Multiple Animals

Johannes Signer & Brian Smith

January 2022

Why should we care?

- Most telemetry studies consist of many animals.
- Often individual behave very differently (and we can fully account for these differences in a model).
- We are often interested in population-level effects.

How-to account for individual differences

1. ~~Ignore individuals and fit data to all animals.~~
2. Fit an individual model for each individual.
3. Use a mixed-model strategy.

Resource Selection Function

- Global availability (unmatched)
- (weighted) Logistic regression[1]

Step-Selection Function

- Availability conditioned on current position (matched)
- Conditional logistic regression

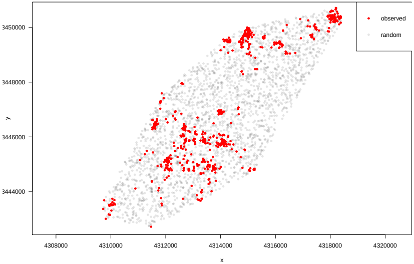
[1] Fithian & Hastie. "Finite-sample equivalence in statistical models for presence-only data." The annals of applied statistics 7.4 (2013): 1917.

Resource Selection Function

- Global availability (unmatched)
- (weighted) Logistic regression[1]

Step-Selection Function

- Availability conditioned on current position (matched)
- Conditional logistic regression



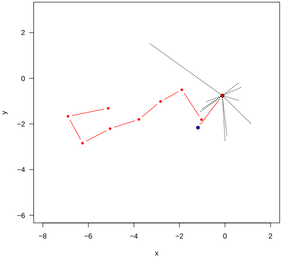
[1] Fithian & Hastie. "Finite-sample equivalence in statistical models for presence-only data." The annals of applied statistics 7.4 (2013): 1917.

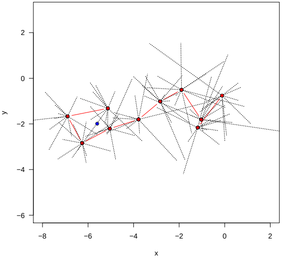
Resource Selection Function

- Global availability (unmatched)
- (weighted) Logistic regression[1]

Step-Selection Function

- Availability conditioned on current position (matched)
- Conditional logistic regression





[1] Fithian & Hastie. "Finite-sample equivalence in statistical models for presence-only data." The annals of applied statistics 7.4 (2013): 1917.

2. Fit an individual model for each individual.

- A somewhat naive approach could be, to fit to each individual animal the model of interests (e.g., a SSF or an iSSF).
- In a next step we can then "do statistics" with the coefficients of the individual model. For example, we could
  - calculate the mean and confidence intervals to obtain population level effects, or
  - use a linear models to relate coefficient values to other explanatory covariates.
- A difficulty is if we have extreme observations or some levels of a categorical covariate is not observed for all animals.

There are different programming strategies, how one could approach such a situation:

a. ~~Write customized code for each individual.~~

b. Use some kind of looping structure (for example a `for`-loop).

c. Use a nest-unnest approach, as we have seen previously (for example with the `purrr` package).

An example of this approach was used in Signer et al. 2019

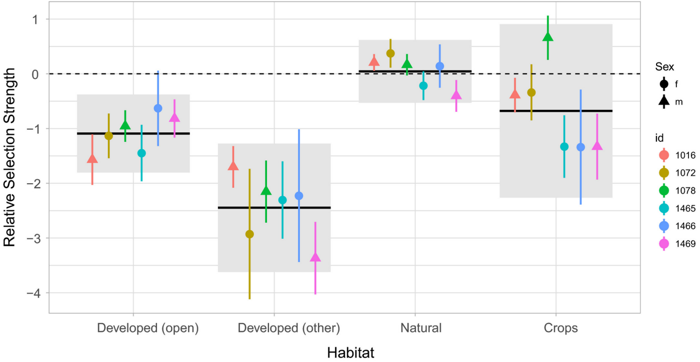


Figure 1: Source Signer et al. 2019

3. Use a mixed-model strategy.

- For HSF this is *relatively* straight forward. We can make use of well established tools that were developed for GLMMs.
- For iSSFs this is slightly more challenging. We have to use a likelihood equivalent reformulation of the iSSF as a poisson regression with random effects for each strata with a fixed large variance.

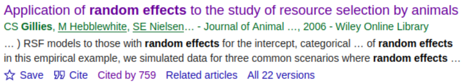
Random effects for HSFs

- Random effects were proposed for HSFs over 15 years ago[2]

[2] Gillies et al. "Application of random effects to the study of resource selection by animals." Journal of Animal Ecology 75.4 (2006): 887-898.

Random effects for HSFs

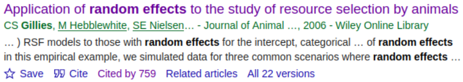
- Random effects were proposed for HSFs over 15 years ago[2]



[2] Gillies et al. "Application of random effects to the study of resource selection by animals." Journal of Animal Ecology 75.4 (2006): 887-898.

Random effects for HSFs

- Random effects were proposed for HSFs over 15 years ago[2]


Application of **random effects** to the study of resource selection by animals
CS **Gillies**, M Hebblewhite, SE Nielsen… - Journal of Animal …, 2006 - Wiley Online Library
…) RSF models to those with **random effects** for the intercept, categorical … of **random effects** in this empirical example, we simulated data for three common scenarios where **random effects** …
Save Cite Cited by 759 Related articles All 22 versions

- Majority of studies between 2016 and 2020 (80 %) only include random intercept and no random slope(s).

[2] Gillies et al. "Application of random effects to the study of resource selection by animals." Journal of Animal Ecology 75.4 (2006): 887-898.

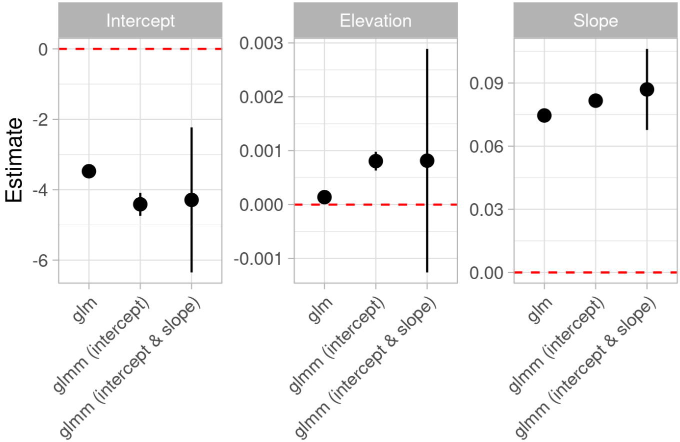
- Data on habitat selection of Mountain Goats[3]
- Generalized linear model with binomial response (GLM), random intercept (GLMM 1), and random intercept and slopes (GLMM 2).

[3] Lele & Keim, (2006) Weighted distributions and estimation of resource selection probability functions. Ecology 87, 3021–3028.

Let us fit three models to tracking data from wild goats:

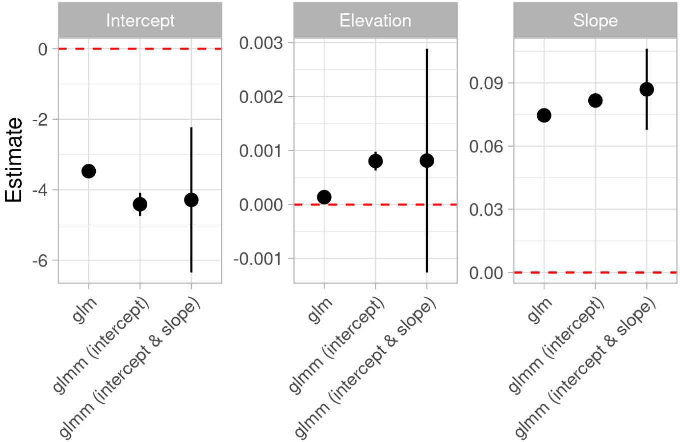
```r
# This is a naive approach (ignoring different animals)
m1 <- glmmTMB(STATUS ~ ELEVATION + SLOPE,
              data = goats, family = binomial())

# This is the random intercept model
m2 <- glmmTMB(STATUS ~ ELEVATION + SLOPE + (1 | ID),
              data = goats, family = binomial())

# This is a random slope and intercept model
m3 <- glmmTMB(STATUS ~ ELEVATION + SLOPE +
                (ELEVATION + SLOPE | ID),
              data = goats, family = binomial())
```

Comparing the model coefficients:



[4] Schielzeth, & Forstmeier. "Conclusions beyond support: overconfident estimates in mixed models." Behavioral Ecology 20.2 (2008): 416-420.

Comparing the model coefficients:



For RSF use random intercept **and** random slope(s)[4].

[4] Schielzeth, & Forstmeier. "Conclusions beyond support: overconfident estimates in mixed models." Behavioral Ecology 20.2 (2008): 416-420.

Accounting for animal-specific variation (SSF)

Conditional logistic regression with random effects is more difficult

$$\mathrm{P}(y_{ntj} = 1 \,|\, \boldsymbol{x}_{nt\cdot}) = \pi_{ntj} = \frac{\exp(\beta^\top \boldsymbol{x}_{ntj})}{\sum_{j=1}^{J} \exp(\beta^\top \boldsymbol{x}_{nti})}$$

- $n = 1, \ldots, N$ individuals, with realized steps,
- time points $t = 1, \ldots, T_n$, with
- $j = 1, \ldots, J_{n,t}$ location that were either used or available.

- The conditional logistic regression is a special case of the multinomial model.
- The multinomial model is likelihood-equivalent to the Poisson model.
- Thus we can rewrite to conditional logistic regression as a Poisson regression.

SSF as poisson model

Reformulation as Poisson model[5] [6]

$$E(y_{nti}) = \mu_{nti} = \exp(\alpha_{nt} + \boldsymbol{\beta}^\top \boldsymbol{x}_{nti} + \boldsymbol{u}^\top \boldsymbol{z}_{nti}) \ , \quad y_{nti} \sim \mathrm{Po}(\mu_{nti})$$

- $\alpha_{nt} \sim N(0, \sigma_\alpha^2)$ are the stratum specific intercepts with σ_α^2 being fixed at a very large value.
- $\boldsymbol{\beta}^\top \boldsymbol{x}_{nti}$ are the selection coefficients and the design matrix, respectively.
- $\boldsymbol{u}^\top \boldsymbol{z}_{nti}$ specify the random effect structure.

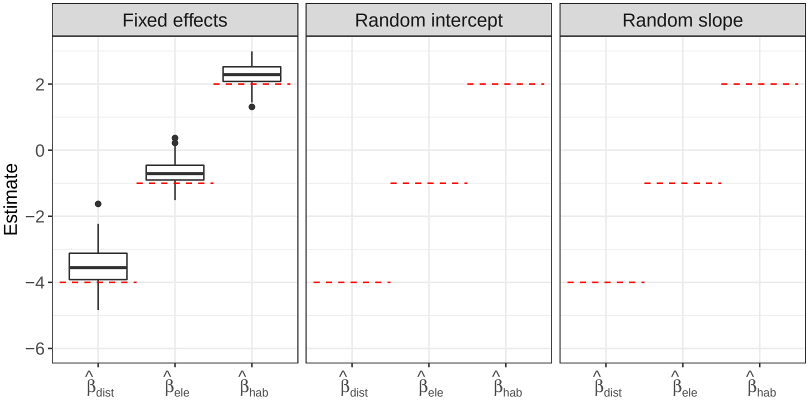
[5] Armstrong et al. "Conditional Poisson models: a flexible alternative to conditional logistic case cross-over analysis." BMC medical research methodology 14.1 (2014): 122.

[6] Muff, S., et al. "Accounting for individual-specific variation in habitat-selection studies: Efficient estimation of mixed-effects models using Bayesian or frequentist computation". Journal of Animal Ecology, (2020): 89(1), 80-92.

Simulation study from Muff et al. 2020

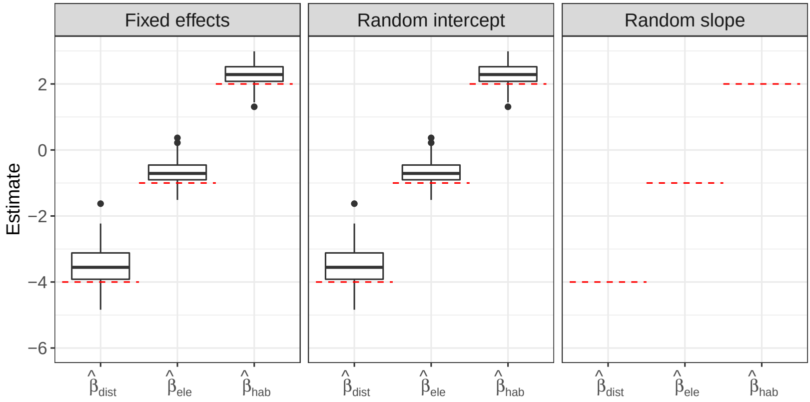
- Simulation of movement for 20 animals with animal-specific selection coefficients.
- For RSFs sample random points within the availability domain
- For SSFs sample random steps from each location

Results HSF



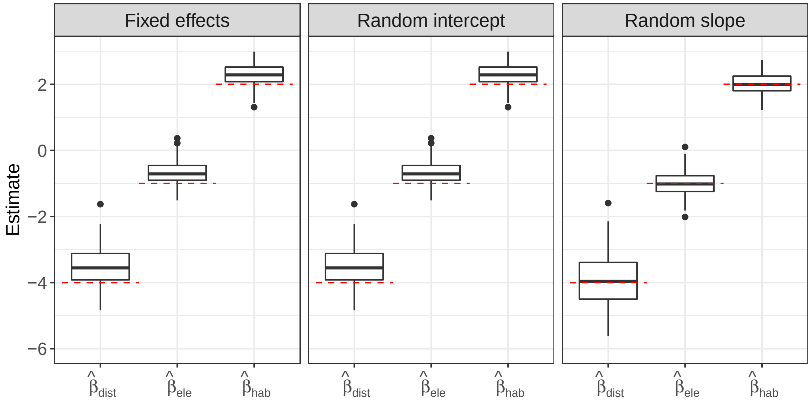
Fixed effects
Random intercept
Random slope
Estimate
2
0
−2
−4
−6
$\hat{\beta}_{dist}$
$\hat{\beta}_{ele}$
$\hat{\beta}_{hab}$
$\hat{\beta}_{dist}$
$\hat{\beta}_{ele}$
$\hat{\beta}_{hab}$
$\hat{\beta}_{dist}$
$\hat{\beta}_{ele}$
$\hat{\beta}_{hab}$

Results HSF



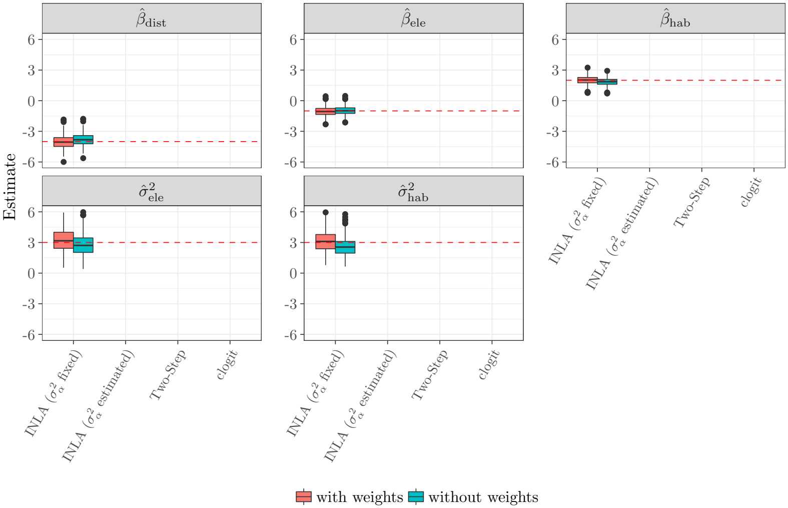
Fixed effects
Random intercept
Random slope
Estimate
2
0
−2
−4
−6
$\hat{\beta}_{dist}$
$\hat{\beta}_{ele}$
$\hat{\beta}_{hab}$
$\hat{\beta}_{dist}$
$\hat{\beta}_{ele}$
$\hat{\beta}_{hab}$
$\hat{\beta}_{dist}$
$\hat{\beta}_{ele}$
$\hat{\beta}_{hab}$

Results HSF



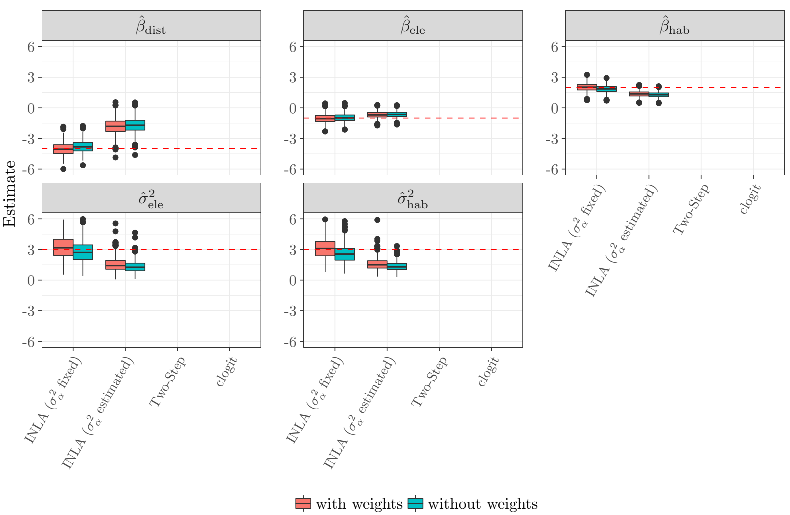
Fixed effects
Random intercept
Random slope
Estimate
2
0
−2
−4
−6
$\hat{\beta}_{dist}$
$\hat{\beta}_{ele}$
$\hat{\beta}_{hab}$

Results SSF



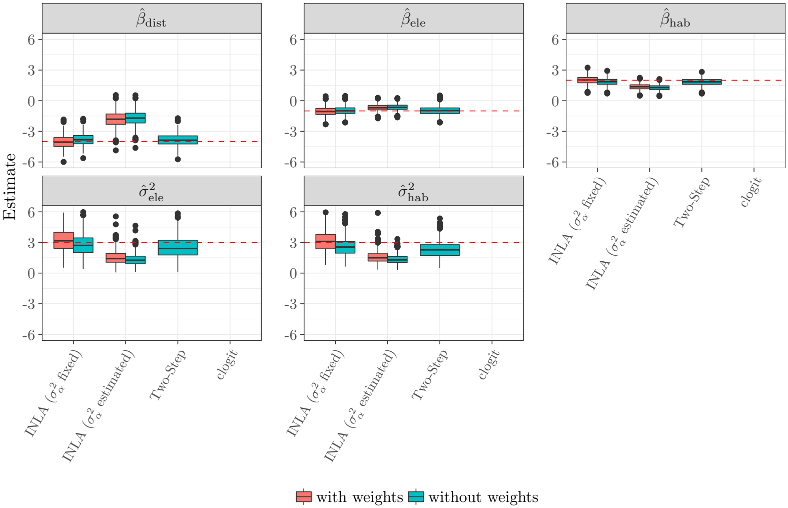
$\hat{\beta}_{\text{dist}}$
$\hat{\beta}_{\text{ele}}$
$\hat{\beta}_{\text{hab}}$
$\hat{\sigma}^2_{\text{ele}}$
$\hat{\sigma}^2_{\text{hab}}$
Estimate
6
3
0
-3
-6
INLA (σ^2_α fixed)
INLA (σ^2_α estimated)
Two-Step
clogit
with weights
without weights

Results SSF



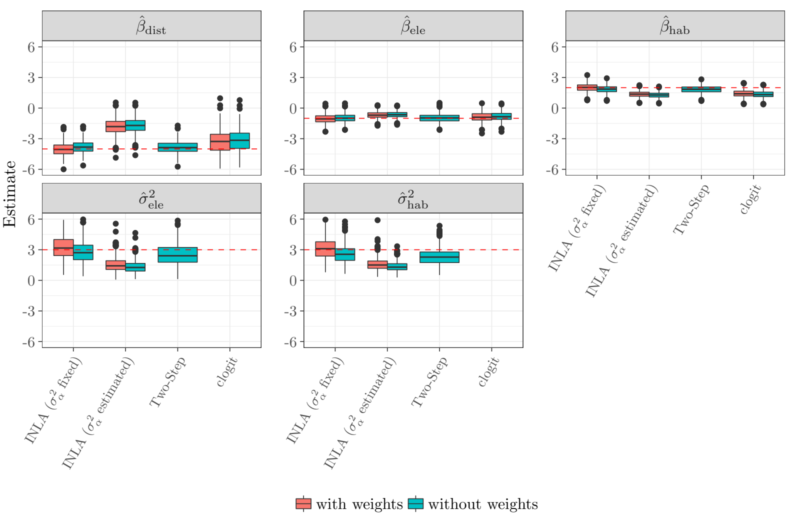
$\hat\beta_{\mathrm{dist}}$
$\hat\beta_{\mathrm{ele}}$
$\hat\beta_{\mathrm{hab}}$
$\hat\sigma^2_{\mathrm{ele}}$
$\hat\sigma^2_{\mathrm{hab}}$
Estimate
6
3
0
-3
-6
INLA (σ^2_α fixed)
INLA (σ^2_α estimated)
Two-Step
clogit
with weights
without weights

Results SSF



$\hat{\beta}_{\text{dist}}$
$\hat{\beta}_{\text{ele}}$
$\hat{\beta}_{\text{hab}}$
$\hat{\sigma}^2_{\text{ele}}$
$\hat{\sigma}^2_{\text{hab}}$
Estimate
6
3
0
-3
-6
INLA (σ^2_α fixed)
INLA (σ^2_α estimated)
Two-Step
clogit
with weights
without weights

Results SSF



$\hat{\beta}_{\text{dist}}$
$\hat{\beta}_{\text{ele}}$
$\hat{\beta}_{\text{hab}}$
$\hat{\sigma}^2_{\text{ele}}$
$\hat{\sigma}^2_{\text{hab}}$
Estimate
6
3
0
-3
-6
INLA (σ^2_α fixed)
INLA (σ^2_α estimated)
Two-Step
clogit
with weights
without weights

An example from Roshier et al. 2021

- This work I did together with David Roshier from Australian Wildlife Conservancy.
- I was only involved in the statistical modeling.

Received: 23 March 2021 | Revised: 31 May 2021 | Accepted: 3 June 2021
DOI: 10.1002/ece3.7810

ORIGINAL RESEARCH

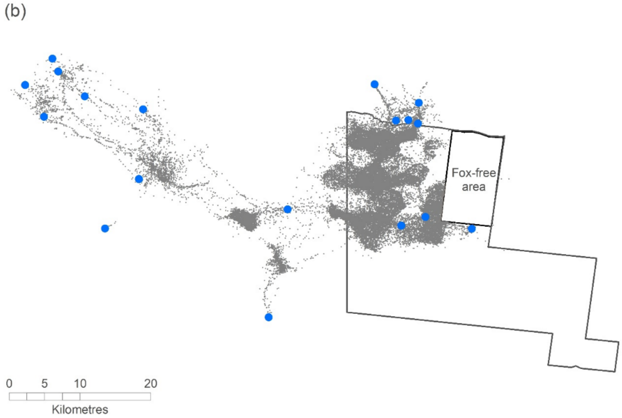
Ecology and Evolution Open Access WILEY

Visitation of artificial watering points by the red fox (*Vulpes vulpes*) in semiarid Australia

David A. Roshier[1,2] | Johannes Signer[3] | Andrew Carter[1,4]

Data

- Telemetry data for 22 individual foxes at 20 min sampling rate
- Location of water sources (in blue)



Analysis

1. Revisitation rates with the `recurse` package[1]
2. aKDE home ranges
3. integrated step selection analysis

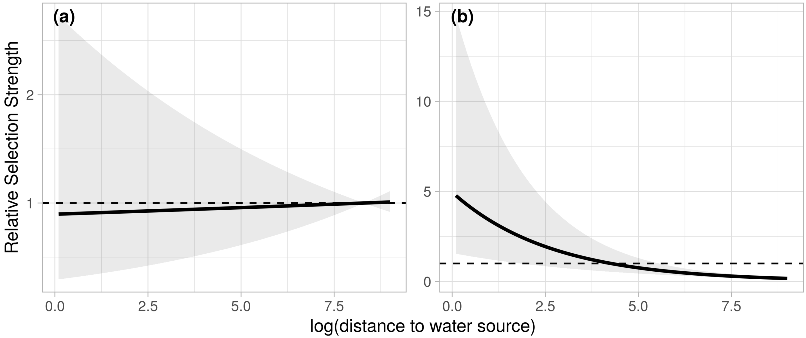
[1] Bracis, C., Bildstein, K. L., & Mueller, T. (2018). Revisitation analysis uncovers spatio-temporal patterns in animal movement data. Ecography, 41(11), 1801-1811.

Questions: iSSA

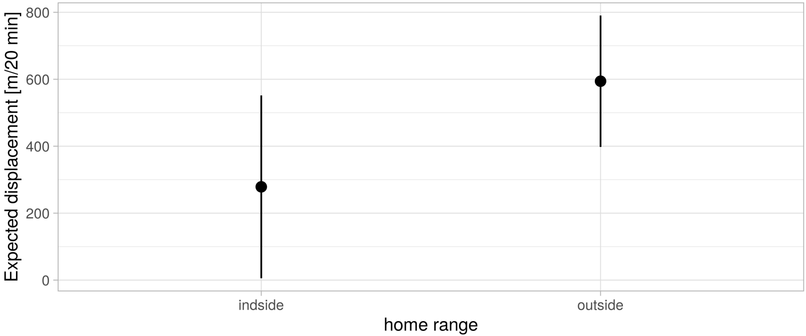
- Do foxes select for pixels closer to water sources?
- Does the selection depends on whether or not foxes are inside their home range?
- Do foxes move faster/slower when inside/outside their home range?

Habitat selection

Habitat selection of foxes inside (a) and outside (b) of their home range.



Expected displacement (i.e., how far do we expect a ‘typical’ fox to travel within a 20 minutes).



Key resources/publications

- Muff, S., Signer, J., & Fieberg, J. (2020). Accounting for individual-specific variation in habitat-selection studies: Efficient estimation of mixed-effects models using Bayesian or frequentist computation. Journal of Animal Ecology, 89(1), 80-92.
- Schielzeth, H., & Forstmeier, W. (2009). Conclusions beyond support: overconfident estimates in mixed models. Behavioral ecology, 20(2), 416-420.