Geospatial Share

Animal Movement Workshop

May 2024

https://github.com/swforrest/geospatial_share_animal_movement

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[4]CSIRO Environment

Photo: Scott Forrest

Acknowledgement of Traditional Owners

- QUT – Turrbal and Yugara
- Ngāi Tahu as Iwi of Otago where the kākā data was collected
- Central Arnhem Land, NT - Dalabon, Rembarrnga and Mayili
- Normanby and Archer River – Cape York, QLD – Balngarrawarra, Wik

Understanding and predicting animal movement

- Understanding where animals are and predicting where they will go is a cornerstone of ecology and management
  - threatened species
  - invasive species

MOVEBANK
for animal tracking data

Data Tools How to Archiving News

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Search Studies

Search Taxon Search [User manual]

Search terms

All Sensor Types

☐ Only studies where I can see data

Search

Search result

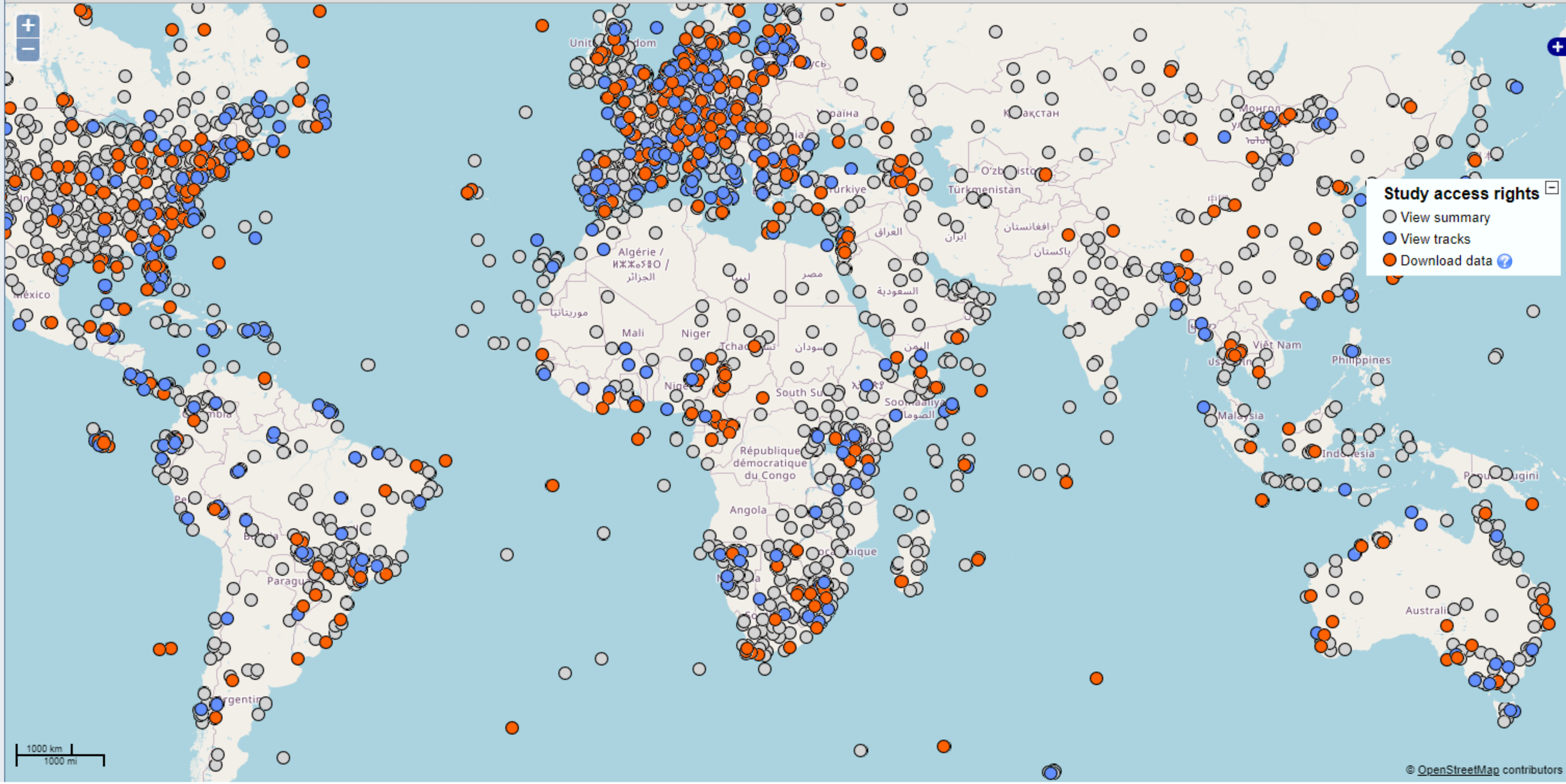
Sort by Animal Identifier

- Chelonia mydas_bijagos_females_2018
- Conservation
- migratory bird migration strategy
- "AEQUILIBRIUM+ Project": Diet of the mediterranean
- "Gulo gulo" Wind River wolverine study
- "KOUILOU-VOCIFER Project": Monitoring of the reintr
- "Oceanodroma castro" "Neves" "Azores"
- "Proyecto Eremita" Geronticus eremita Reintroduction
- "Proyecto Pennatus" Booted Eagle (Hieraaetus penna
- "Realzando el valor socioecológico de una especie en
- 'ATLAS [harod] [Pigeon] [2021]')
- (Bearded Vulture (Gypaetus barbatus), Pyrenees and
- (EBD) Anodorhynchus leari (Lear's Macaw)
- (EBD) Buteo buteo
- (EBD) Common Kestrel (Falco tinnunculus) Spain, ME

6.5 billion locations
7 billion other sensor records
8,285 studies
1,402 taxa
4,180 data owners

Search

Select Zoom Options Link Google Maps Open Layers



Movebank is coordinated by the Max Planck Institute of Animal Behavior, the North Carolina Museum of Natural Sciences, and the University of Konstanz.

MAX PLANCK INSTITUTE
OF ANIMAL BEHAVIOR

Animal movement – what drives it?

- external factors
  - resources
  - abiotic factors
  - other animals
- internal state
  - sex
  - age
  - memory
  - energetic status
  - breeding status

Nathan et al (2008)

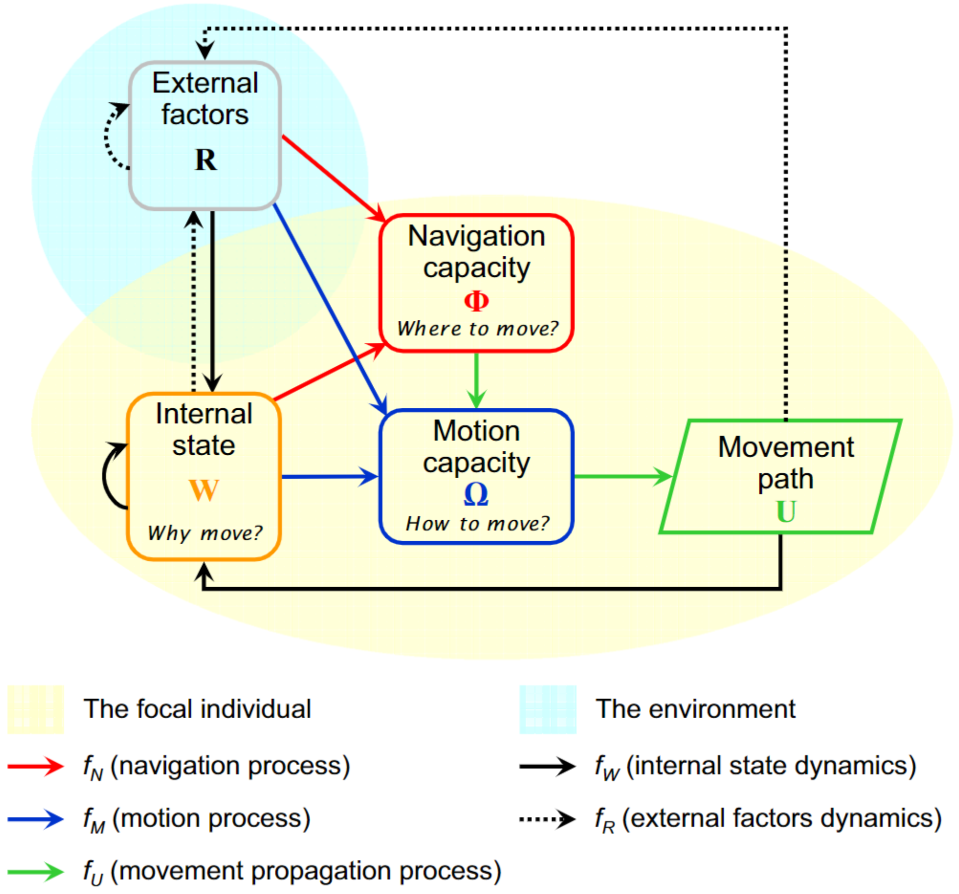
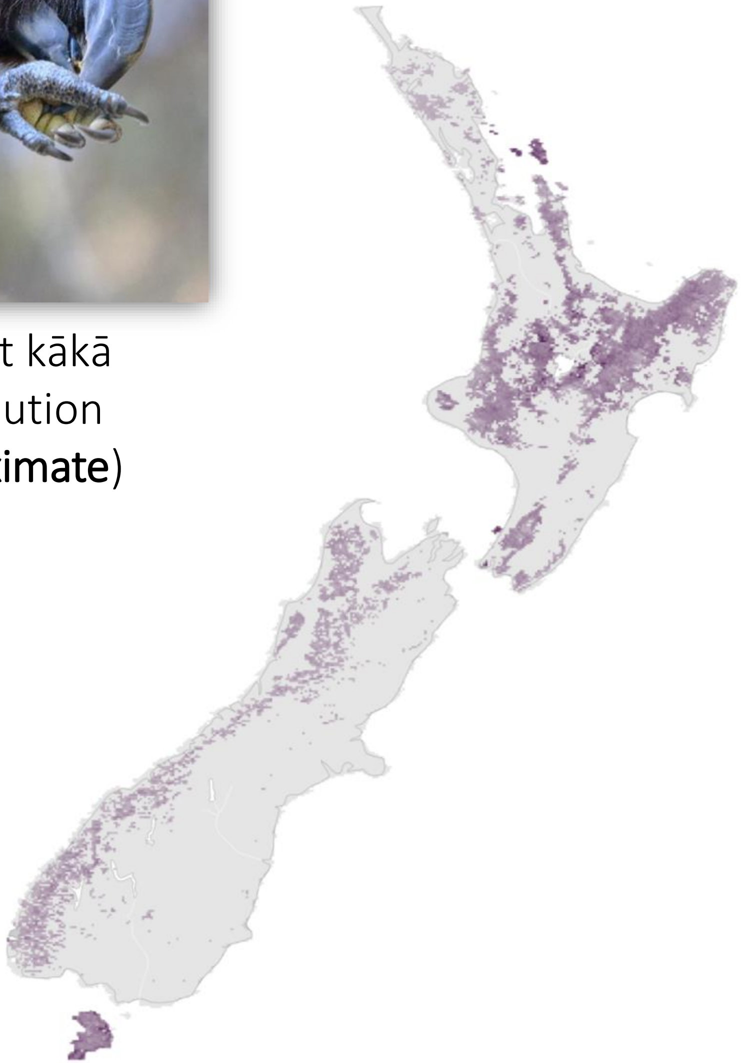


Photo: Scott Forrest

Kākā (*Nestor meridionalis*)



Current kākā Distribution (**approximate**)

Data provided by eBird

- South Island subspecies (*N. m. meridionalis*)
- 450 – 690g forest-dwelling parrot
- Nationally Vulnerable[1] (NZTCS)

- Require a high-level of pest control[2]
- Require large areas of forest[3]

[1]: *Kākā,* Department of Conservation, accessed 30th November 2020
[2]: Wilson, PR et. al (1998)
[3]: Leech, TJ, Gormley, AM, & Seddon, PJ (2008)

Tītipounamu Dave Curtis

Toutouwai Dave Curtis

Fence erected – 2007

Kākā translocated – 2008

Kākā banded since 2008:

~ 100

Kākā detectable from monitoring:

~ 40-50

Orokonui Ecosanctuary

GPS Tags

Lotek

https://www.lotek.com/products/pinpoint-gps-vhf/

- 10x PinPoint VHF 350

- SWIFT fixes
- 3-hour fix interval

- 1-minute activity data

Photo: Charlotte Patterson

GPS tags funded by:

DUNEDIN CITY COUNCIL kaunihera a-rohe o Ōtepoti

sity

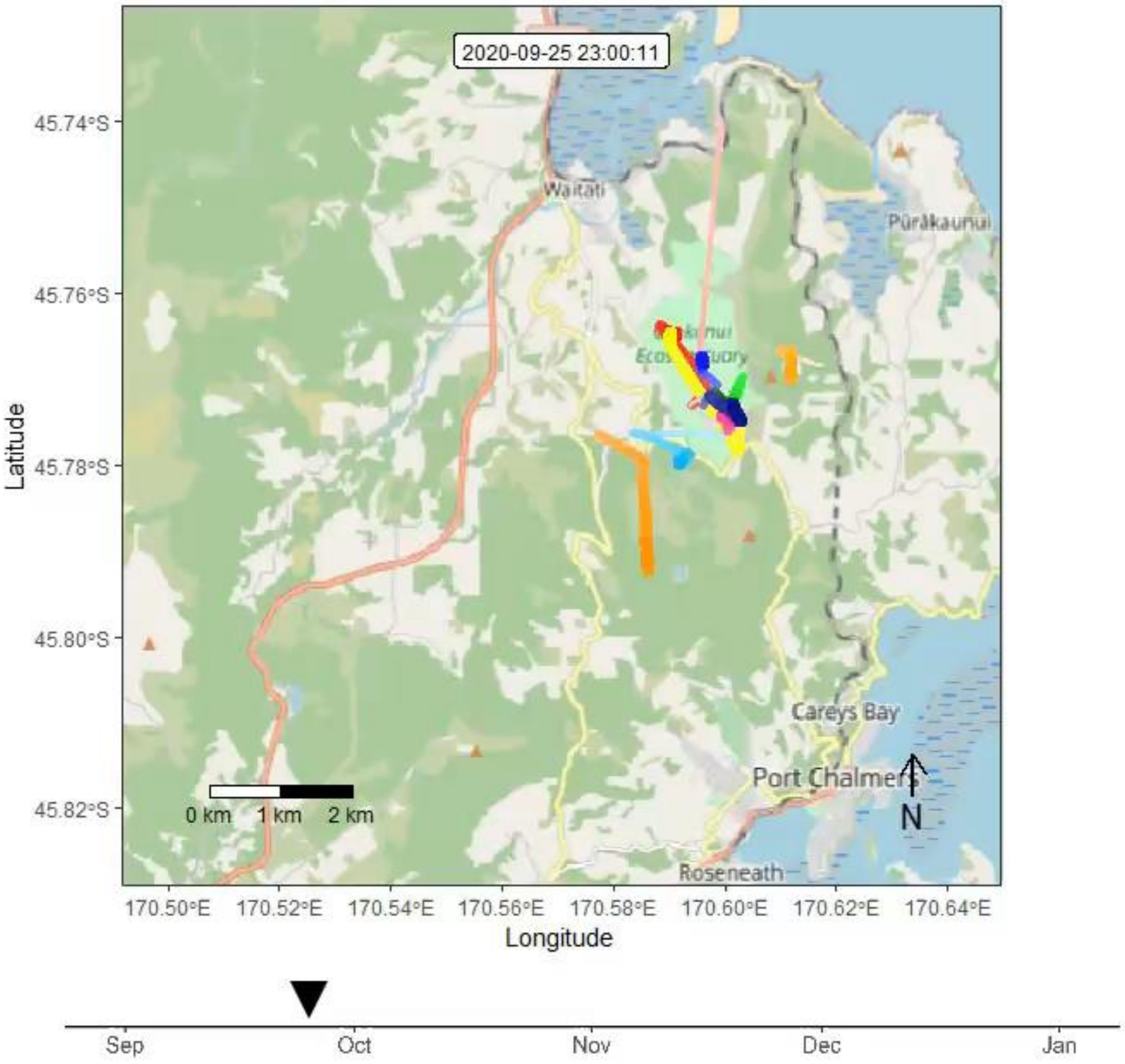
OSPRI

of Technology

HIGHCOUNTRY CONTRACTING EST.2014

QUT Centre for Data Science

CSIRO



Average days:

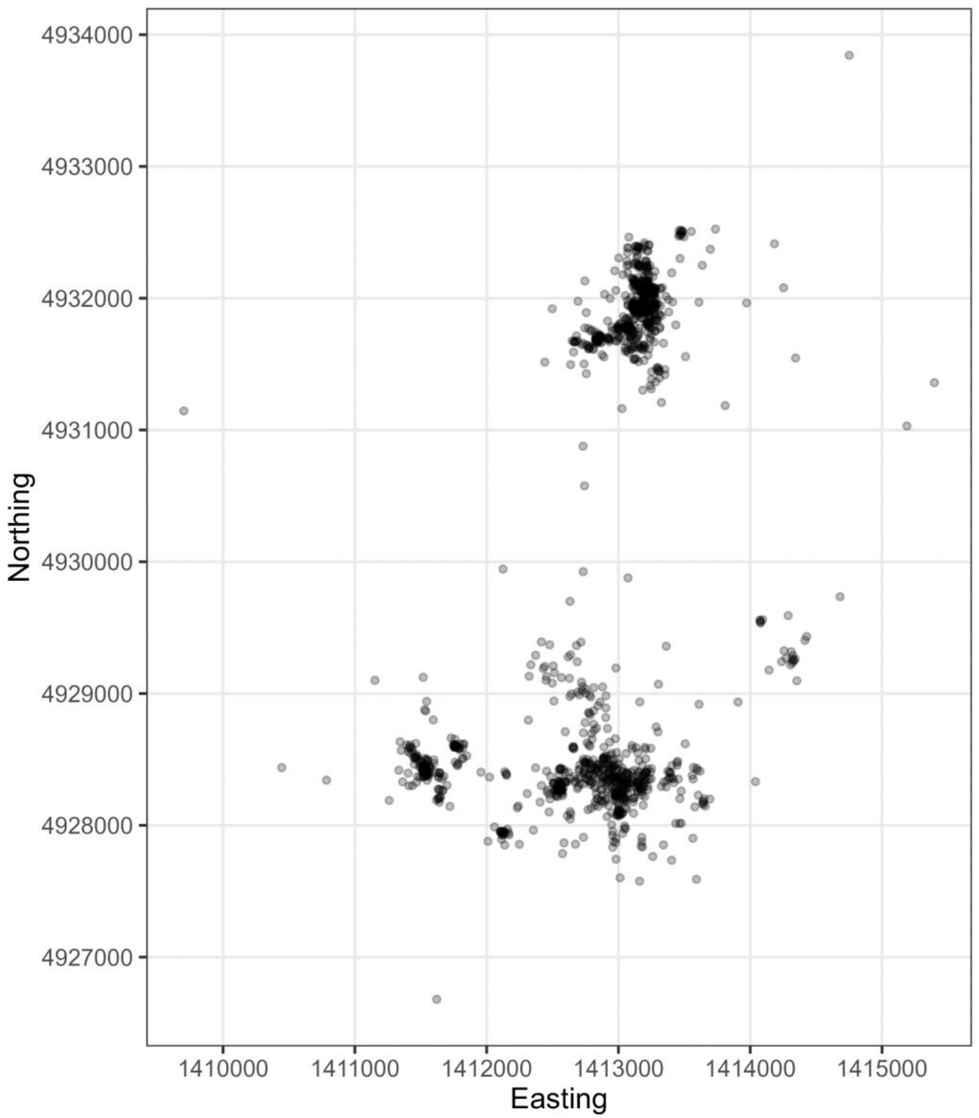
144 (range 111 - 163)

Successful fixes:

10,755

(13,590 attempted)

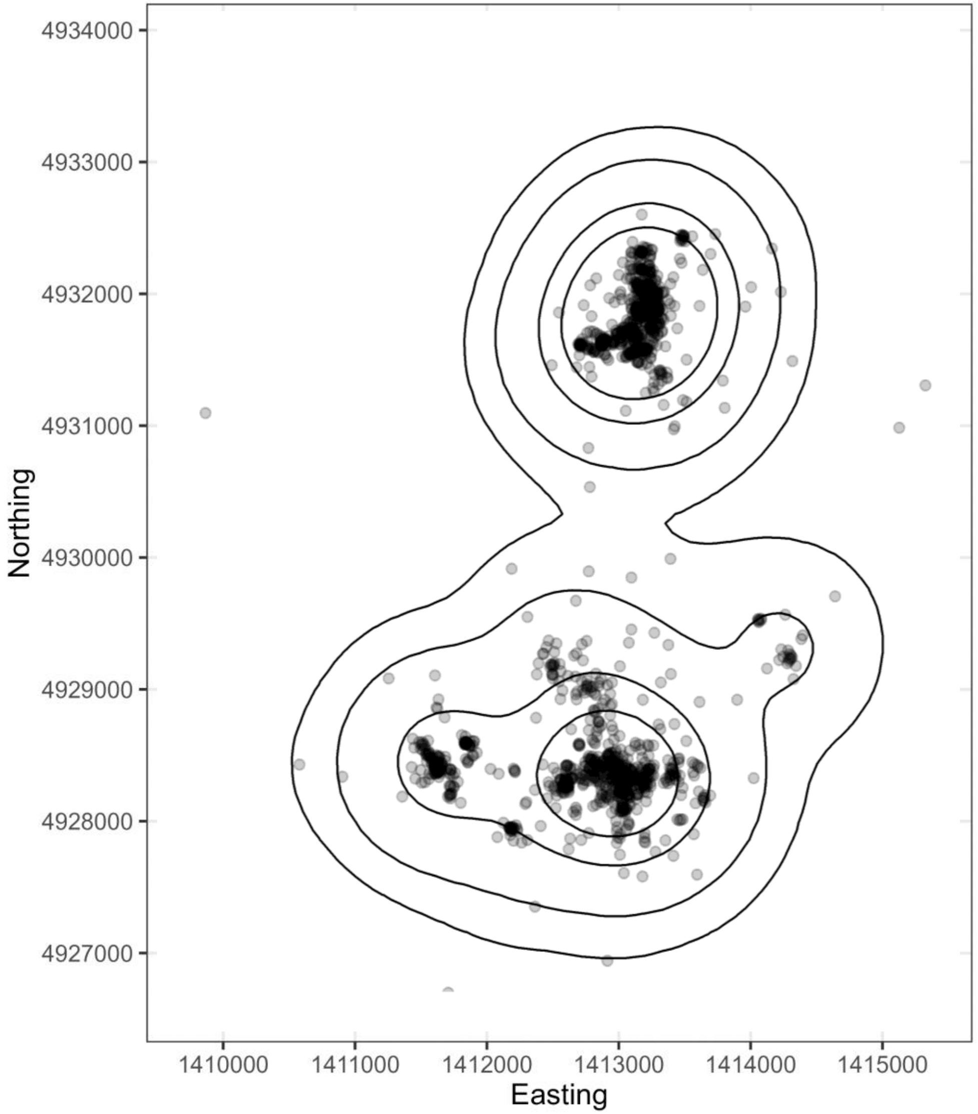
GPS data



Tag ID: 45505

GPS data

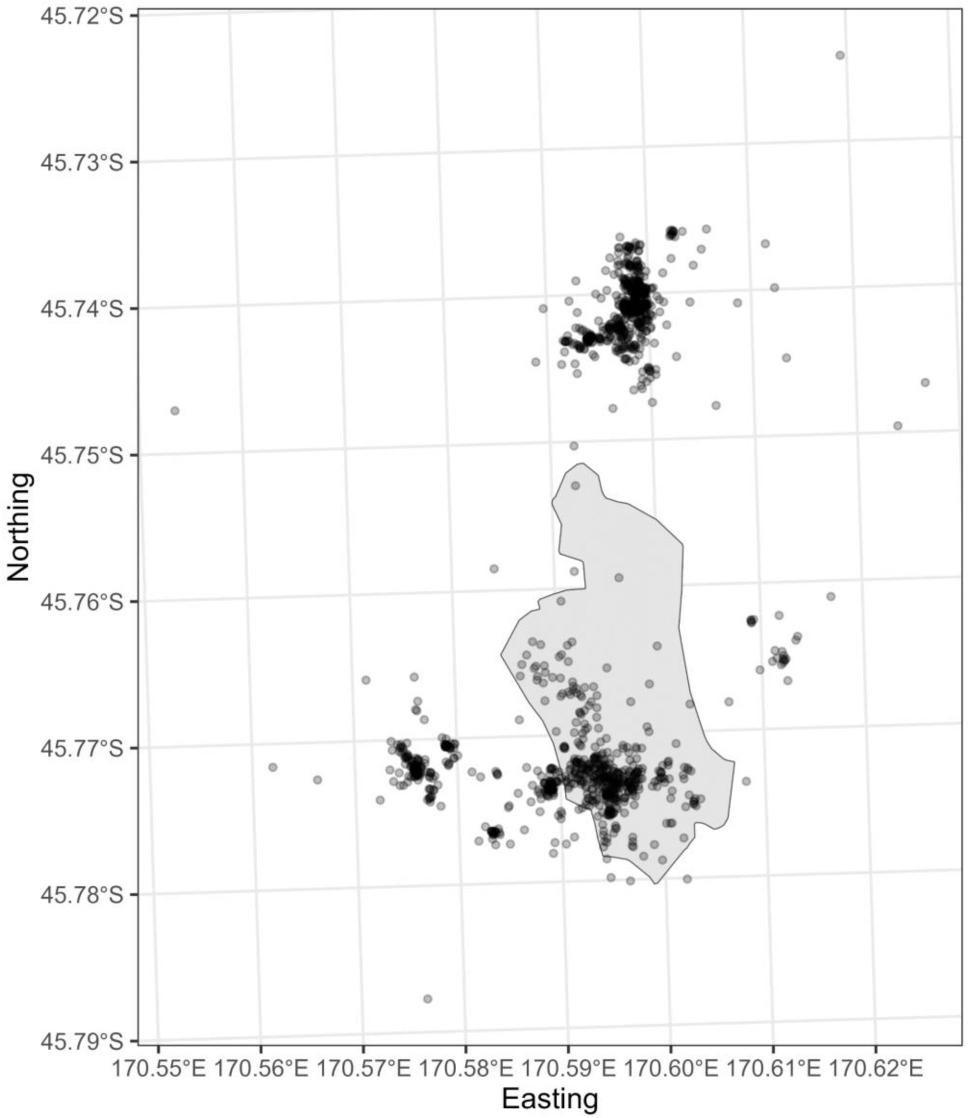
- **Where did the animal go?**



Tag ID: 45505

GPS data

- Where did the animal go?
  - what did it overlap with?



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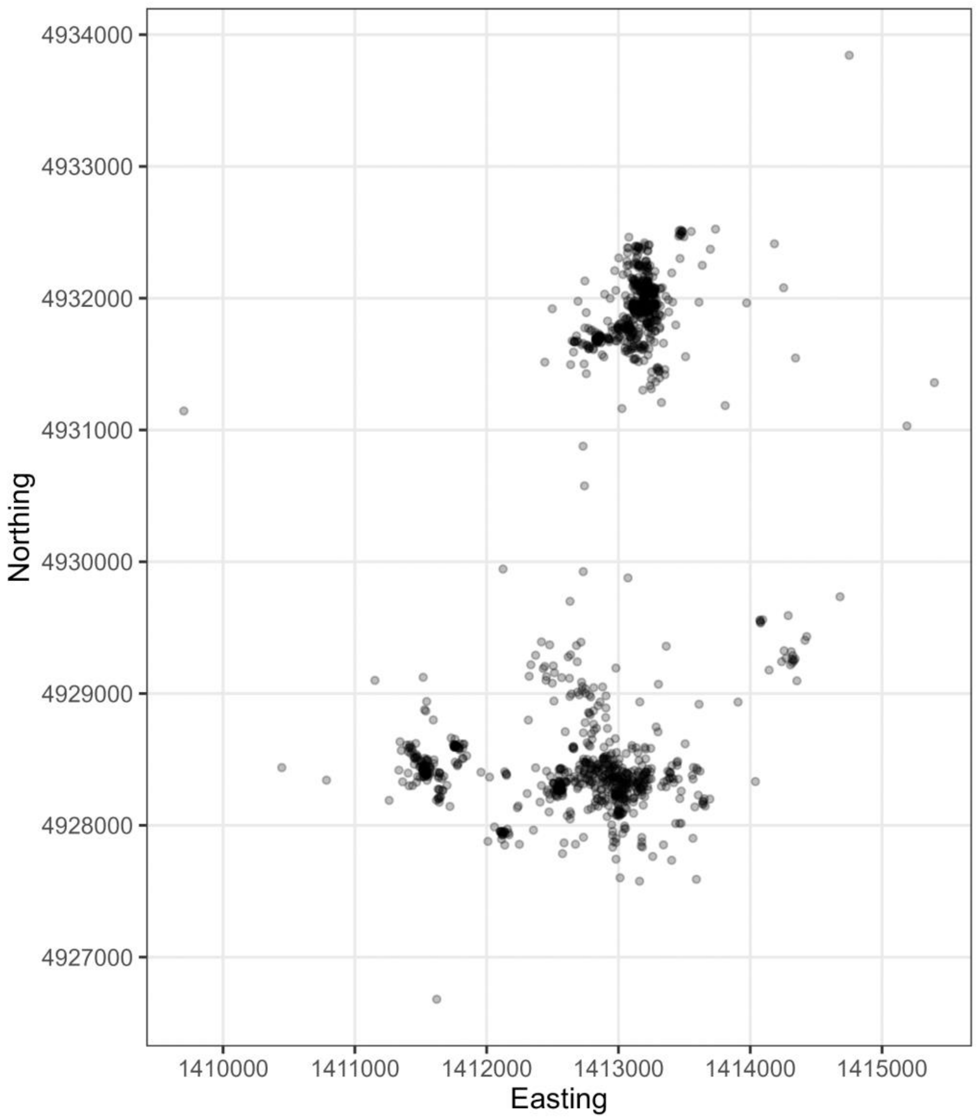
GPS data



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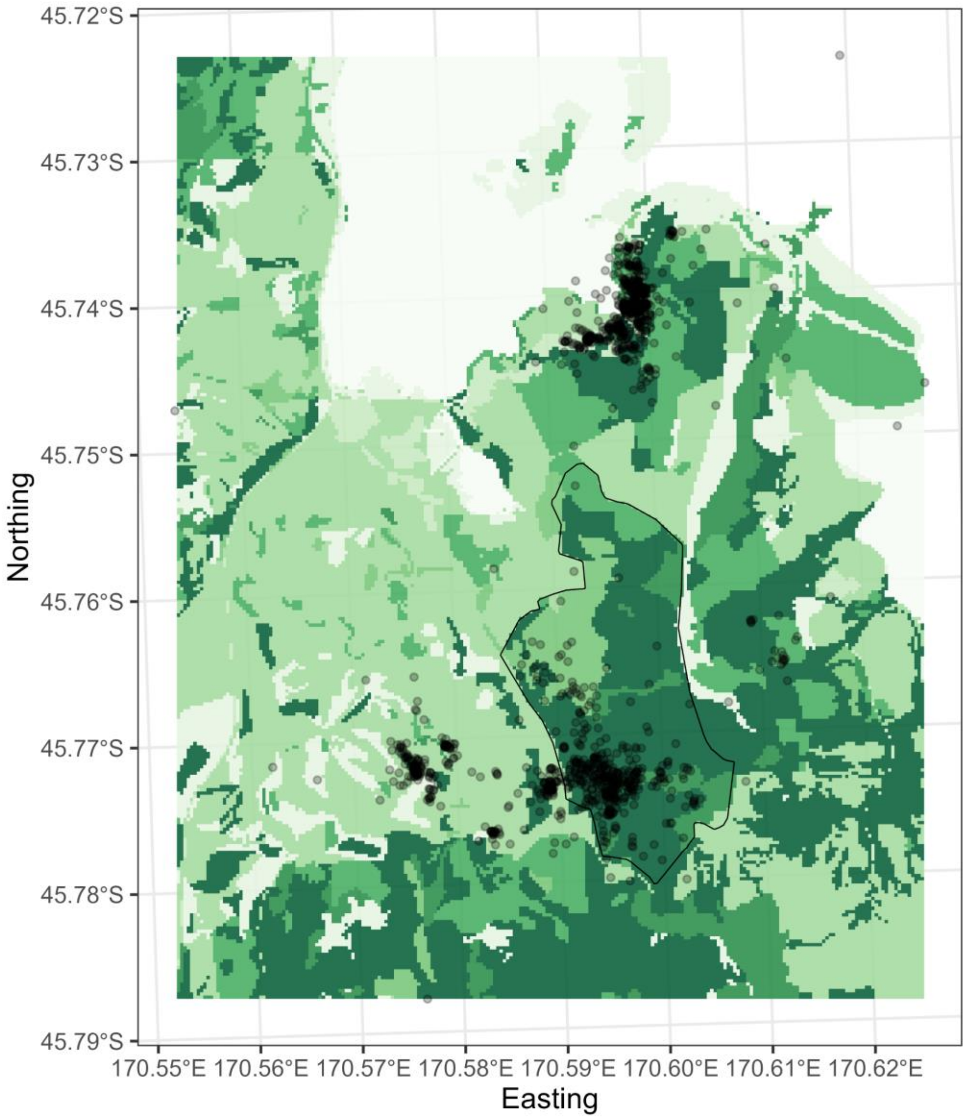
GPS data

- Why was the animal there?



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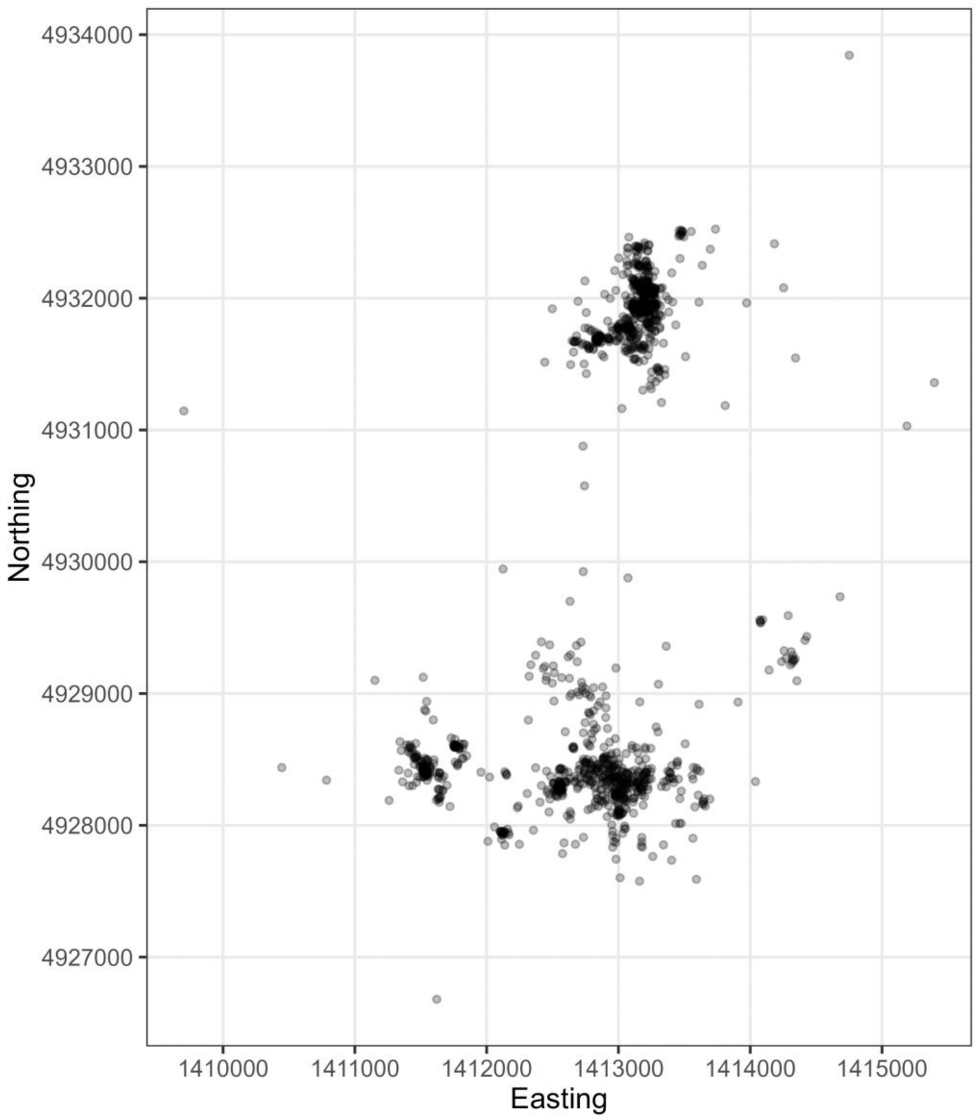

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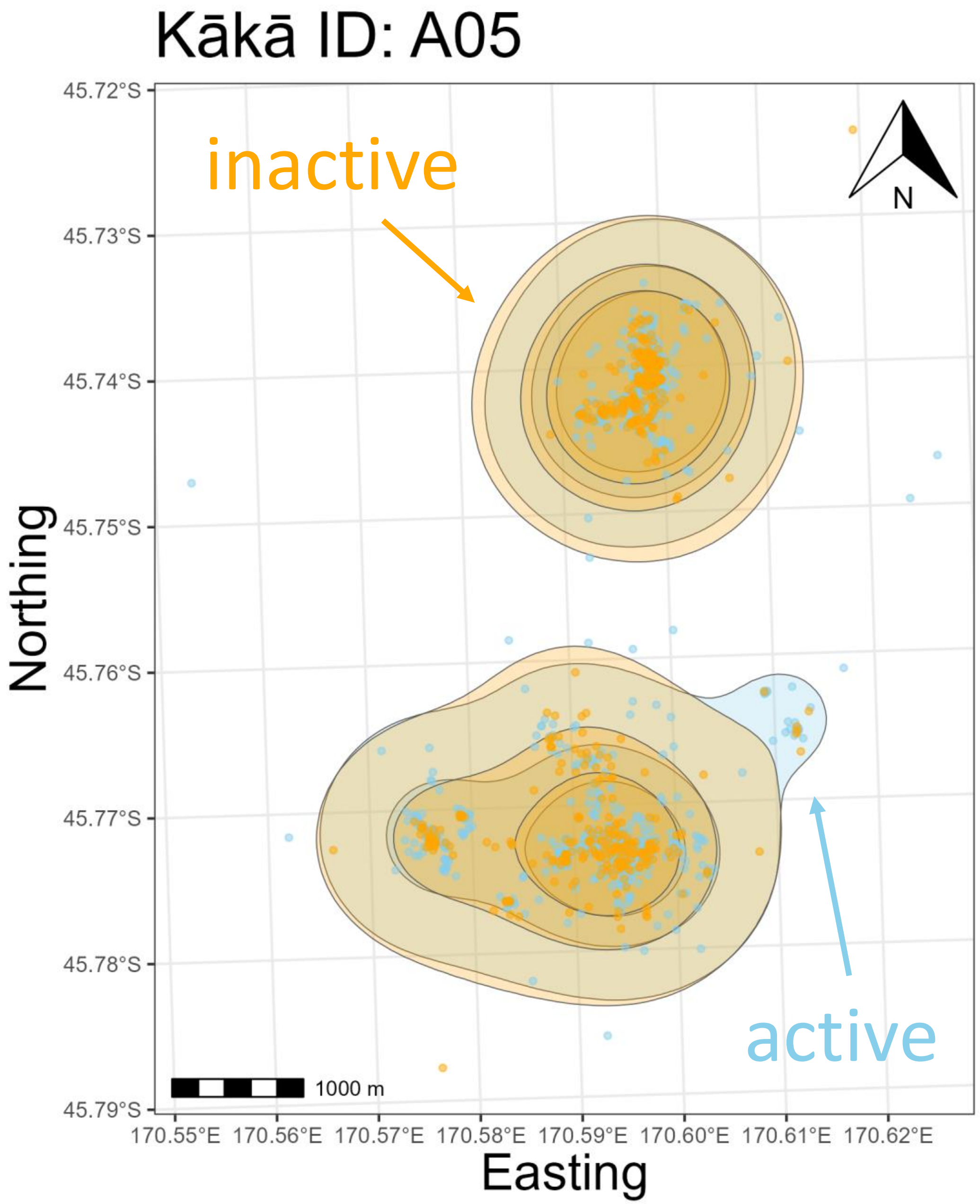
GPS data

- What was the animal doing?



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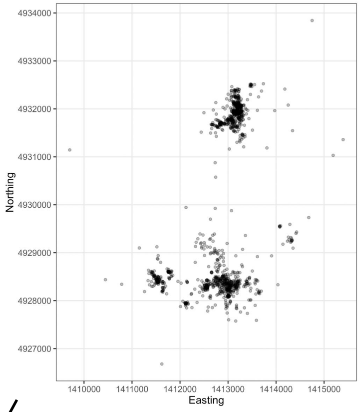
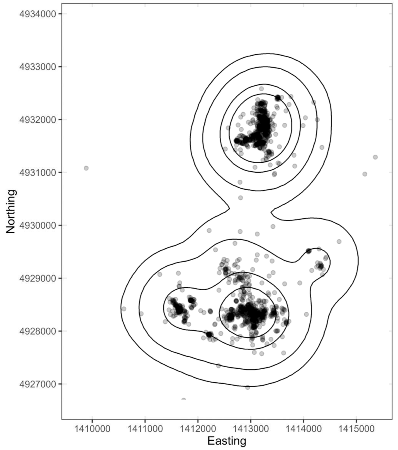
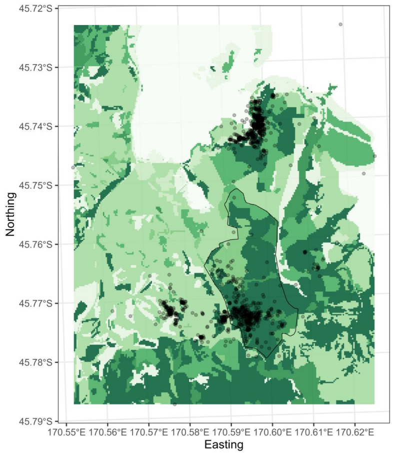
Some broad approaches to processing GPS data
(not mutually exclusive)

GPS data

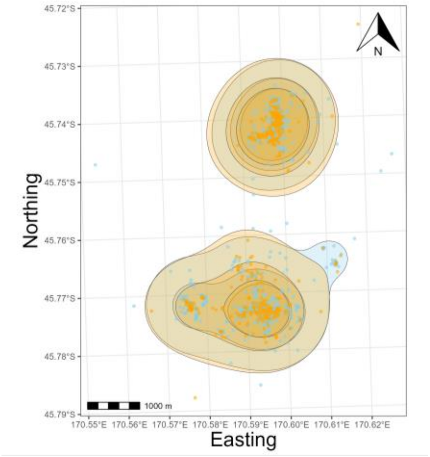




Space use analyses

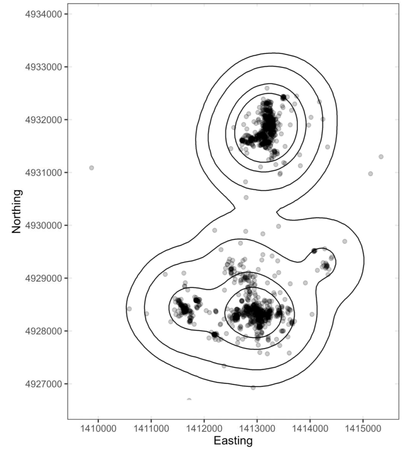


Habitat/resource selection analyses



Behavioural classification

Space use analyses



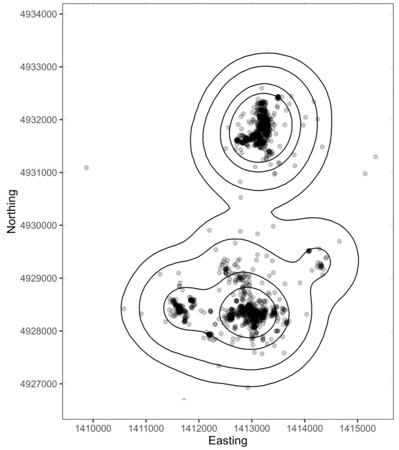
To quantify where an animal spent its time

- home range analyses (range distribution)
- where the animal was during the tracking period (occurrence distribution)
  - overlap with locations of interest (safety/risk, other individuals)

Some considerations

- GPS locations are typically correlated in space and time
- locations are not independent
- the animal travelled between the successive locations

Some common approaches and resources



Earlier approaches (assume 'independent' data)

- Kernel Density Estimation (KDE)
  - Worton, B. J. (1989). Kernel methods for estimating the utilization distribution in home-range studies. *Ecology*, *70*(1), 164–168. https://doi.org/10.2307/1938423
- Minimum Convex Polygons (MCP)

More recent approaches

- Brownian bridge approaches (BBMM and dBBMM)
  - Kranstauber, B., Kays, R., Lapoint, S. D., Wikelski, M., & Safi, K. (2012). A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. *The Journal of Animal Ecology*, *81*(4), 738–746. https://doi.org/10.1111/j.1365-2656.2012.01955.x
- Autocorrelated Kernel Density Estimation (AKDE)
  - Silva, I., Fleming, C. H., Noonan, M. J., Alston, J., Folta, C., Fagan, W. F., & Calabrese, J. M. (2022). Autocorrelation-informed home range estimation: A review and practical guide. *Methods in Ecology and Evolution / British Ecological Society*, *13*(3), 534–544. https://doi.org/10.1111/2041-210x.13786

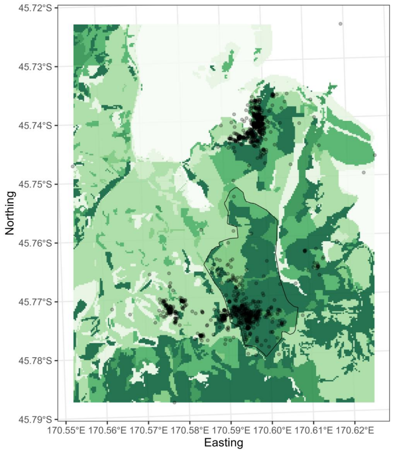
Conceptual considerations (range vs occurrence distributions)

- Alston, J. M., Fleming, C. H., Noonan, M. J., Tucker, M. A., Silva, I., Folta, C., Akre, T. S. B., Ali, A. H., Belant, J. L., Beyer, D., Blaum, N., Böhning-Gaese, K., de Paula, R. C., Dekker, J., Drescher-Lehman, J., Farwig, N., Fichtel, C., Fischer, C., Ford, A. T., … Calabrese, J. M. (2022). Clarifying space use concepts in ecology: range vs. occurrence distributions. In *bioRxiv* (p. 2022.09.29.509951). https://doi.org/10.1101/2022.09.29.509951

Tutorials

- KDE, BBMM, dBBMM, LoCoH (older style R code)
  - https://ecosystems.psu.edu/research/labs/walter-lab/manual/home-range-estimation/link-to-pdf
- AKDE
  - https://ecoisilva.github.io/AKDE_minireview/code/AKDE_R-tutorial.html
  - Signer, J., & Fieberg, J. R. (2021). A fresh look at an old concept: home-range estimation in a tidy world. *PeerJ*, *9*, e11031. https://doi.org/10.7717/peerj.11031

Habitat/resource selection analyses



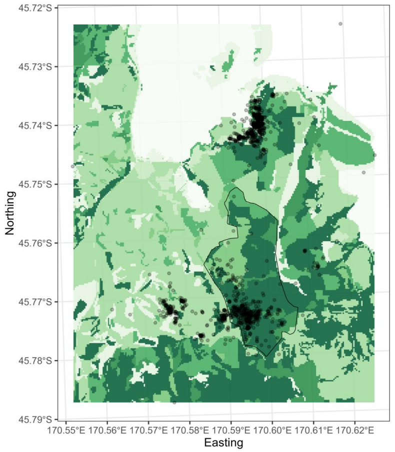
To quantify how the animal was associating with the surrounding environment

- determine ‘preferences’ (description or inference)
- generate predictions (prediction)

Some considerations

- locations are not independent
- we never get true absences

Some common approaches and resources



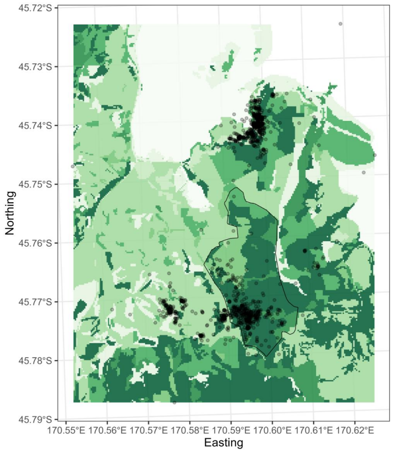
Earlier approaches (assume independent data)

- Resource Selection Functions (RSF)
  - Boyce, M., & McDonald, L. (1999). Relating populations to habitats using resource selection functions. *Trends in Ecology & Evolution*, *14*(7), 268–272. https://doi.org/10.1016/s0169-5347(99)01593-1
  - Fieberg, J., Signer, J., Smith, B., & Avgar, T. (2021). A "How to" guide for interpreting parameters in habitat-selection analyses. *The Journal of Animal Ecology*, *90*(5), 1027–1043. https://doi.org/10.1111/1365-2656.13441
    - this paper has good code for RSFs and for SSFs (on the next slide)

More recent approaches (typically assume independent data)

- Species Distribution Models (SDM)
  - Franklin, J. (2009). *Mapping Species Distributions: Spatial Inference and Prediction* (p. 340). Cambridge University Press. https://play.google.com/store/books/details?id=sQ7bngEACAAJ
  - Guisan, A., Thuiller, W., & Zimmermann, N. E. (2017). *Habitat suitability and distribution models: With applications in R* (pp. 1–478). Cambridge University Press. https://doi.org/10.1017/ 9781139028271

Some common approaches and resources



More recent approaches (assume dependent data)

- Step Selection Functions (SSF)
    - Thurfjell, H., Ciuti, S., & Boyce, M. (2014). Applications of step-selection functions in ecology and conservation. *Movement Ecology*, *2*(1), 4. https://doi.org/10.1186/2051-3933-2-4
    - Avgar, T., Potts, J. R., Lewis, M. A., & Boyce, M. (2016). Integrated step selection analysis: bridging the gap between resource selection and animal movement. *Methods in Ecology and Evolution*, *7*(5), 619–630. https://doi.org/10.1111/2041-210x.12528
    - Northrup, J. M., Vander Wal, E., Bonar, M., Fieberg, J., Laforge, M. P., Leclerc, M., Prokopenko, C. M., & Gerber, B. D. (2022). Conceptual and methodological advances in habitat-selection modeling: guidelines for ecology and evolution. *Ecological Applications*, *32*(1), e02470. https://doi.org/10.1002/eap.2470
- Mixed (hierarchical) modelling for RSFs and SSFs
    - 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. *The Journal of Animal Ecology*, *89*(1), 80–92. https://doi.org/10.1111/1365-2656.13087
- Generating predictions from SSFs (including simulation)
    - Potts, J. R., & Börger, L. (2023). How to scale up from animal movement decisions to spatiotemporal patterns: An approach via step selection. *The Journal of Animal Ecology*, *92*(1), 16–29. https://doi.org/10.1111/1365-2656.13832
    - Signer, J., Fieberg, J., Reineking, B., Schlägel, U., Smith, B., Balkenhol, N., & Avgar, T. (2023). Simulating animal space use from fitted integrated Step-Selection Functions (iSSF). *Methods in Ecology and Evolution*. https://doi.org/10.1111/2041-210x.14263

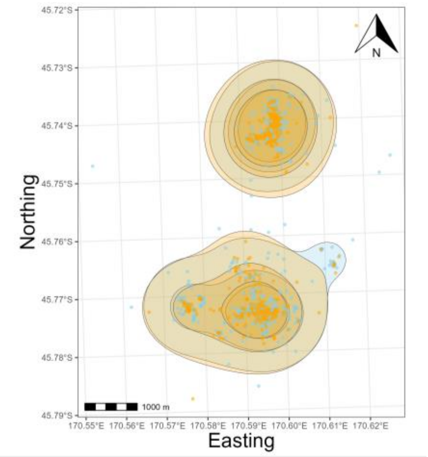
Tutorials and coding examples

These papers have very useful code for SSFs

- Signer, J., Fieberg, J., & Avgar, T. (2019). Animal movement tools (amt): R package for managing tracking data and conducting habitat selection analyses. *Ecology and Evolution*, *9*(2), 880–890. https://doi.org/10.1002/ece3.4823
- Fieberg, J., Signer, J., Smith, B., & Avgar, T. (2021). A “How to” guide for interpreting parameters in habitat-selection analyses. *The Journal of Animal Ecology*, *90*(5), 1027–1043. https://doi.org/10.1111/1365-2656.13441

- ## For hierarchical models
  - 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. *The Journal of Animal Ecology*, *89*(1), 80–92. https://doi.org/10.1111/1365-2656.13087

Behavioural classification

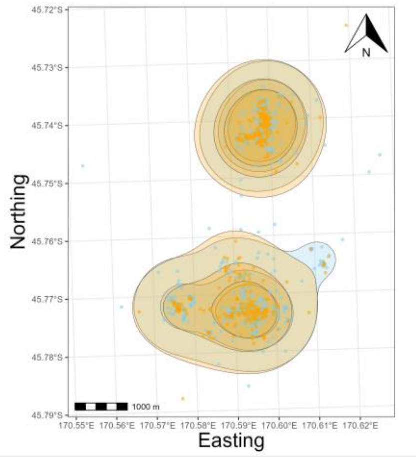


To quantify how the animal was spending its time

- activity budgets (resting/foraging/…)

Can be related to certain areas in space (as in the plot) but is typically non-spatial. There are recent approaches that combine step selection functions and behavioural classification (Pohle et al 2024 on next slide).

Some common approaches and resources



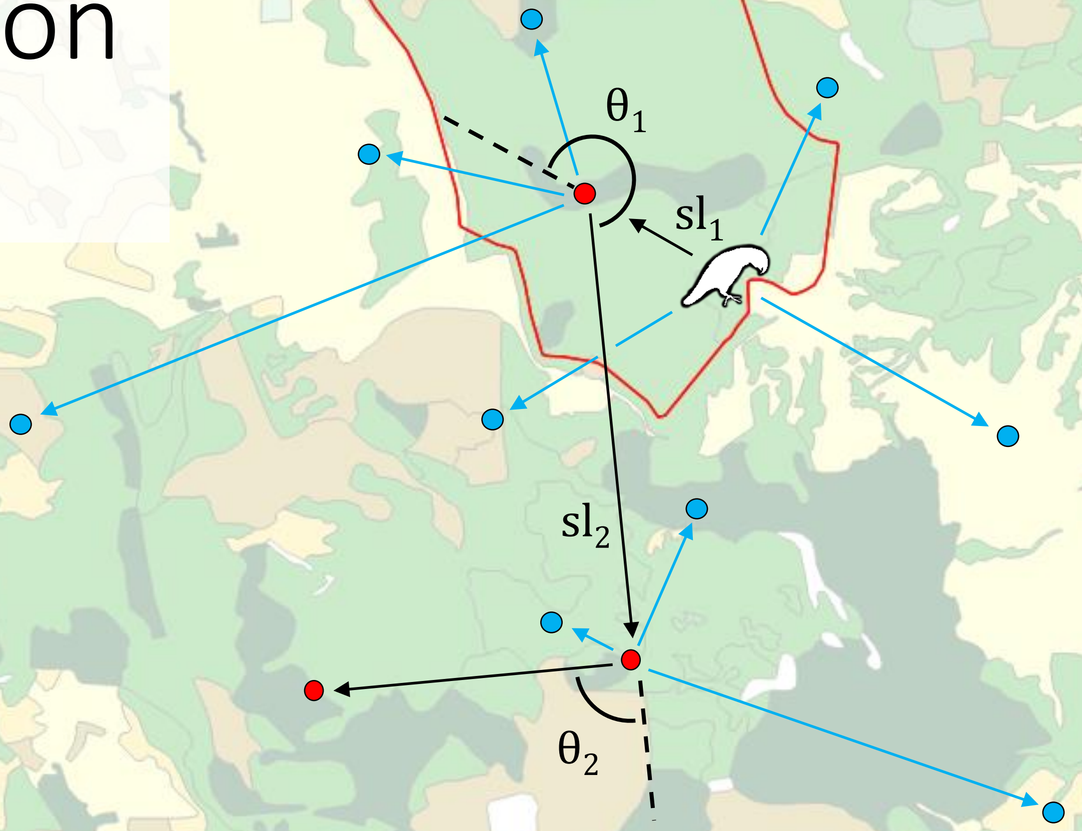
Most common approaches

- Hidden Markov Models (HMM)
    - Langrock, R., King, R., Matthiopoulos, J., Thomas, L., Fortin, D., & Morales, J. M. (2012). Flexible and practical modeling of animal telemetry data: hidden Markov models and extensions. *Ecology*, *93*(11), 2336–2342. https://doi.org/10.1890/11-2241.1
    - McClintock, B. T., & Michelot, T. (2018). momentuHMM: R package for generalized hidden Markov models of animal movement. *Methods in Ecology and Evolution / British Ecological Society*, *9*(6), 1518–1530. https://doi.org/10.1111/2041-210X.12995
- Combining HMMs and step selection functions
    - Pohle, J., Signer, J., Eccard, J. A., Dammhahn, M., & Schlägel, U. E. (2024). How to account for behavioral states in step-selection analysis: a model comparison. *PeerJ*, *12*, e16509. https://doi.org/10.7717/peerj.16509

More recent approaches

- machine/deep learning techniques

Step-selection functions



We take random ‘steps’ at each GPS location to sample the local availability, which become the 0s in our conditional logistic regression framework

(Fortin 2005, Thurfjell 2014)

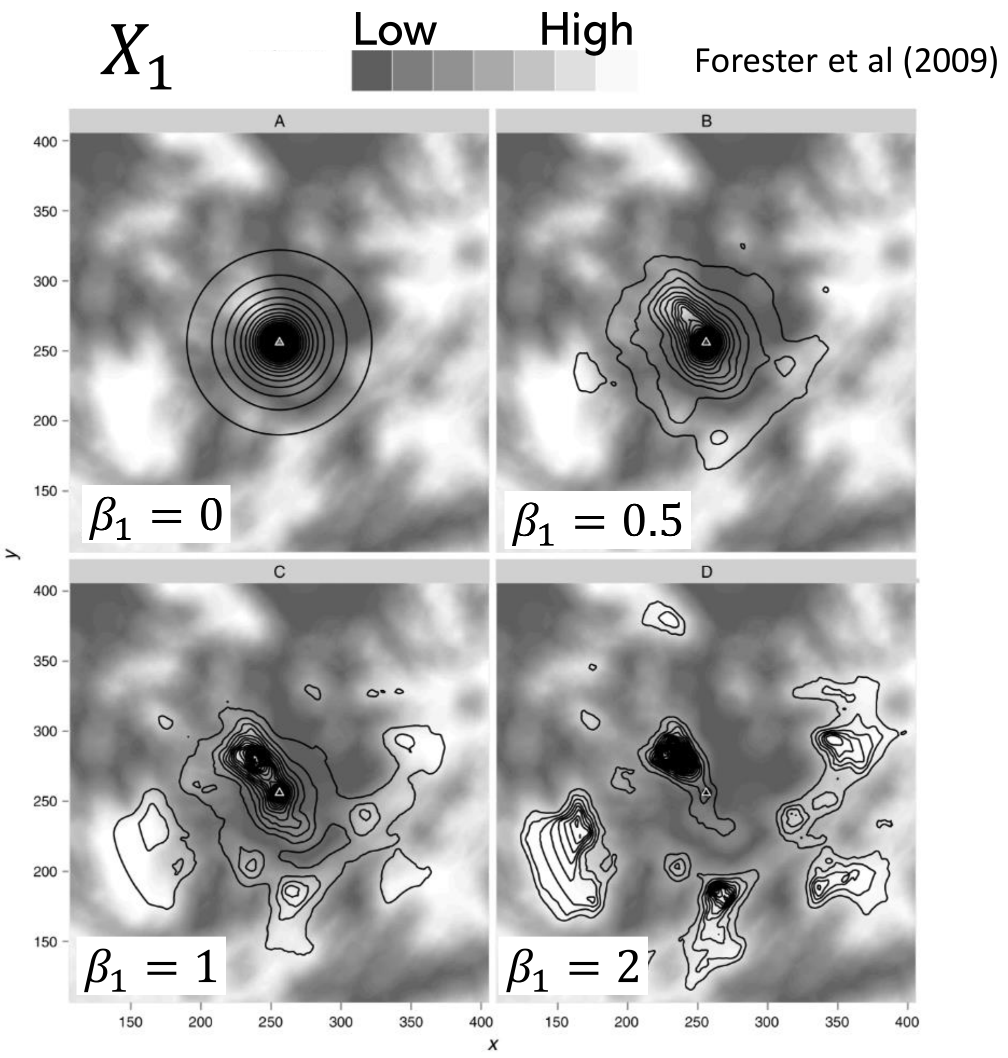
Step selection function

we are trying to estimate the movement parameters, θ, and the habitat selection parameters, β from our observed and randomly sampled steps

probability of next step

$$p(s_t|s_{t-2}, s_{t-1}; \boldsymbol{\beta}, \boldsymbol{\theta}) = \frac{\overbrace{\phi(s_{t-2}, s_{t-1}, s_t; \boldsymbol{\theta})}^{\text{movement kernel}}\overbrace{\omega(\mathbf{X}(s_t); \boldsymbol{\beta})}^{\text{habitat selection}}}{\int_{q_t \in S} \phi(s_{t-2}, s_{t-1}, q_t; \boldsymbol{\theta})\omega(\mathbf{X}(q_t); \boldsymbol{\beta})\, dq_t}$$

s_t is a location in space at time t
$\boldsymbol{\beta}$ are habitat selection parameters
$\boldsymbol{\theta}$ are movement parameters
$\boldsymbol{X}$ are habitat covariates



Step selection function

if we set our habitat selection component to 0, we are left with the 'intrinsic' movement dynamics of the animal, which is typically some function that decays with distance from the current location, such as an exponential or gamma distribution. There is often also correlated turning angles (but shown as uniform here)

probability of next step

$$p(s_t|s_{t-2}, s_{t-1}; \boldsymbol{\beta}, \boldsymbol{\theta}) = \frac{\overbrace{\phi(s_{t-2}, s_{t-1}, s_t; \boldsymbol{\theta})}^{\text{movement kernel}}\overbrace{\cancel{\omega(\mathbf{X}(s_t); \boldsymbol{\beta})}}^{\text{habitat selection}}}{\int_{q_t \in S} \phi(s_{t-2}, s_{t-1}, q_t; \boldsymbol{\theta})\cancel{\omega(\mathbf{X}(q_t); \boldsymbol{\beta})}\, dq_t}$$

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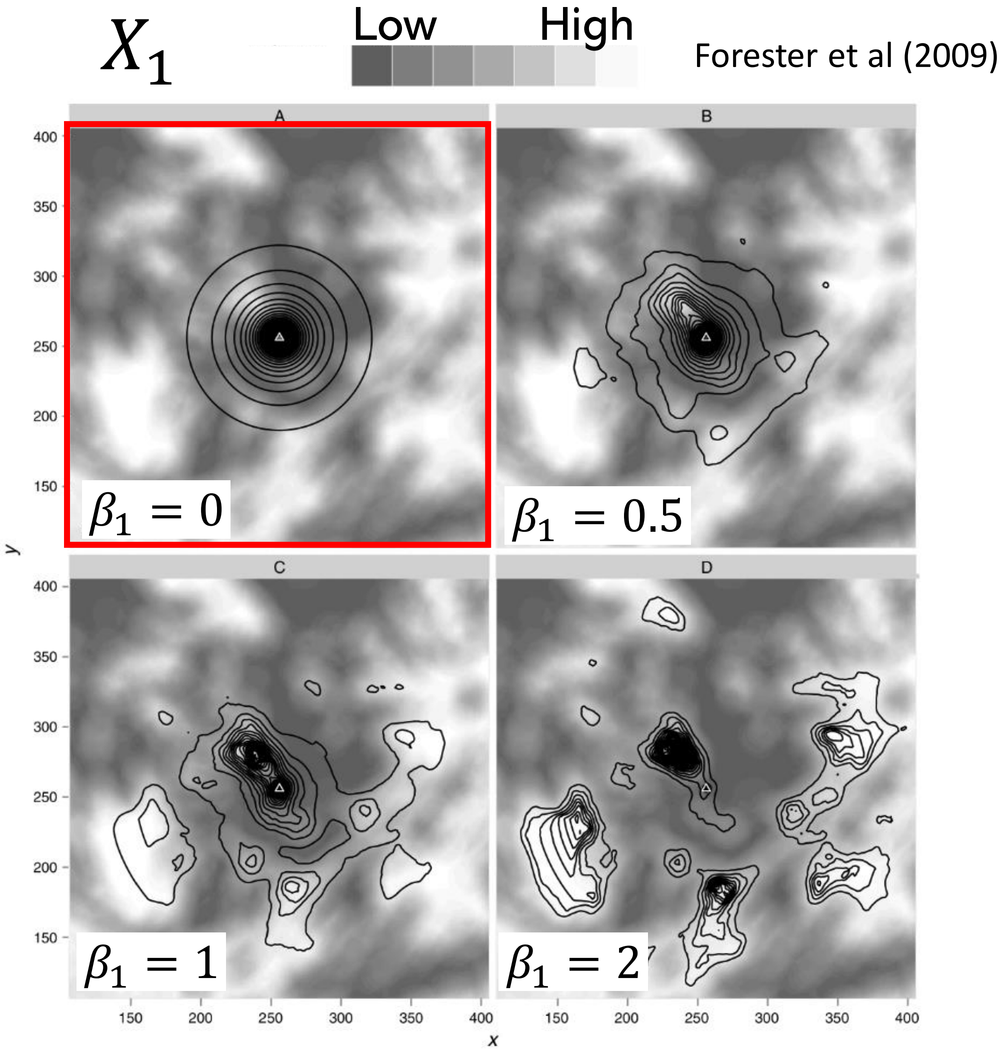

Step selection function

when the habitat selection parameters are large, then the habitat is very influential on where the next step is likely to land

probability of next step

$$p(s_t|s_{t-2}, s_{t-1}; \boldsymbol{\beta}, \boldsymbol{\theta}) = \frac{\underbrace{\phi(s_{t-2}, s_{t-1}, s_t; \boldsymbol{\theta})}_{\text{movement kernel}}\underbrace{\omega(\mathbf{X}(s_t); \boldsymbol{\beta})}_{\text{habitat selection}}}{\int_{q_t \in S} \phi(s_{t-2}, s_{t-1}, q_t; \boldsymbol{\theta})\omega(\mathbf{X}(q_t); \boldsymbol{\beta})\, dq_t}$$

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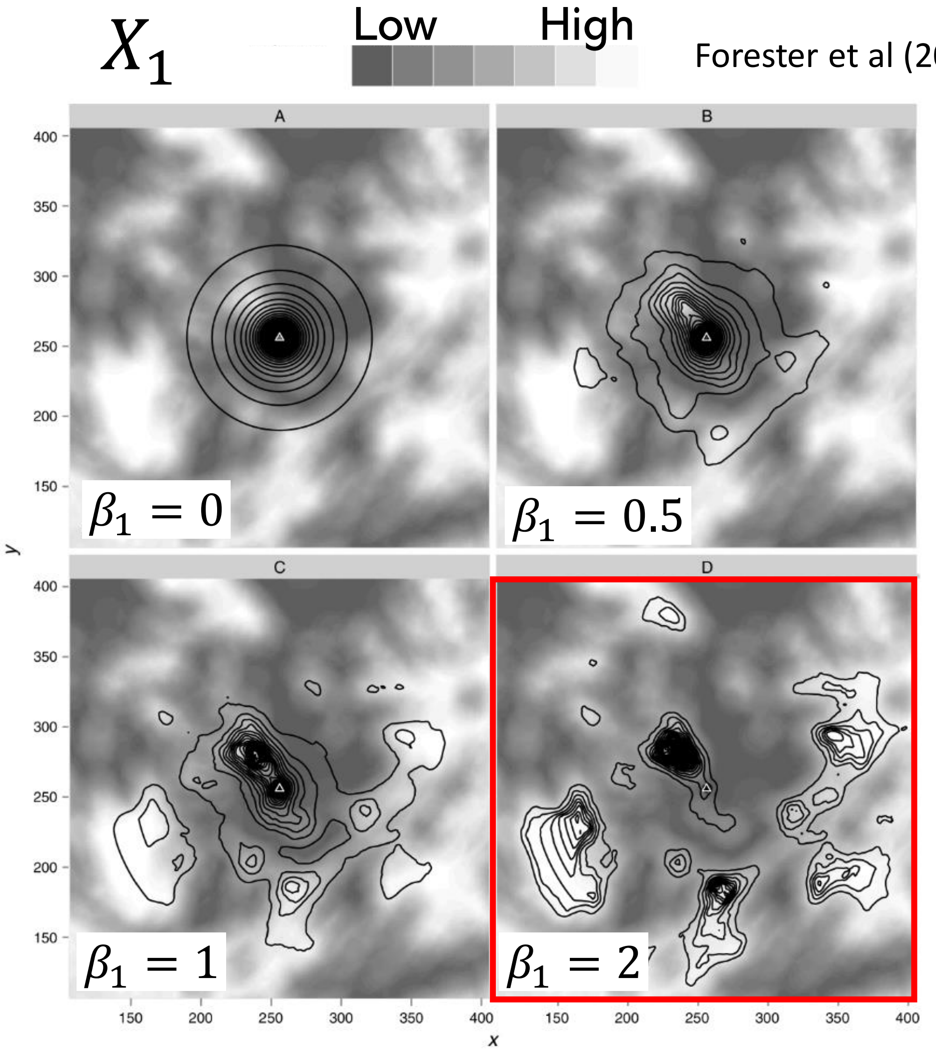

Forester et al (2009)

Step selection coding example

Code and data available from the GitHub repo below, as well as rendered html files which include all of the outputs:

- https://github.com/swforrest/geospatial_share_animal_movement