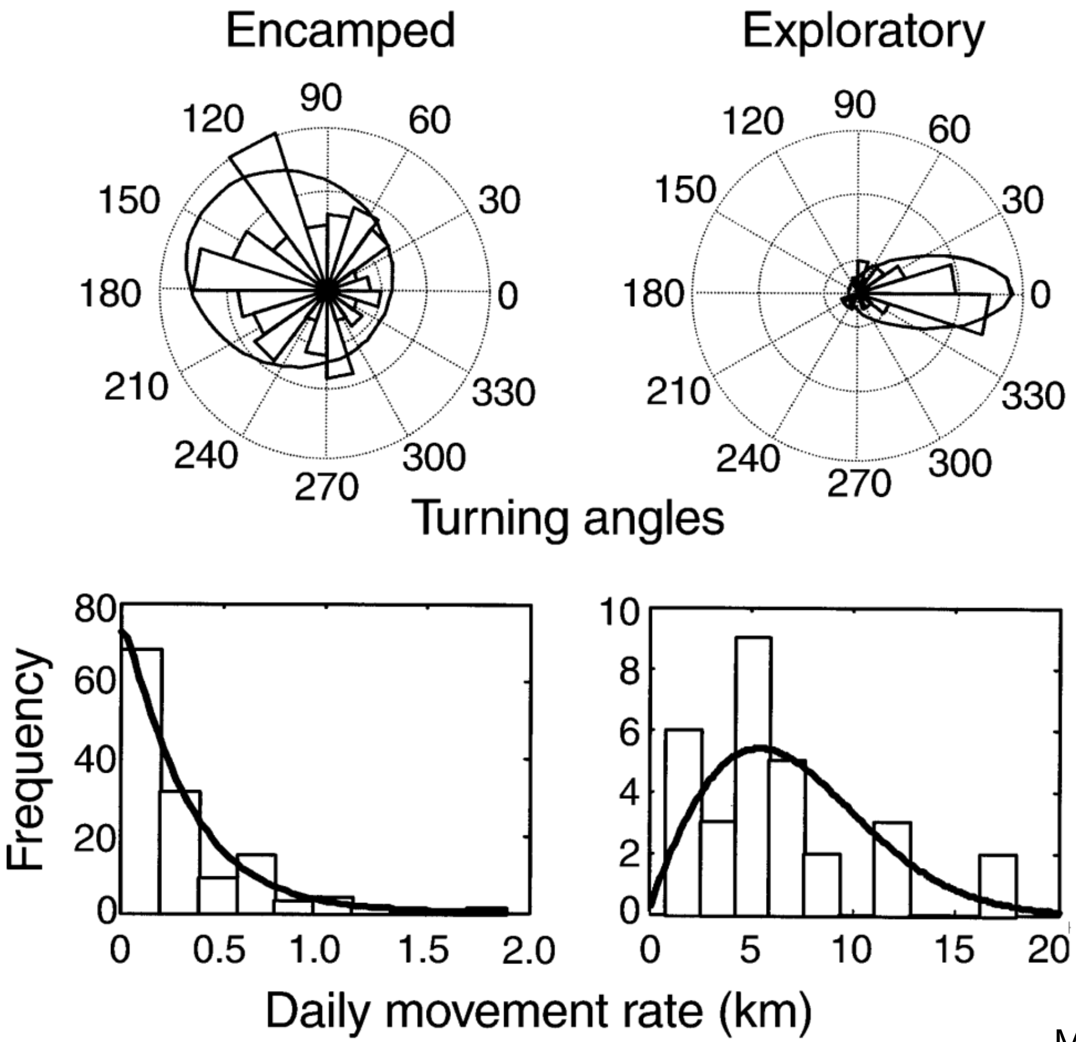


Silveira et al. 2016 PLOS One

Movement processes or patterns

How do elks move in different behavioral states?

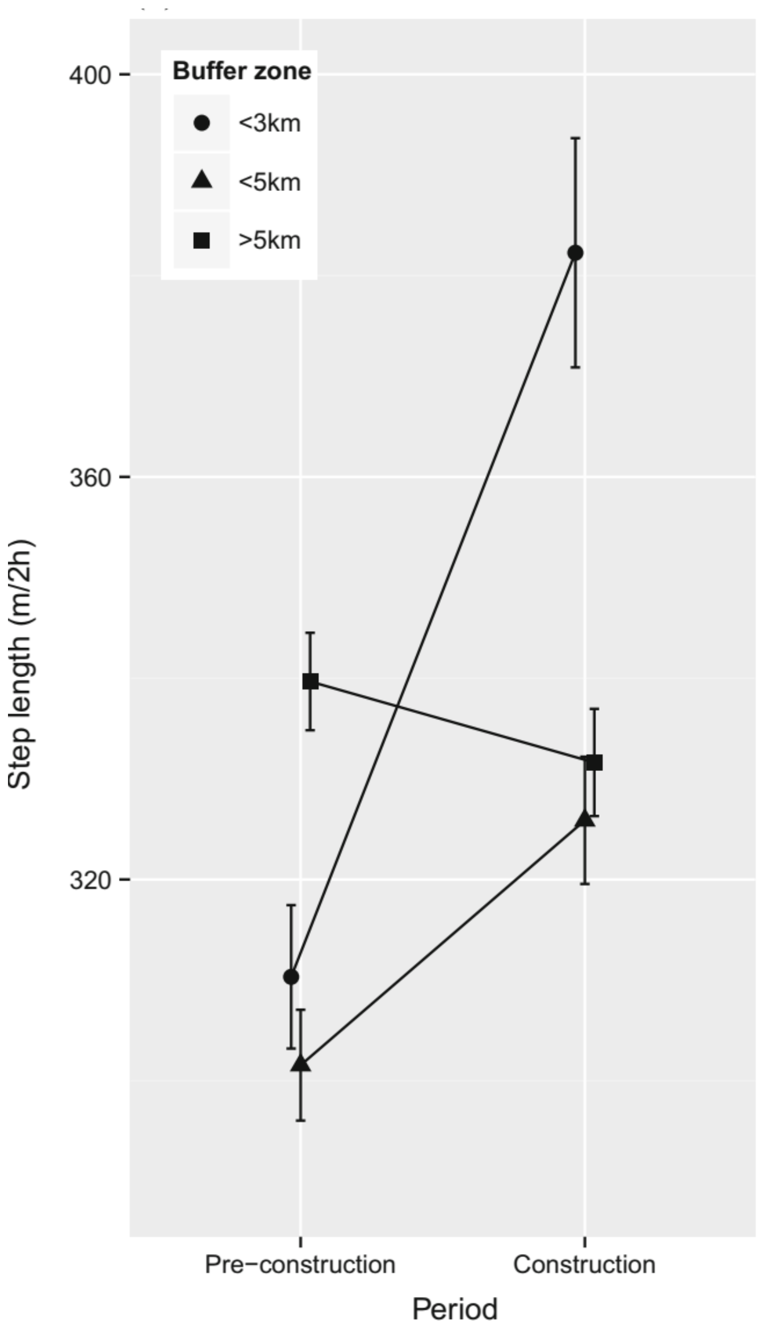
Cervus elaphus



Morales et al. 2004 Ecol.

Movement processes or patterns

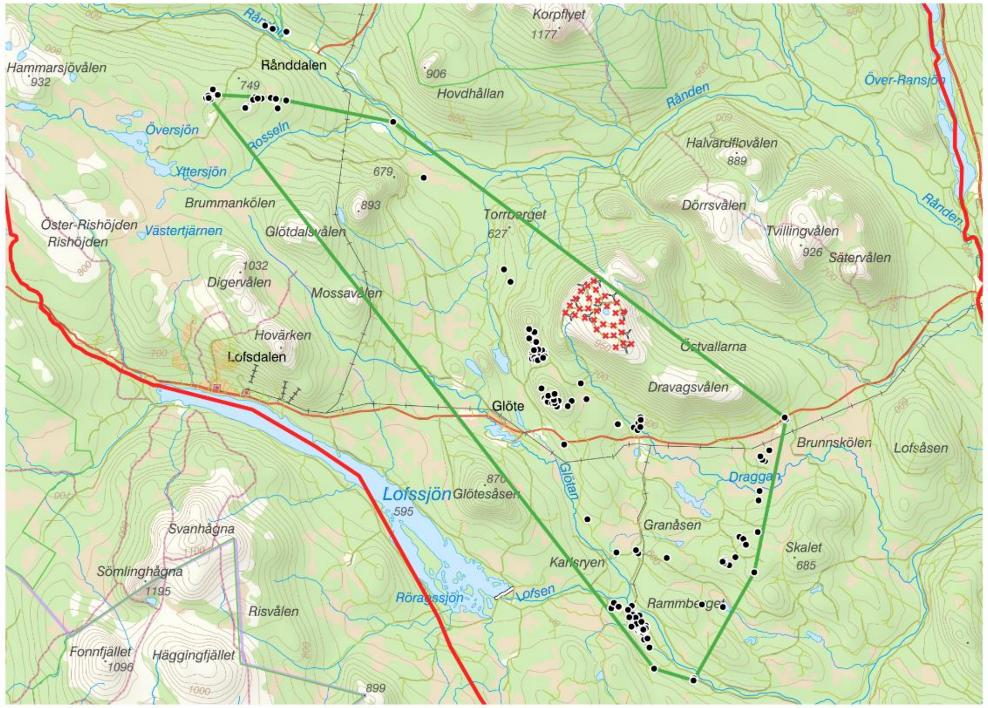
How do reindeer movement rate changes
with distance to wind farms, before
and during their construction?

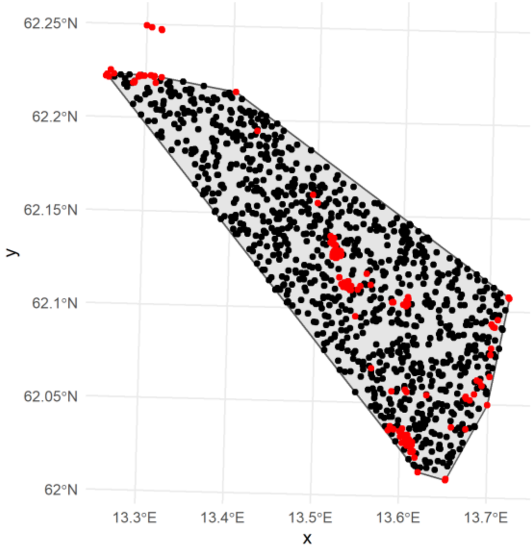


Skarin et al 2018 Land. Ecol.

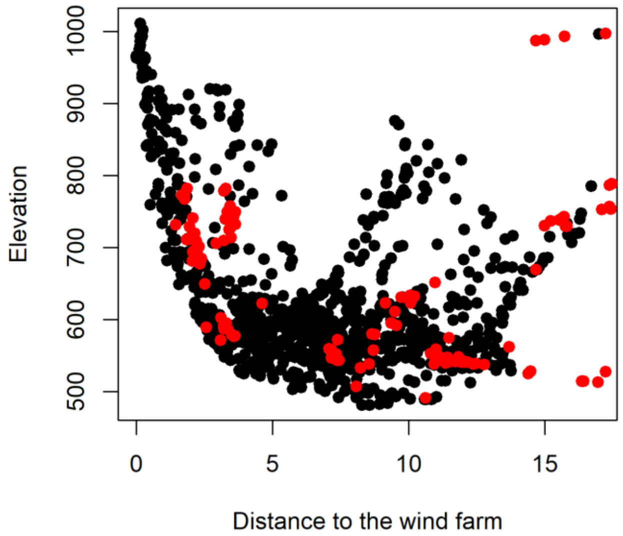
Resource selection process

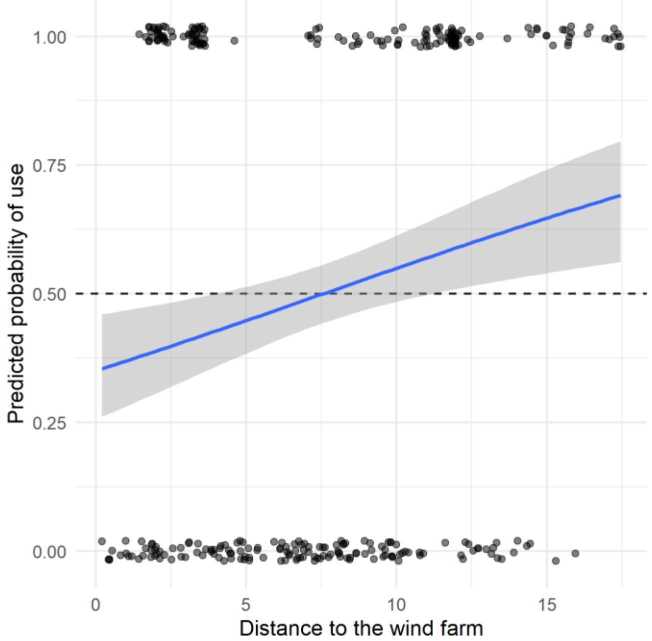
Resource selection functions (RSF)





use-availability design

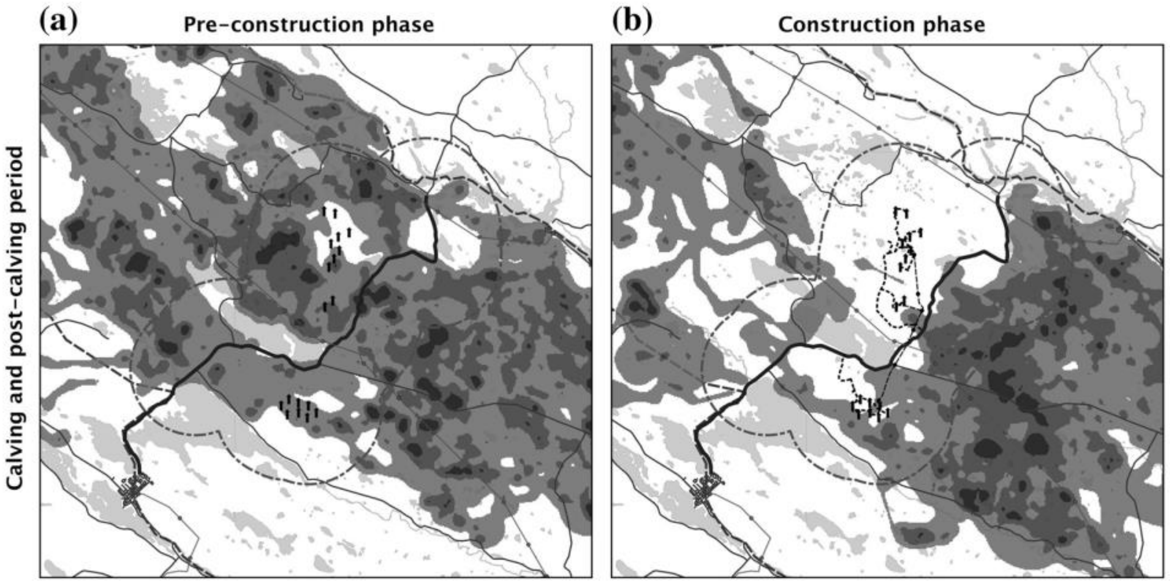




Resource selection process

Resource selection functions (RSF)

Calving	Second-order			Third-order		
	Estimate	SE	Pr(>|z|)[a]	Estimate	[illegible]	[illegible]
Barren ground	−0.271	0.157	0.083	0.728	[illegible]	[illegible]
Heath	1.427	0.101	0.000	1.227	0.102	0.000
Broad leaved forest	0.267	0.165	0.106	−0.077	0.155	0.617
Coniferous forest	−0.130	0.067	0.051	−0.007	0.075	0.923
Mixed forest	−0.370	0.096	0.000	−0.436	0.101	0.000
Clear cuts	0.757	0.069	0.000	0.924	0.076	0.000
Young forest	0.080	0.067	0.232	0.150	0.075	0.044
Mires	0.167	0.064	0.009	0.110	0.074	0.138
Slope (degrees)	−0.106	0.006	0.000	−0.030	0.007	0.000
Distance to water (log)	0.056	0.008	0.000	−0.007	0.002	0.000
Distance to power lines (sqrt)	−0.003	0.001	0.000	−0.005	0.001	0.000
Distance to large road (sqrt)	0.017	0.001	0.000	0.008	0.001	0.000
Distance to small road (sqrt)[b]	–	–	–	−0.004	0.001	0.001
Distance to wind park (sqrt)	−0.009	0.001	0.000	−0.002	0.001	0.002
Distance to wind park (sqrt): construction phase	0.001	0.001	0.003	0.003	0.001	0.000

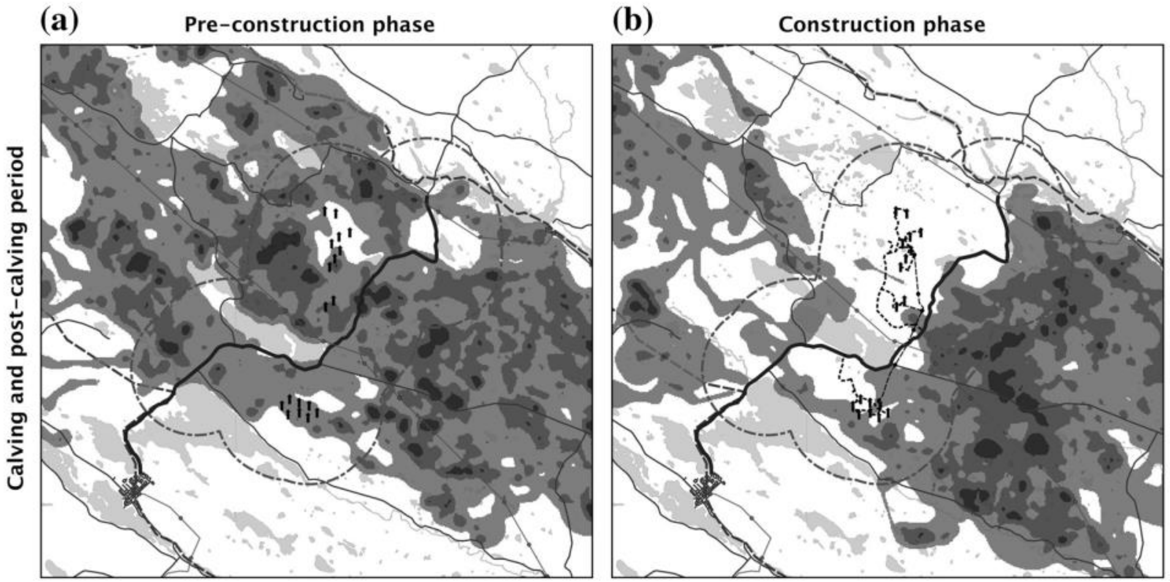


Selection before construction

Skarin et al 2018 Land. Ecol.

Resource selection process

Resource selection functions (RSF)



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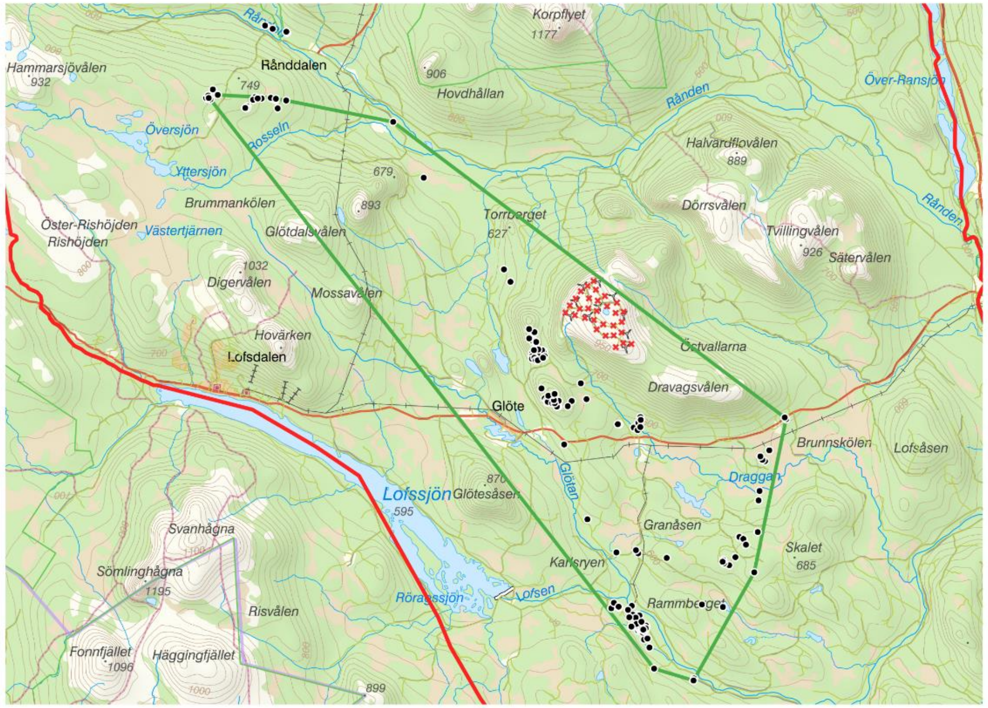
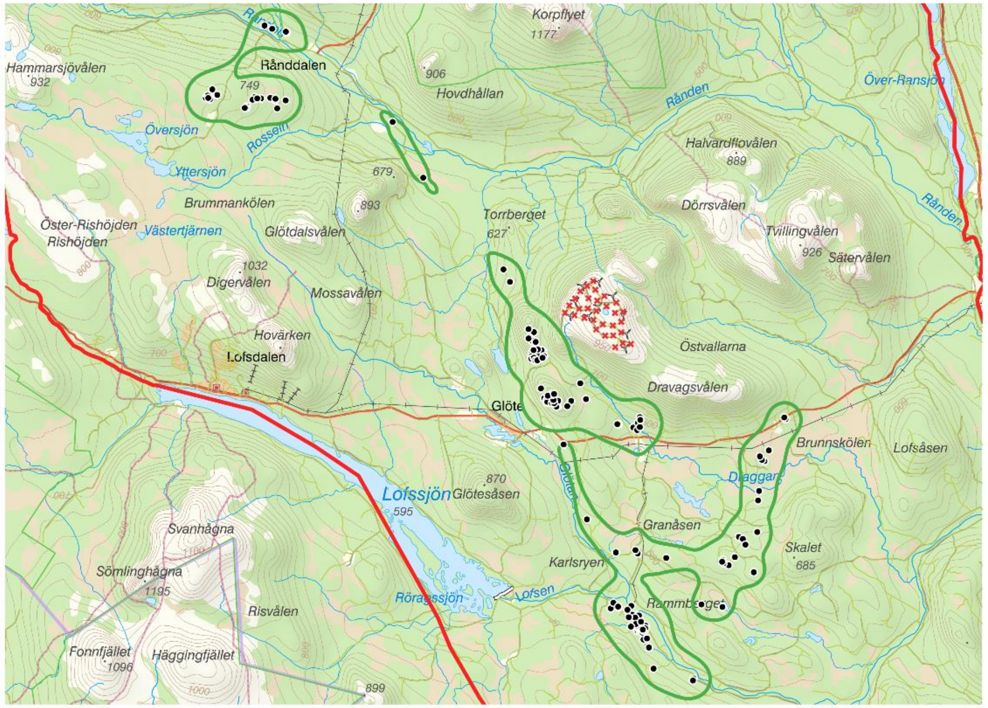
Avoidance during construction

Skarin et al 2018 Land. Ecol.

Resource selection process

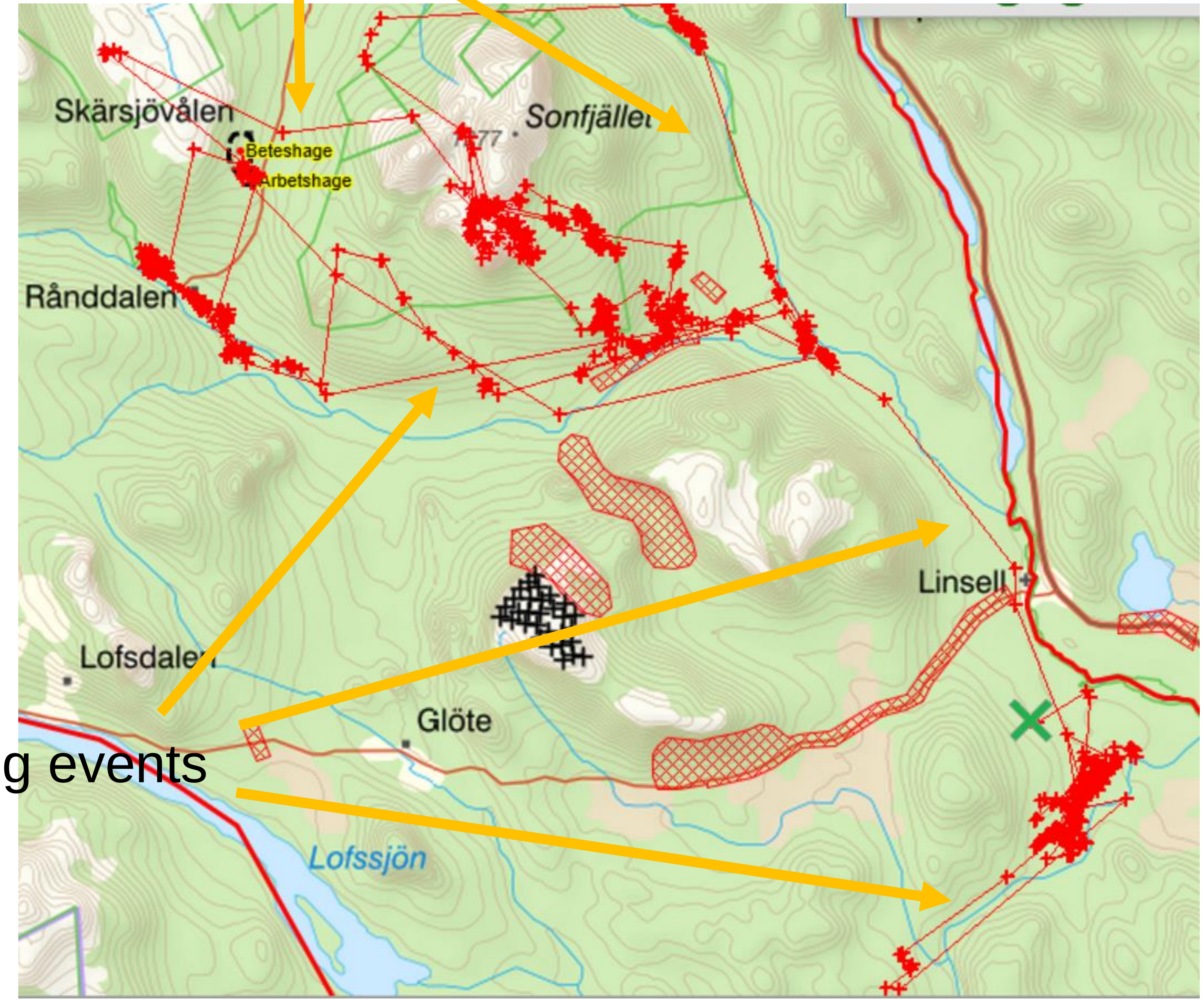
Resource selection functions (RSF)





It is difficult to define availability!

Herding events



Herding events

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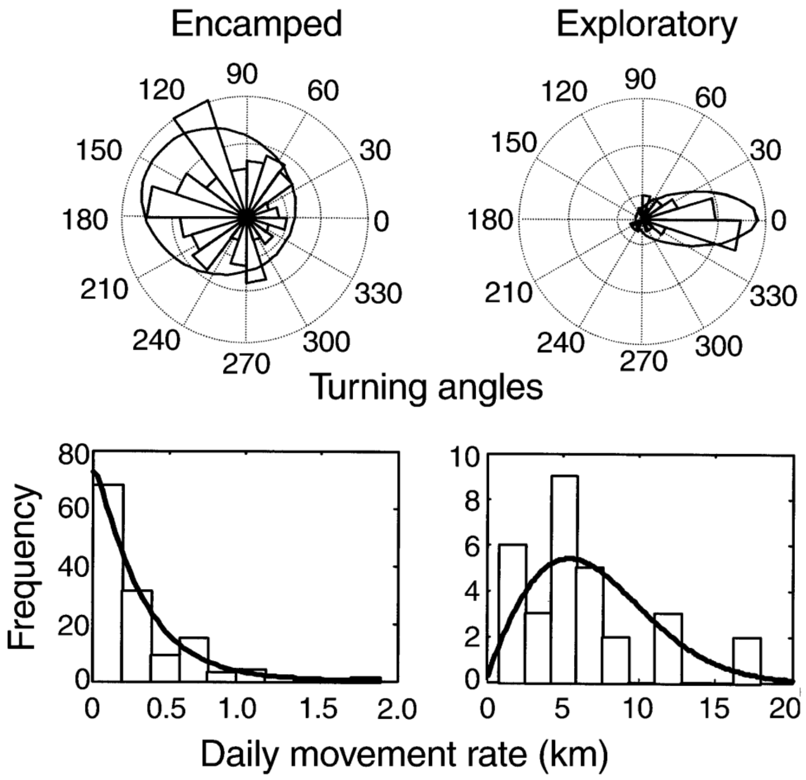
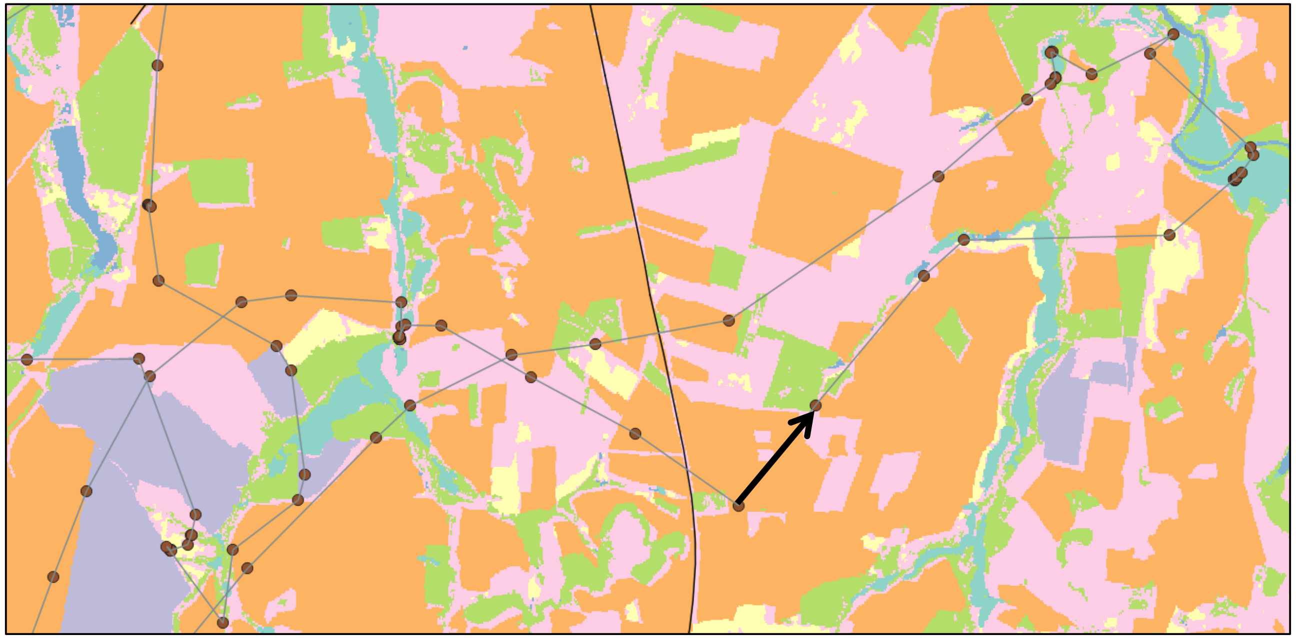
Resource selection process

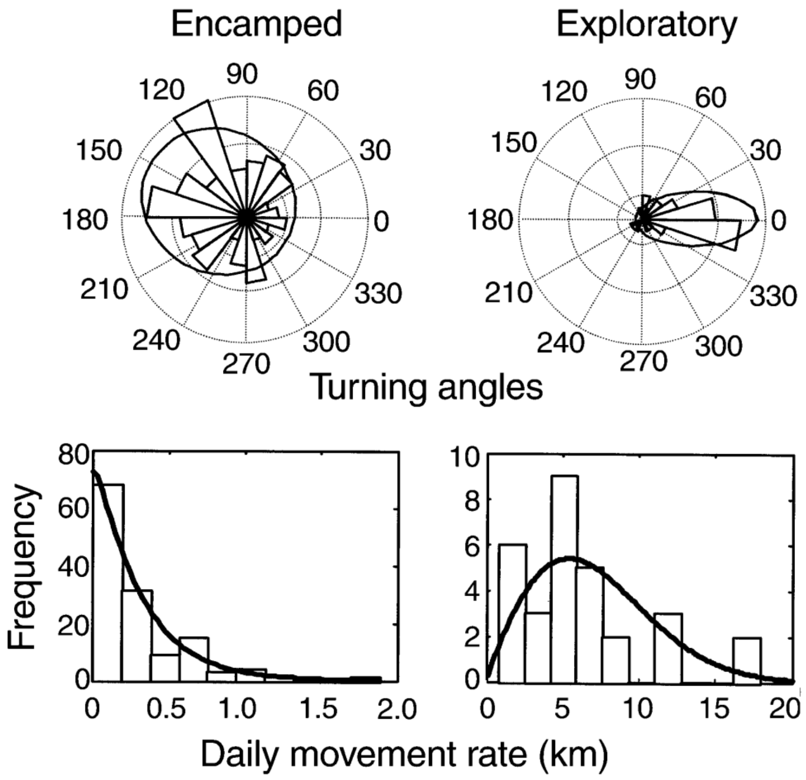
Step selection functions (SSF)

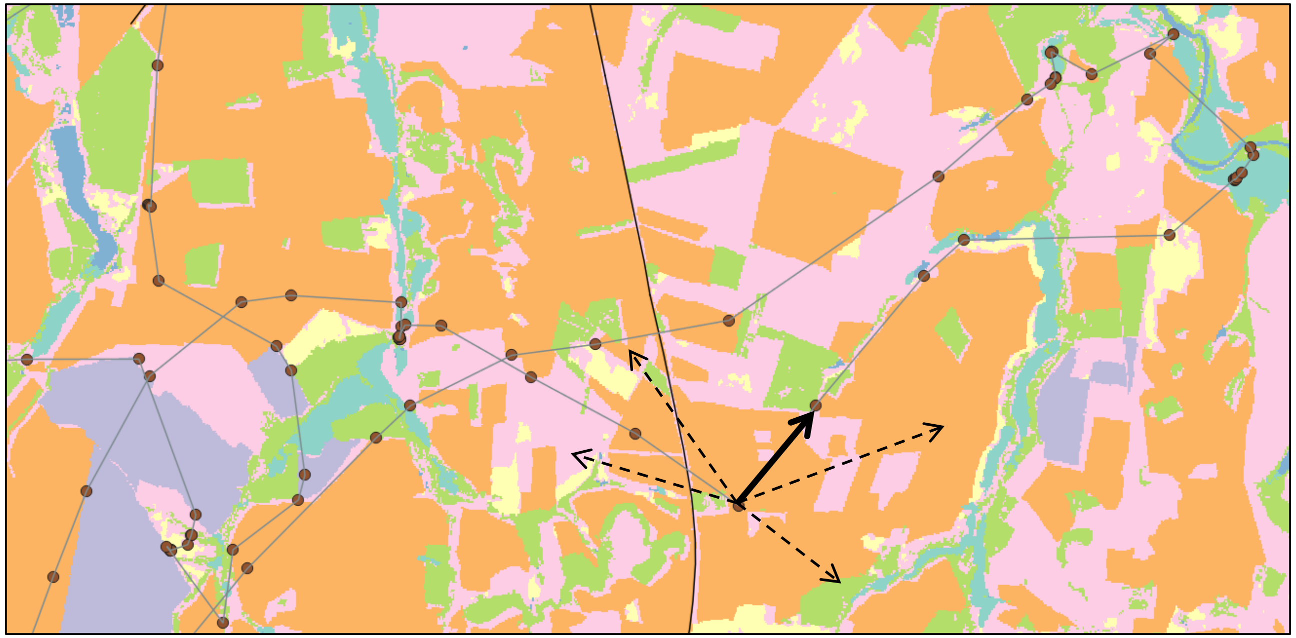




Resource selection process

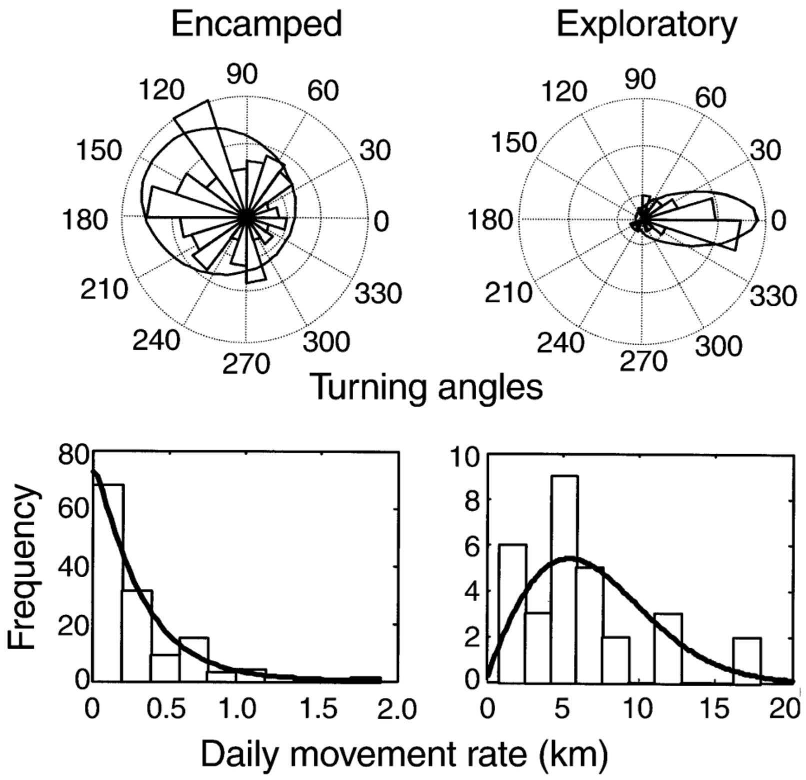
Step selection functions (SSF)

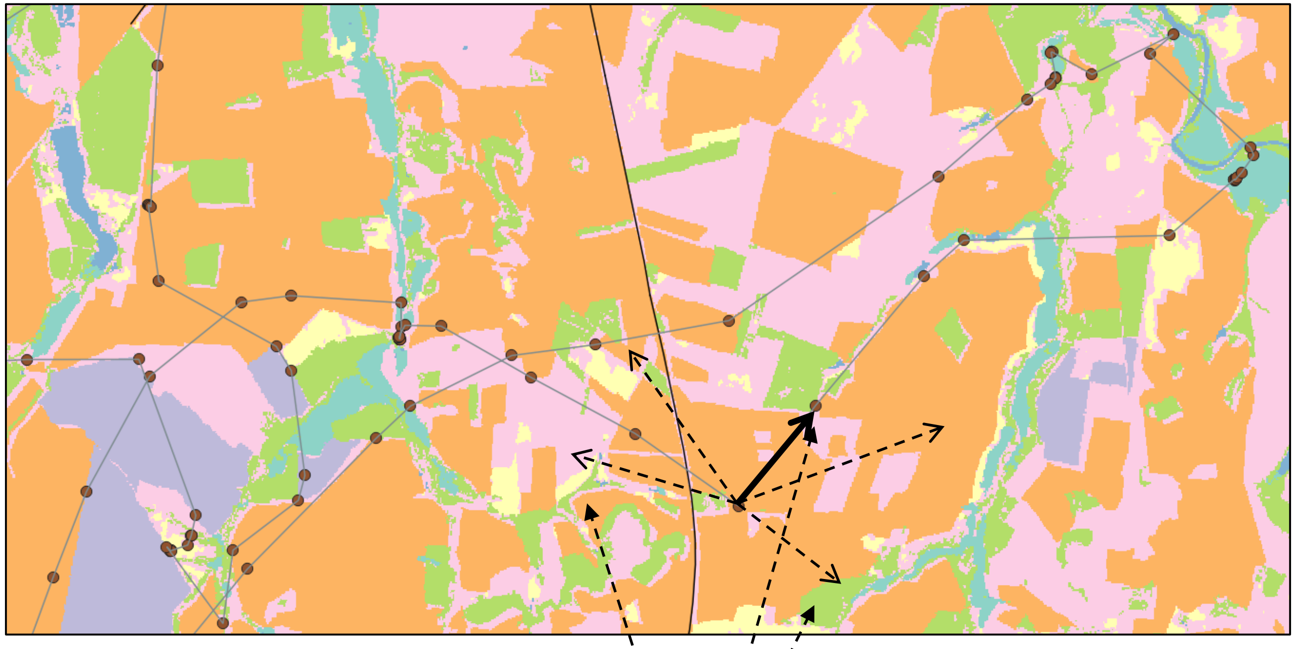




Resource selection process

Step selection functions (SSF)

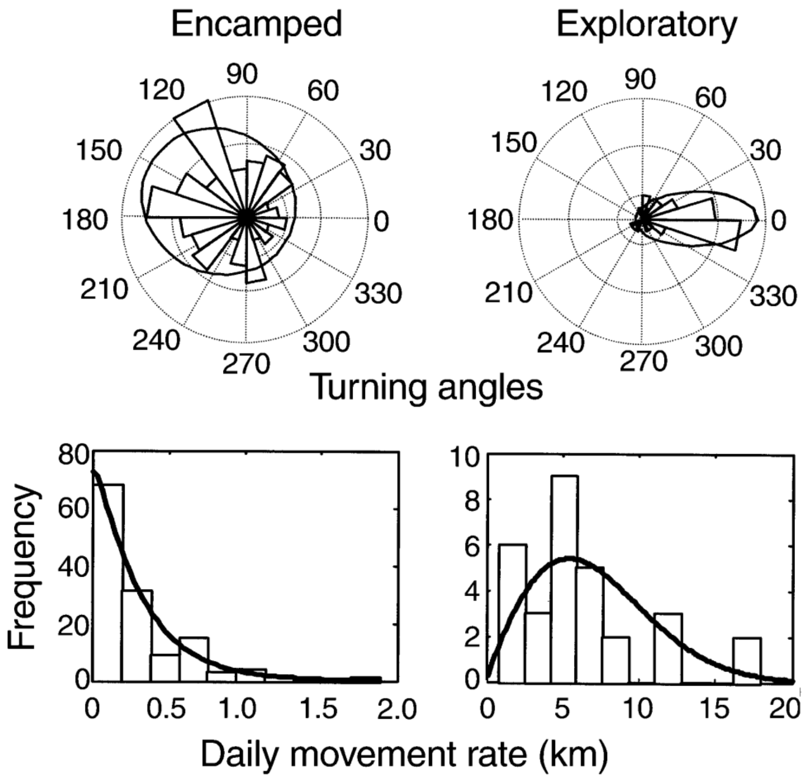


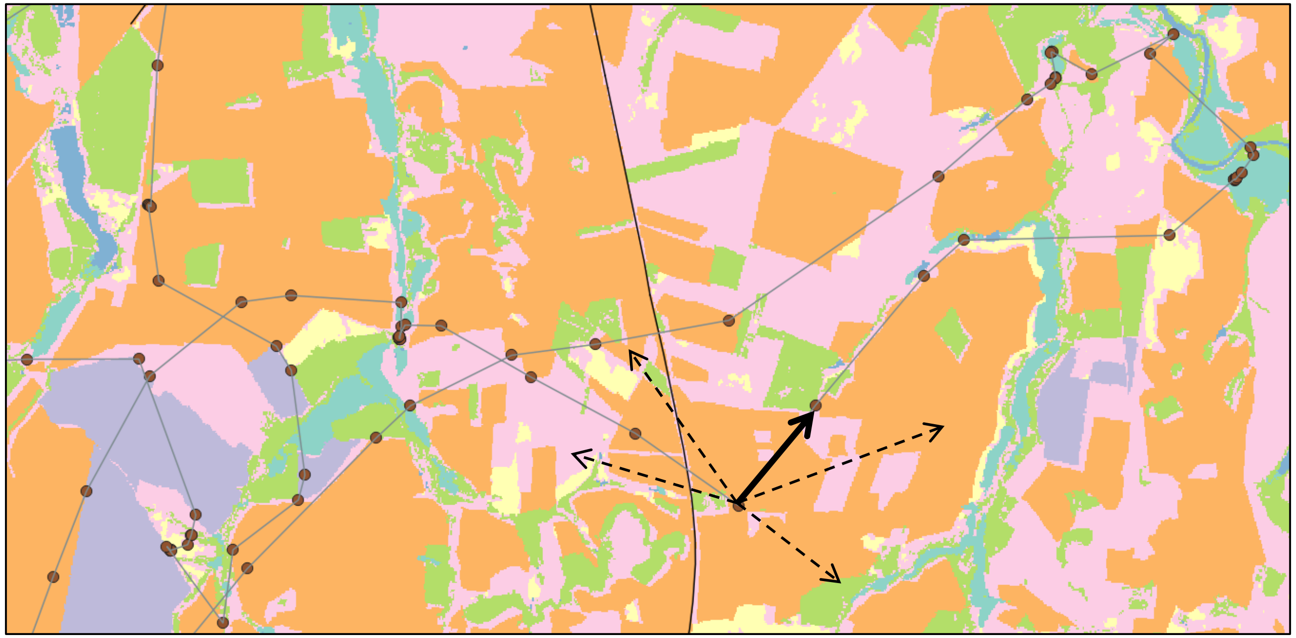


We are generally interested in the conditions at the **end point** of the step

Resource selection process

Step selection functions (SSF)





The issue: movement and resource selection are not independent

iSSA: integrated step-selection analysis

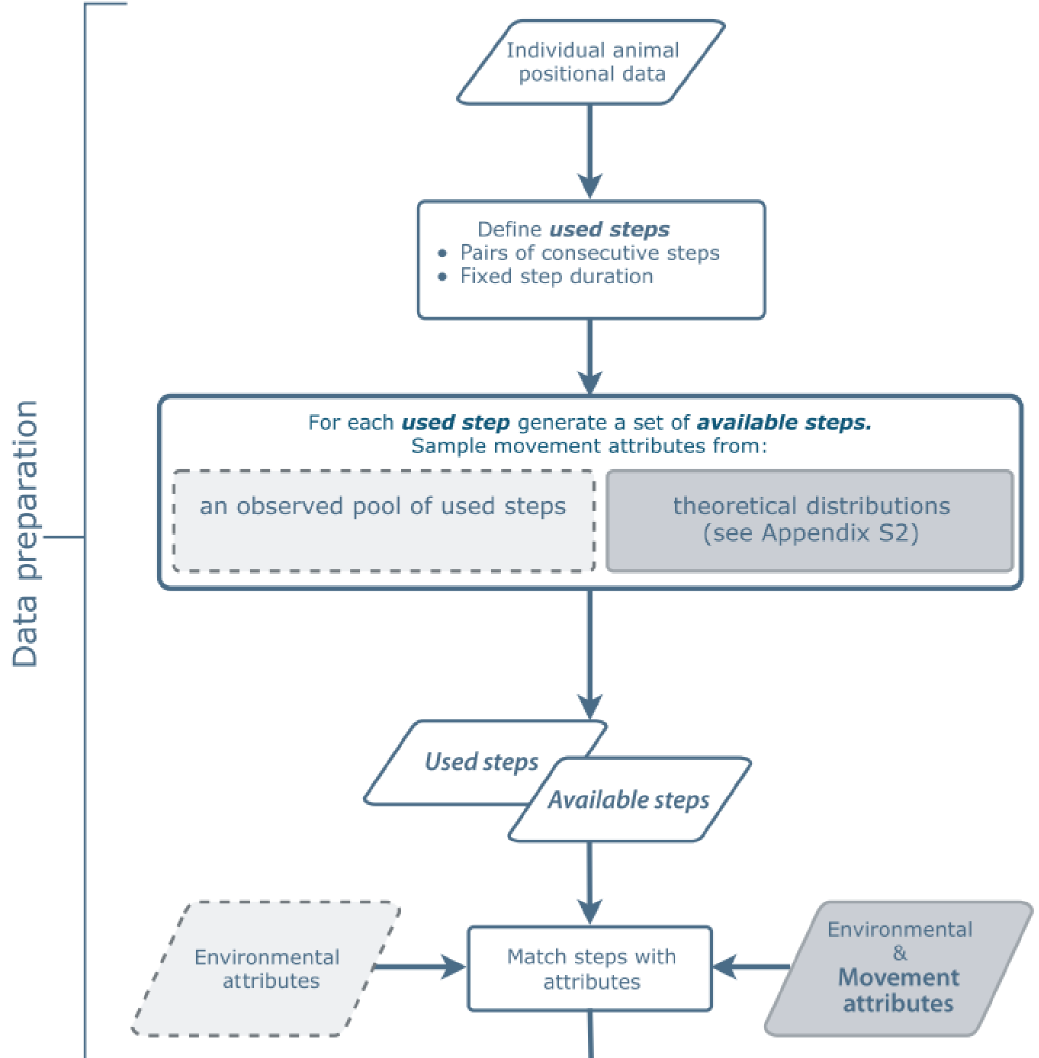
i-Step selection functions (iSSF)

mechanistic habitat-mediated
movement model

habitat-independent distributions of
step lengths and turning angles

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis



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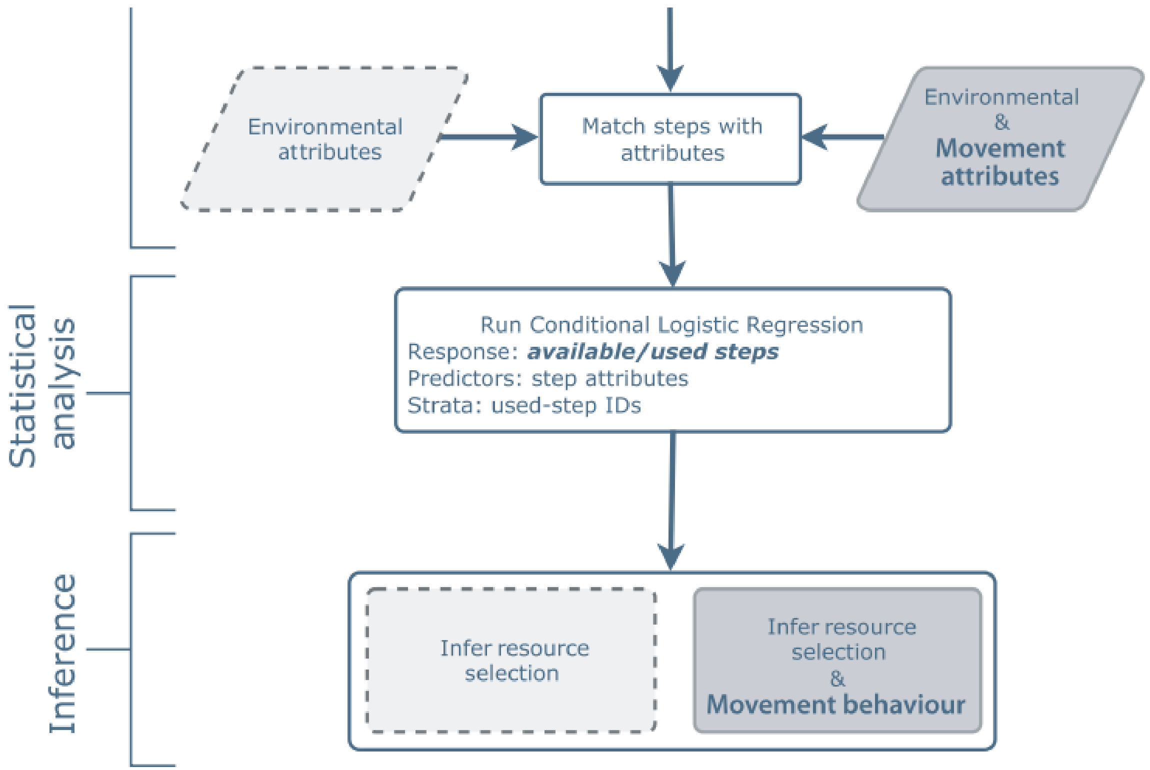

- Long- and short- term target prioritization
- Barrier crossing and avoidance behaviour
- Interactions with conspecifics and intraspecifics

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

An example

We are modelling the movement and habitat selection according to habitat quality and time of the day:

- *h* is habitat quality covariate (continuous)
- *D* is the time of the day (day/night)

Response variable:

- Use-availability (binary, 1/0) set

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

An example

(use-ava)
y ~

$$\prod_{t=3}^{T} \frac{\exp[b_3 \cdot h(x_t) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha_t) + b_6 \cdot l_t + (b_7 + b_8 \cdot D_t) \cdot \ln(l_t)]}{\sum_{i=0}^{s} \exp[b_3 \cdot h(x'_{t,i}) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha'_{t,i}) + b_6 \cdot l'_{t,i} + (b_7 + b_8 \cdot D_t) \cdot \ln(l'_{t,i})]}$$

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

An example

selection for
habitat

$$y \sim \prod_{t=3}^{T} \frac{\exp[b_3 \cdot h(x_t) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha_t) + b_6 \cdot l_t + (b_7 + b_8 \cdot D_t) \cdot \ln(l_t)]}{\sum_{i=0}^{s} \exp[b_3 \cdot h(x'_{t,i}) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha'_{t,i}) + b_6 \cdot l'_{t,i} + (b_7 + b_8 \cdot D_t) \cdot \ln(l'_{t,i})]}$$

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

An example

selection for habitat

Effects on movement

$$y \sim \prod_{t=3}^{T} \frac{\exp[b_3 \cdot h(x_t) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha_t) + b_6 \cdot l_t + (b_7 + b_8 \cdot D_t) \cdot \ln(l_t)]}{\sum_{i=0}^{s} \exp[b_3 \cdot h(x'_{t,i}) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha'_{t,i}) + b_6 \cdot l'_{t,i} + (b_7 + b_8 \cdot D_t) \cdot \ln(l'_{t,i})]}$$

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

An example

selection for habitat

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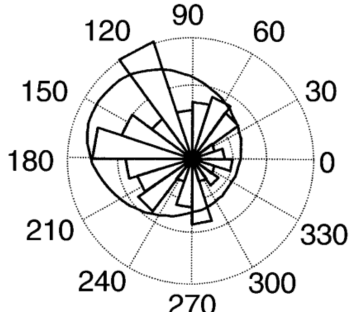
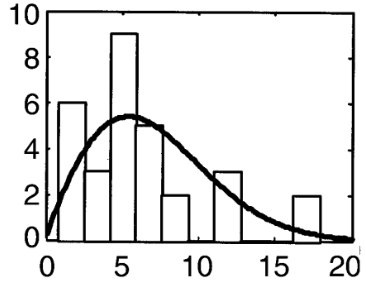


von Mises(μ, κ)



gamma (shape, scale)

Avgar et al. 2016 Meth. Ecol. Evol.

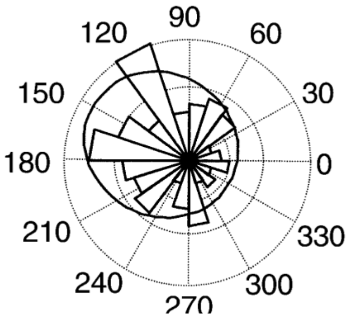
iSSA: integrated step-selection analysis

An example

selection for habitat

habitat-independent directional persistence

$$y \sim \prod_{t=3}^{T} \frac{\exp[b_3 \cdot h(x_t) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha_t) + b_6 \cdot l_t + (b_7 + b_8 \cdot D_t) \cdot \ln(l_t)]}{\sum_{i=0}^{s} \exp[b_3 \cdot h(x'_{t,i}) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha'_{t,i}) + b_6 \cdot l'_{t,i} + (b_7 + b_8 \cdot D_t) \cdot \ln(l'_{t,i})]}$$



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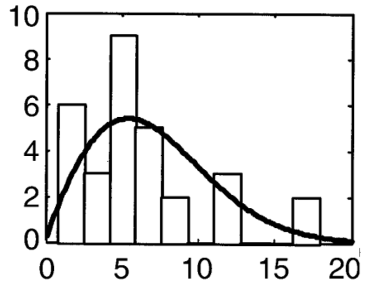


gamma (shape, scale)

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

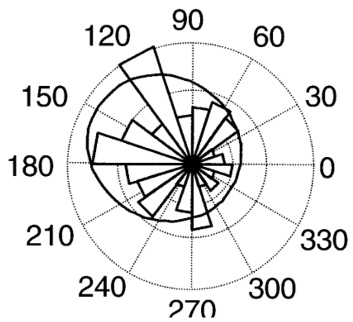
An example

selection for habitat

habitat-independent directional persistence

habitat-independent step length

$$y \sim \prod_{t=3}^{T} \frac{\exp[b_3 \cdot h(x_t) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha_t) + b_6 \cdot l_t + (b_7 + b_8 \cdot D_t) \cdot \ln(l_t)]}{\sum_{i=0}^{s} \exp[b_3 \cdot h(x'_{t,i}) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha'_{t,i}) + b_6 \cdot l'_{t,i} + (b_7 + b_8 \cdot D_t) \cdot \ln(l'_{t,i})]}$$



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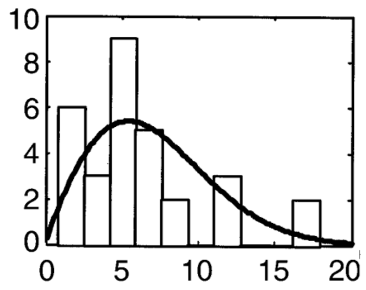


gamma (shape, scale)

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

An example

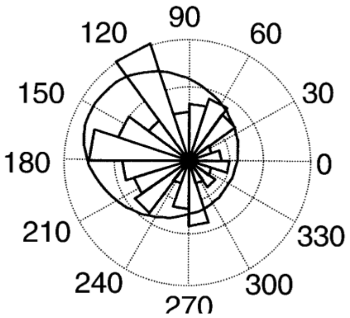
selection for habitat

habitat-independent directional persistence

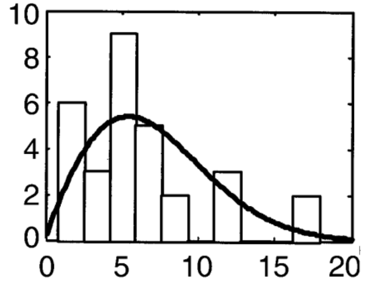
habitat-independent step length

$$y \sim \prod_{t=3}^{T} \frac{\exp[b_3 \cdot h(x_t) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha_t) + b_6 \cdot l_t + (b_7 + b_8 \cdot D_t) \cdot \ln(l_t)]}{\sum_{i=0}^{s} \exp[b_3 \cdot h(x'_{t,i}) + [b_4 + b_5 \cdot y(x_{t-1})] \cdot \cos(\alpha_{t-1} - \alpha'_{t,i}) + b_6 \cdot l'_{t,i} + (b_7 + b_8 \cdot D_t) \cdot \ln(l'_{t,i})]}$$

step length varies along the day



von Mises(μ, κ)



gamma (shape, scale)

Avgar et al. 2016 Meth. Ecol. Evol.

iSSA: integrated step-selection analysis

A real example

Journal of Applied Ecology

BRITISH ECOLOGICAL SOCIETY

Journal of Applied Ecology 2017, **54,** 470–479 doi: 10.1111/1365-2664.12768

Characterizing wildlife behavioural responses to roads using integrated step selection analysis

Christina M. Prokopenko*, Mark S. Boyce and Tal Avgar

Cervus elaphus

Prokopenko et al. 2016 J. Appl. Ecol.

iSSA: integrated step-selection analysis

Core model

Habitat selection terms

y ~ elevation (end point) + NDVI (end point):*TimeofDay* + $NDVI^2$ +

TimeofDay:ln*StepLength* (start point) +

*SnowDepth:*ln*Step Length* (start point) +

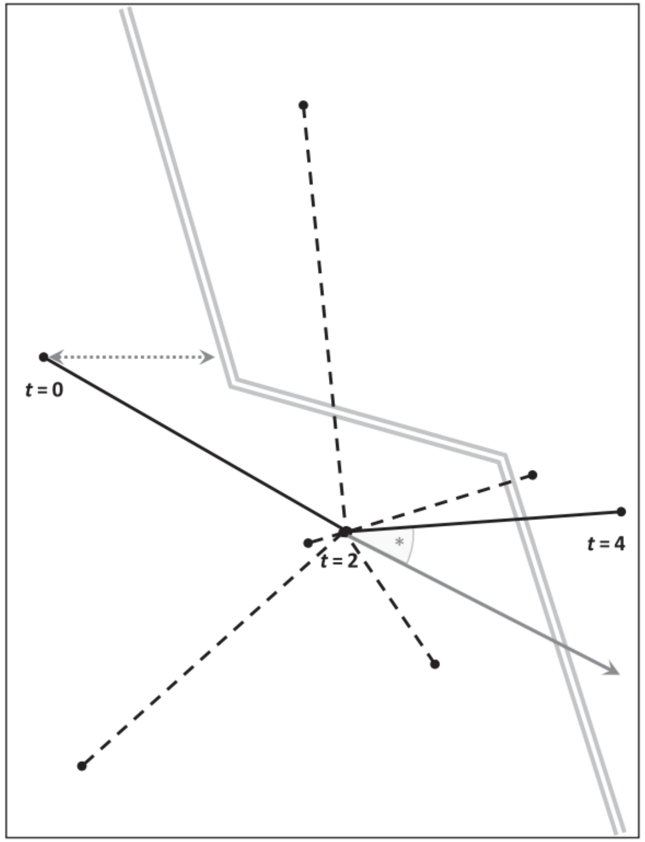
cos*TurnAngle* (start point)

Movement parameters

Prokopenko et al. 2016 J. Appl. Ecol.

iSSA: integrated step-selection analysis

Hypotheses



Model	Road covariates	Minimum AIC tally
1. Influence of road proximity on selection	Core Model + ln*RoadDist* (end point): *TimeOfDay*	63
2. Influence of road crossing on movement	Core Model + *RoadCros*: *TimeOfDay*	25
3. Influence of road proximity on cover selection and movement	Core Model + ln*RoadDist* (start point): NDVI (end point) + ln*RoadDist* (start point): ln*StepLength*	15
4. Influence of road crossing on cover selection and movement	Core Model + *RoadCros*: NDVI (end point) + *RoadCros*: ln*StepLength*	30

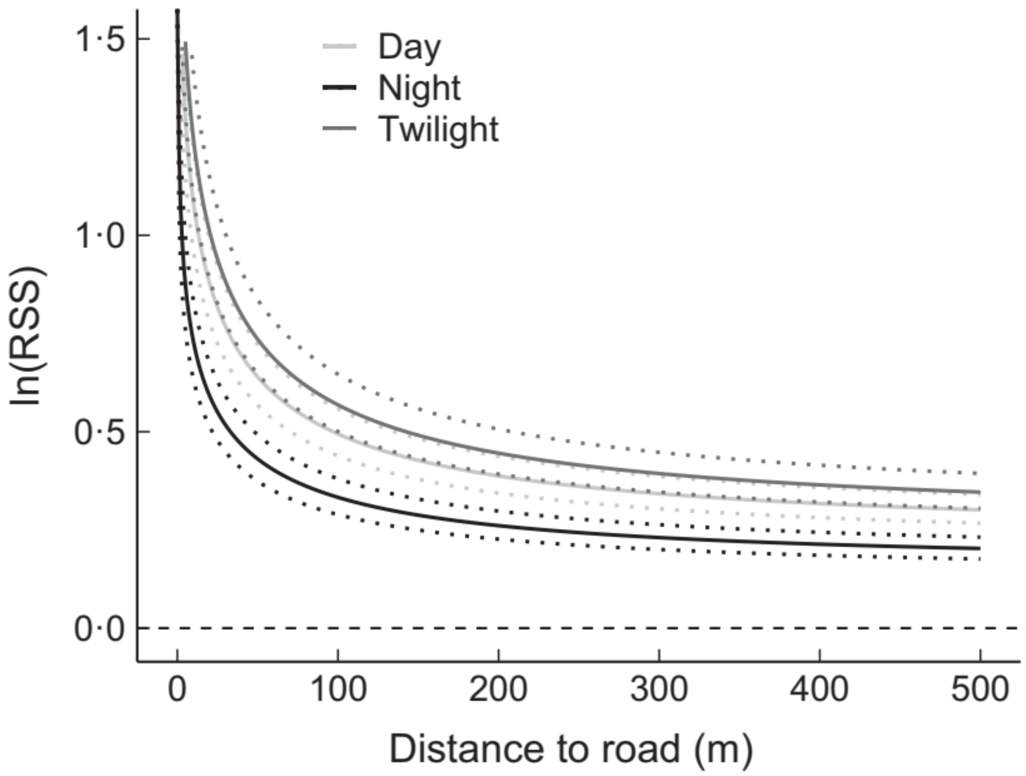
direct effects

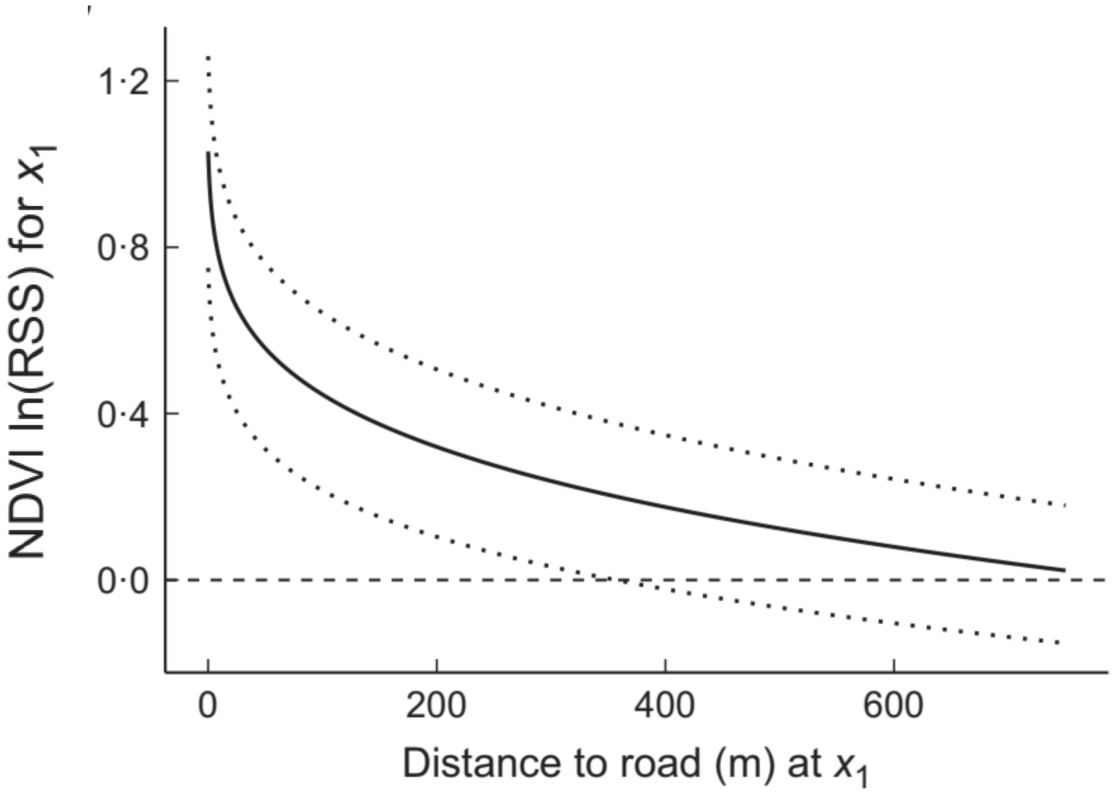
indirect effects

Prokopenko et al. 2016 J. Appl. Ecol.

iSSA: integrated step-selection analysis

avoidance





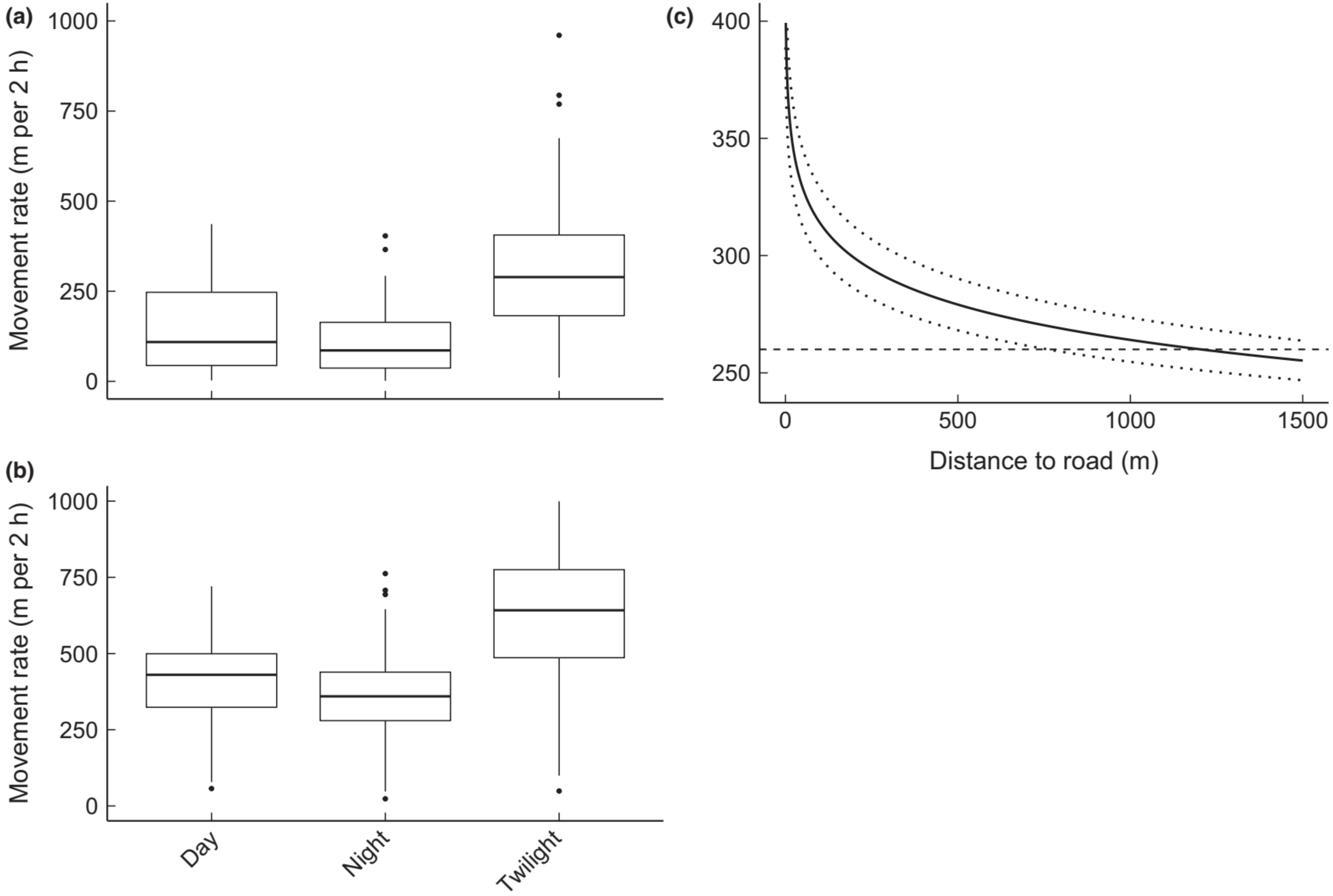
“RSS of location x_1 over x_2 ($NDVI_{x_2}$ = 20%, $NDVI_{x_1}$ = 50%) “

Prokopenko et al. 2016 J. Appl. Ecol.

iSSA: integrated step-selection analysis

1 km from road

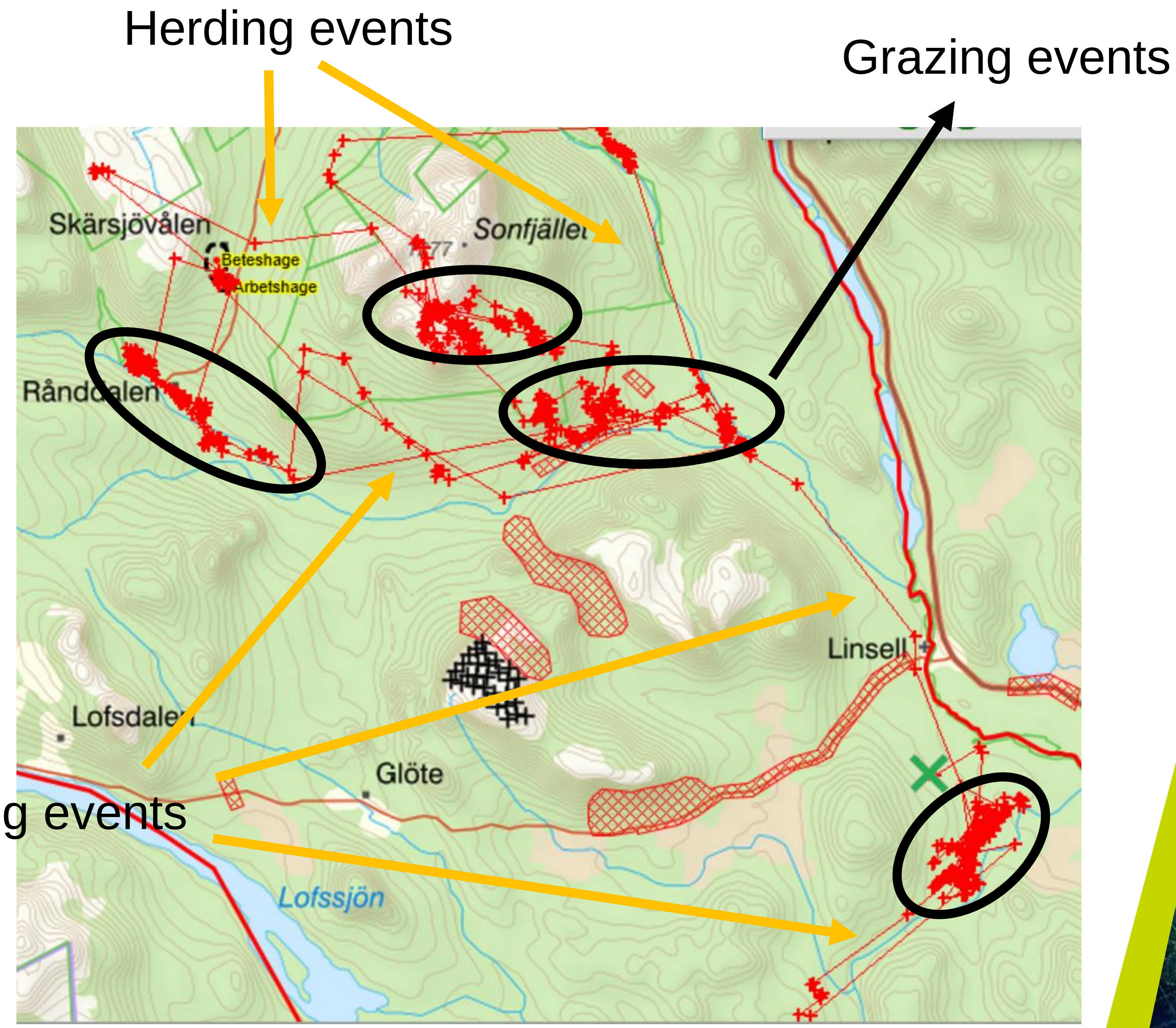
1 m from road



ko et al. 2016 J. Appl. Ecol.

For reindeer…

SSA or iSSA are interesting approaches



For reindeer… in winter:

- Reindeer prefer lichen areas, forested areas
- Reindeer avoid wind farms and roads
- Reindeer avoid less WF in bad winter conditions
- Reindeer avoid less WF and roads when predators are abundant
- Reindeer move faster and closer to WF and roads with predators
- Reindeer cross roads more often with predators
- Reindeer cross roads more after the construction of the wind farm
- Reindeer move slower with snow

For reindeer… in snow-free season:

- Calving: Reindeer avoid wind farms and roads
- Calving: Reindeer move faster close to and in sight of WF and close to roads
- Calving: Reindeer move faster and avoid less WF and roads when the abundance of predators (bears?) is high
- Summer: Reindeer avoid less WF and roads because of insect harassment in forested areas
- Summer: Reindeer move faster close to and in sight of WF and close to roads (may less fast than during calving?)
- Autumn: … ?

Thank you for you attention!
Tack så mycket!
Obrigado!

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SCIENCE AND EDUCATION FOR SUSTAINABLE LIFE