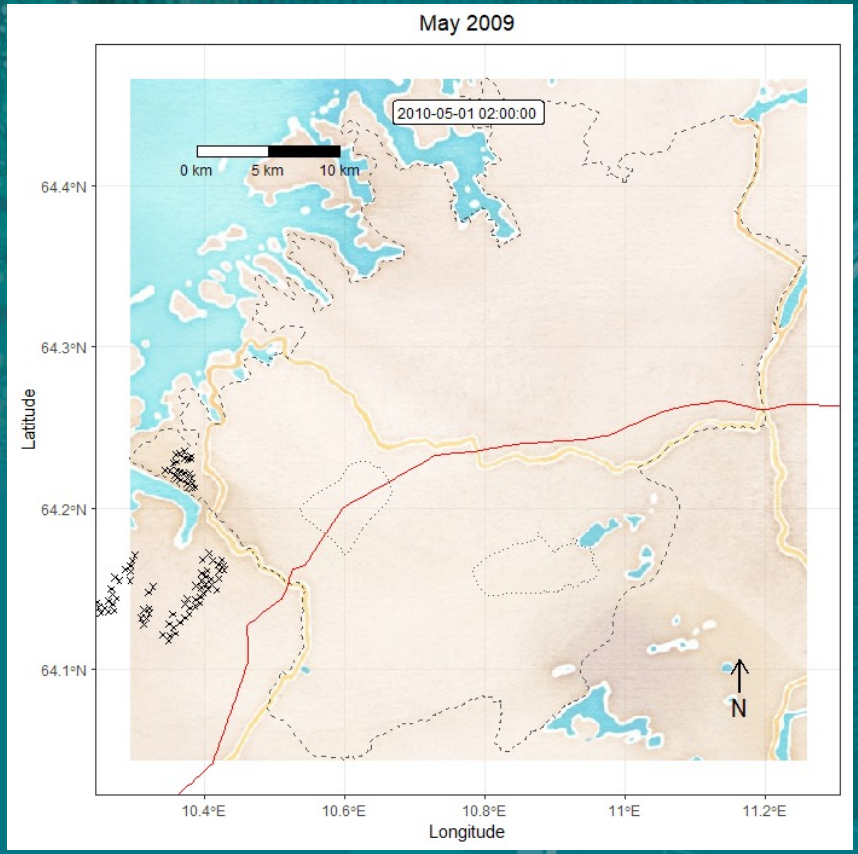
Introduction to animal movement analysis

PhD-course 8-12 September 2025



Why study animal movement?

- The holy grail in population ecology?
- Answers on distribution and abundance of organisms, i.e. the spatio-temporal denstiy of organisms

FRONTISPIECE. Female grizzly bear equipped with radio collar. This bear, No. 40, was radiotracked for portions of 8 consecutive years. Note placement of numbered ear tags and individualized color markers.

First radio telemetry study 1962

Porcupine (*Erethizon dorsatum*)

Early summer activities of porcupines as determined by radio-positioning techniques. Marshall et al. 1962

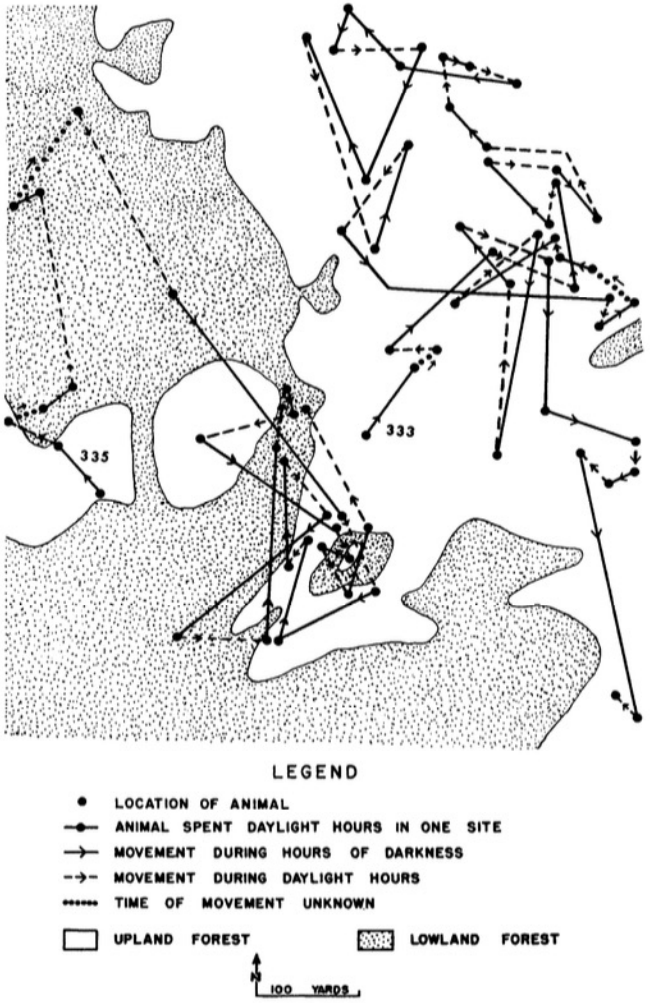
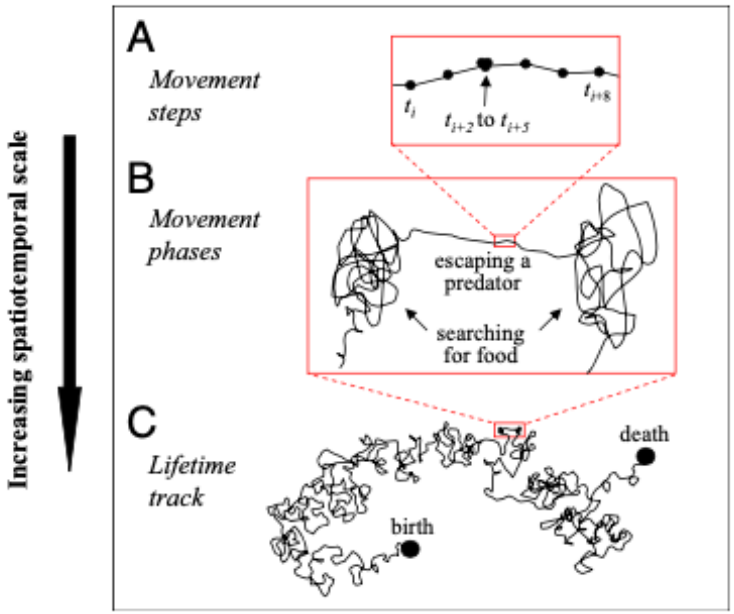


FIG. 1. Schematic diagram showing locations of adult porcupines at dawn and dusk. Points are connected by lines to indicate sequence, not routes followed.

Movement ecology paradigm – Nathan et al. 2008



Nathan et al. 2008

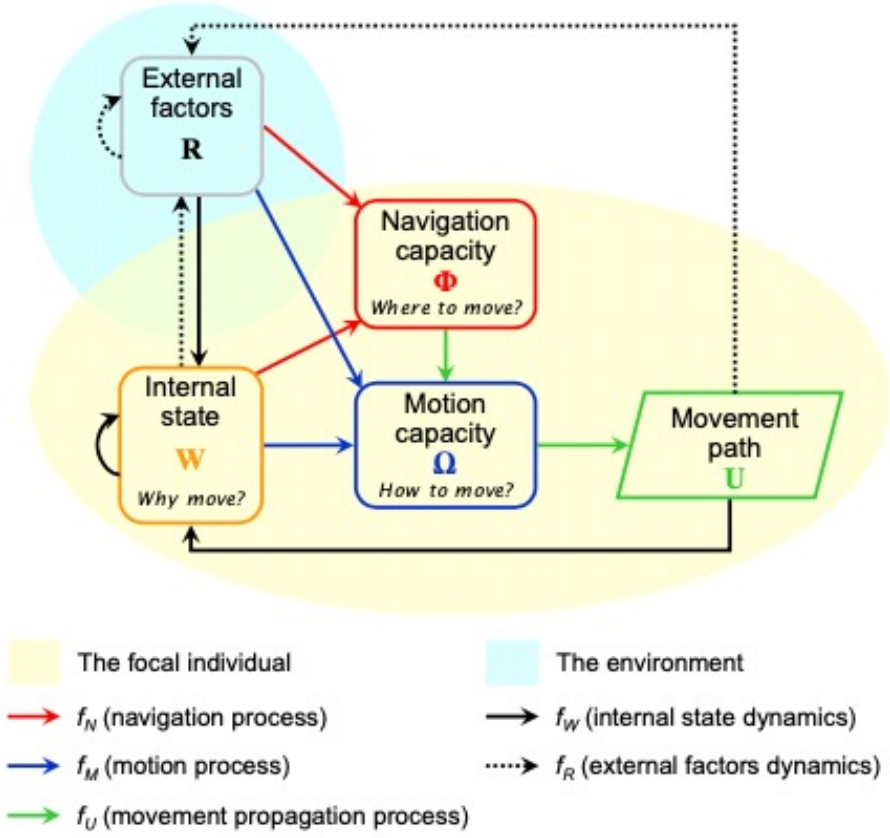
- Change of an organism's spatial location in time
- Spreading of species
  - For ex movement of seeds
- Animal movement
  - Migratory birds
  - Vertical movement of animals in the sea
  - Terrestrial animal movement

Movement ecology paradigm

Framework around movement:

1. **Internal state** - why move?
2. **Motion capacity** - how to move?
3. **Navigation capacities** of the individual - when and where to move?
4. **External factors** affecting movement

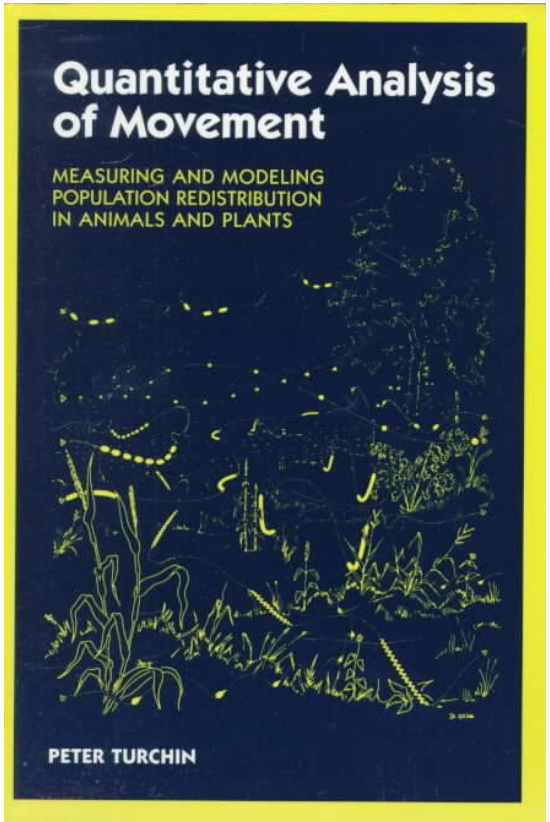
Movement behaviour can explain evolutionary aspects and fitness of the species (Nathan et al. 2008).



Nathan et al. 2008

Quantitive Analysis of Movement – Turchin 1998

- "..the most general compilation of theory and practical tools to analyze movement data of any kind" (Nathan et al. 2008)
- Borrowed terminology from fluid dynamics to describe organism movement
- From **Lagrangian** perspective – tracking movements of a single individual in discrete time – to **Eulerian** perspective – population-level movement in continious-time



Revolution of Animal telemetry

- Replaced direct-observations and its related problems

Photo: Jeff Kerby

Answer questions like

- Where was it?
- How did it get there?
- Where could it go?
- Where did it prefer to go?
- What was it doing?

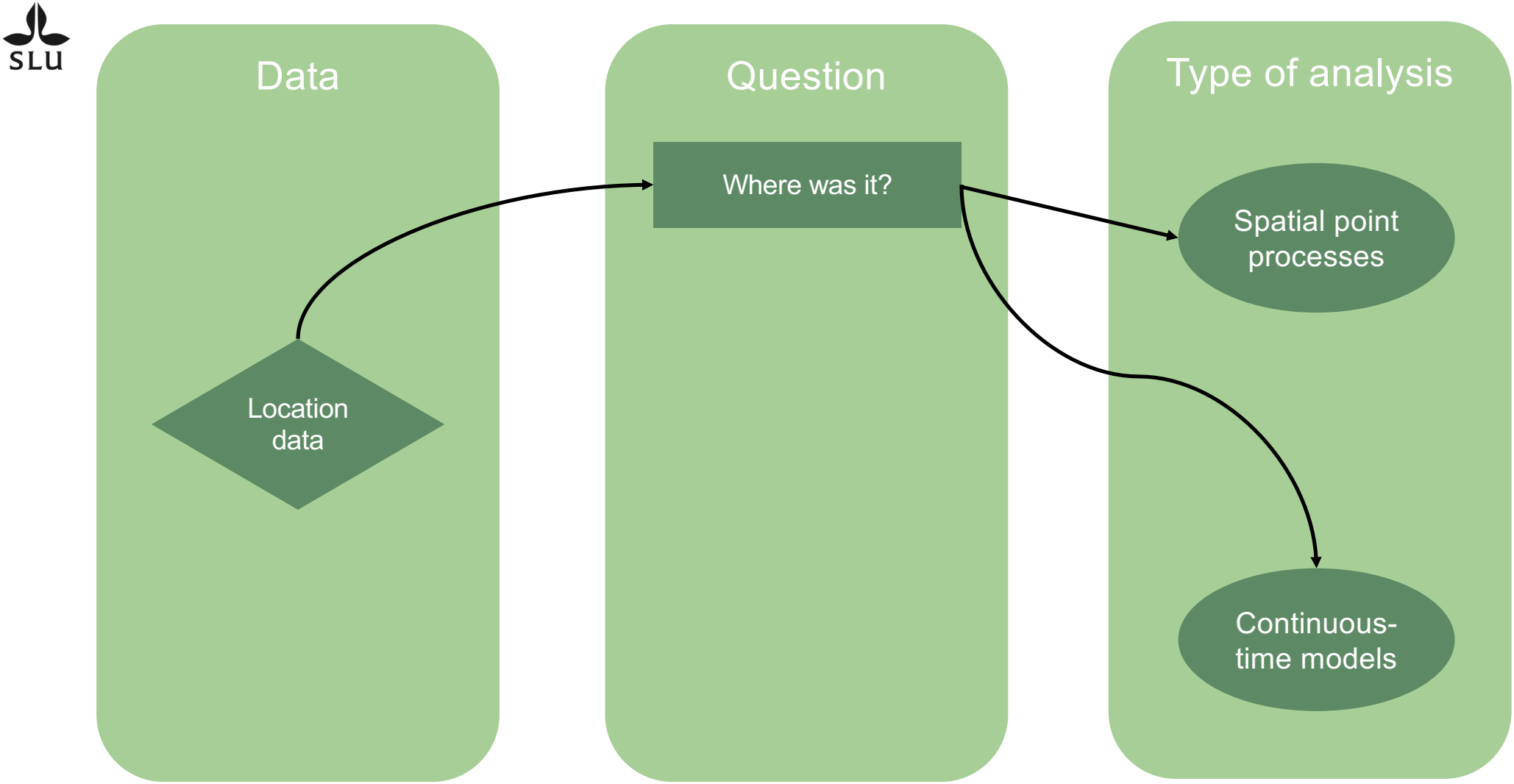
From Hooten et al. 2021 (Figure 1.1)

Data

Question

Type of analysis

From Hooten et al. 2021 (Figure 1.1)



From Hooten et al. 2021 (Figure 1.1)

Home range

Territory or home range? - Thoughts on home range definition emerged from the reasoning about territoriality.

William H. Burt 1943:

Home range then is the area, usually around a home site, over which the animal normally travels in search of food. Territory is the protected part of the home range, be it the entire home range or only the nest. Every kind of mammal may be said to have a home range, stationary or shifting.

Only those that protect some part of the home range, by fighting or agressive gestures, from others of their kind, during some phase of their lives, may be said to have territories.

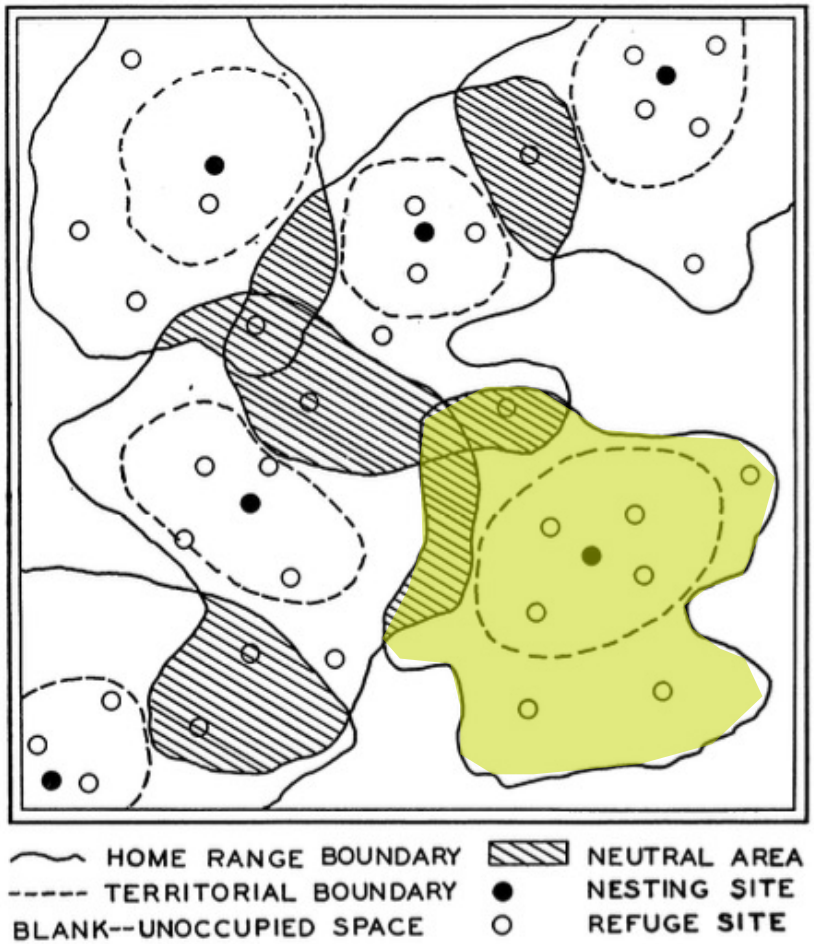
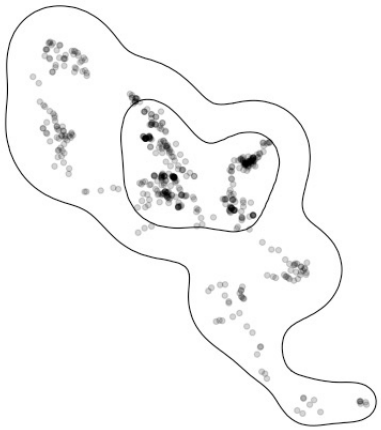
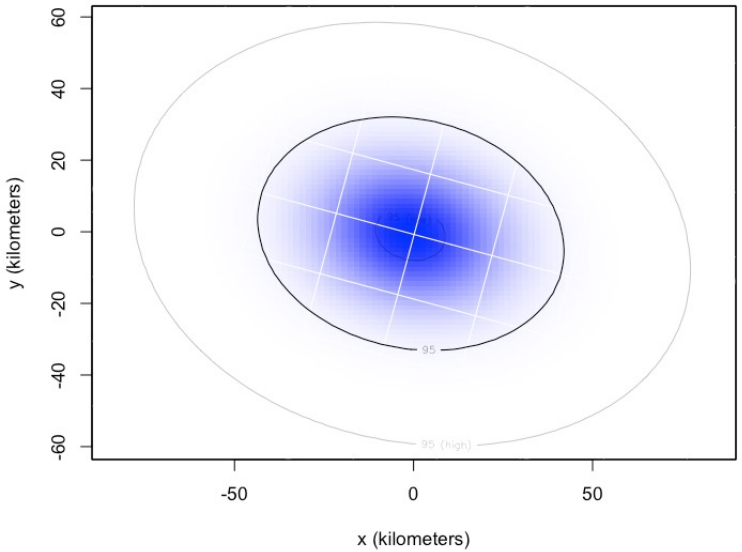


FIG. 1. Theoretical quadrat with six occupants of the same species and sex, showing territory and home range concepts as presented in text.

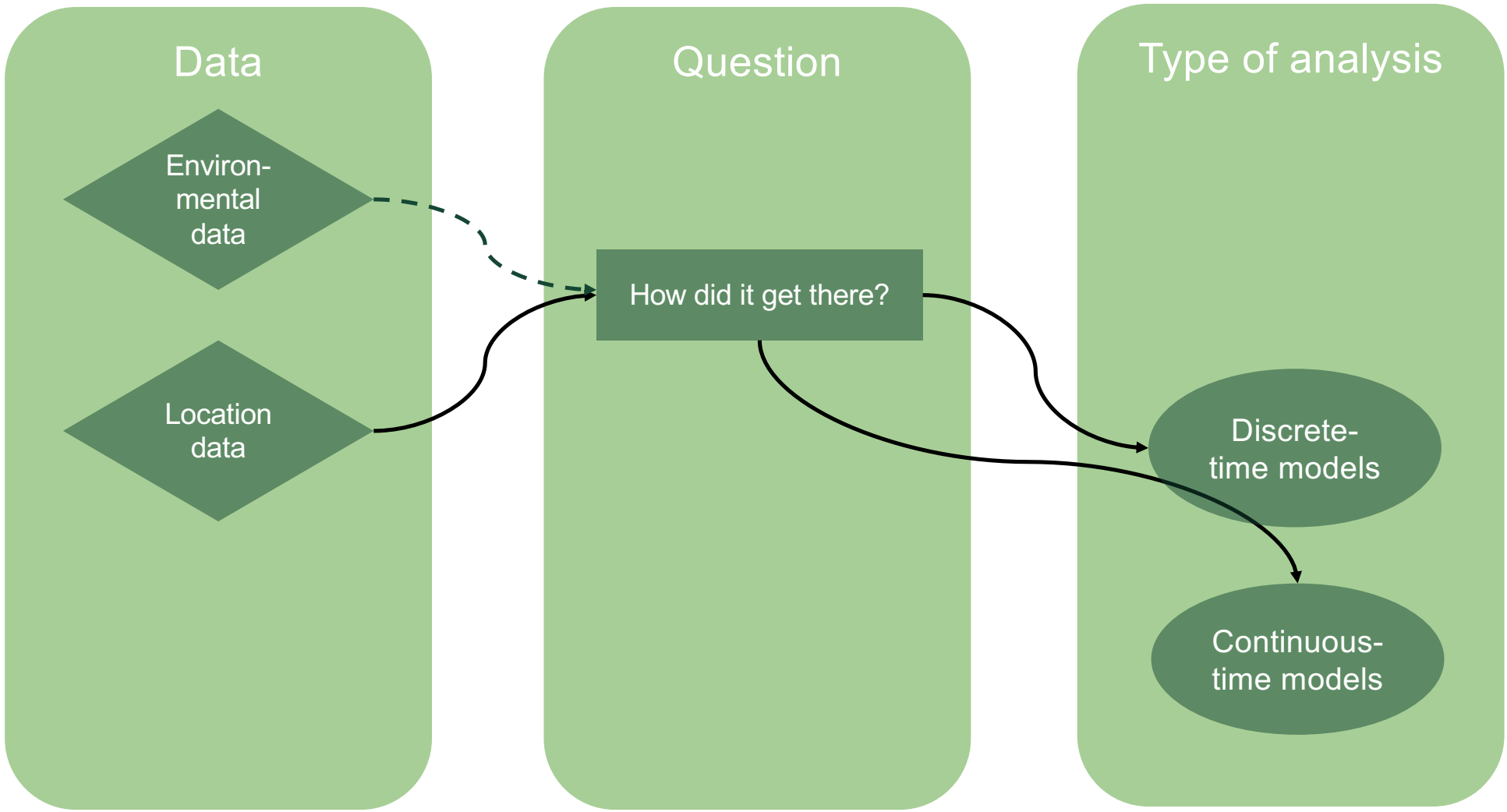
Space use



Kernel home range – spatial point process

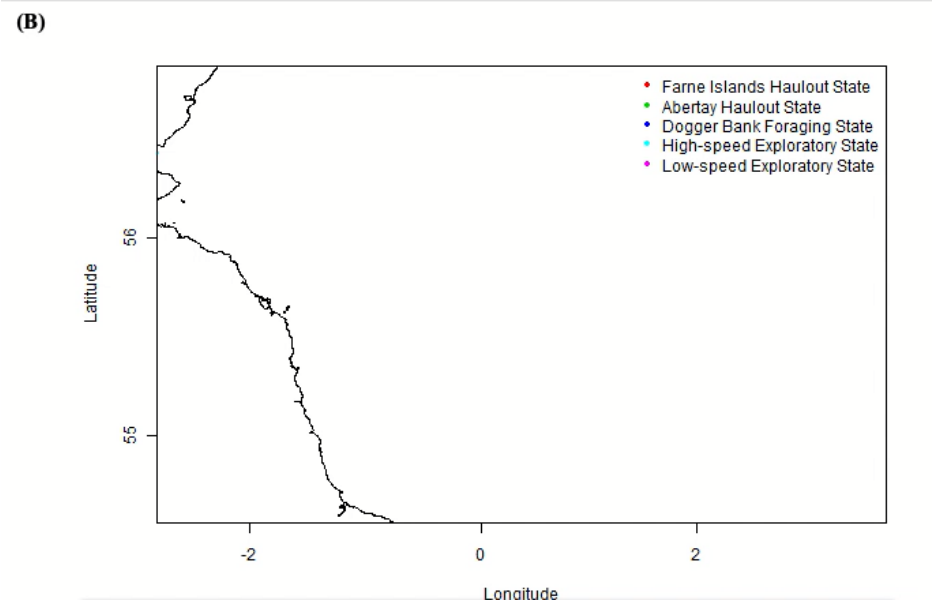


Autocorrelated kernel density estimate – continuous-time models



From Hooten et al. 2021 (Figure 1.1)

Movement



Correlated random walk – discrete time model

McClintock et al. 2012 https://doi.org/10.1890/11-0326.1

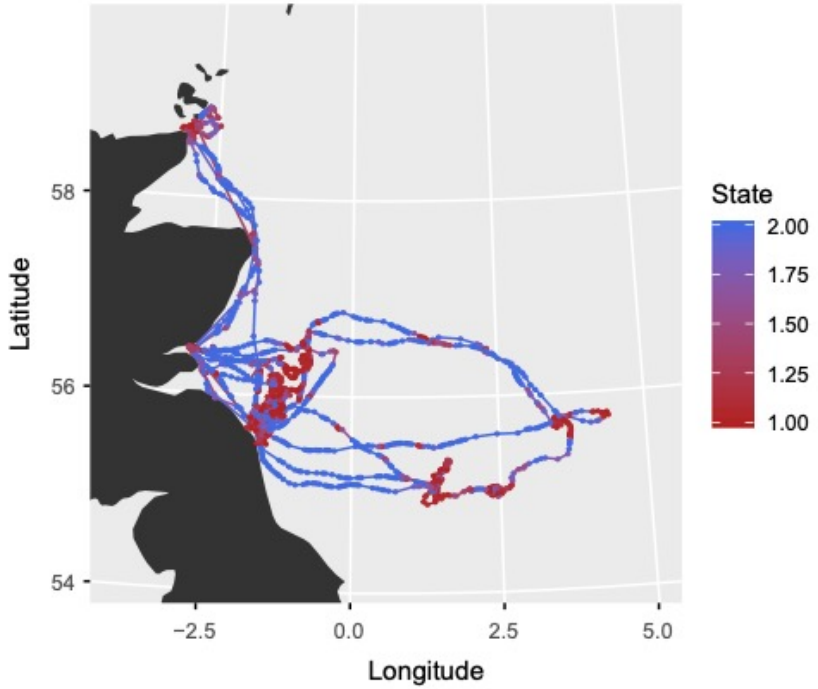
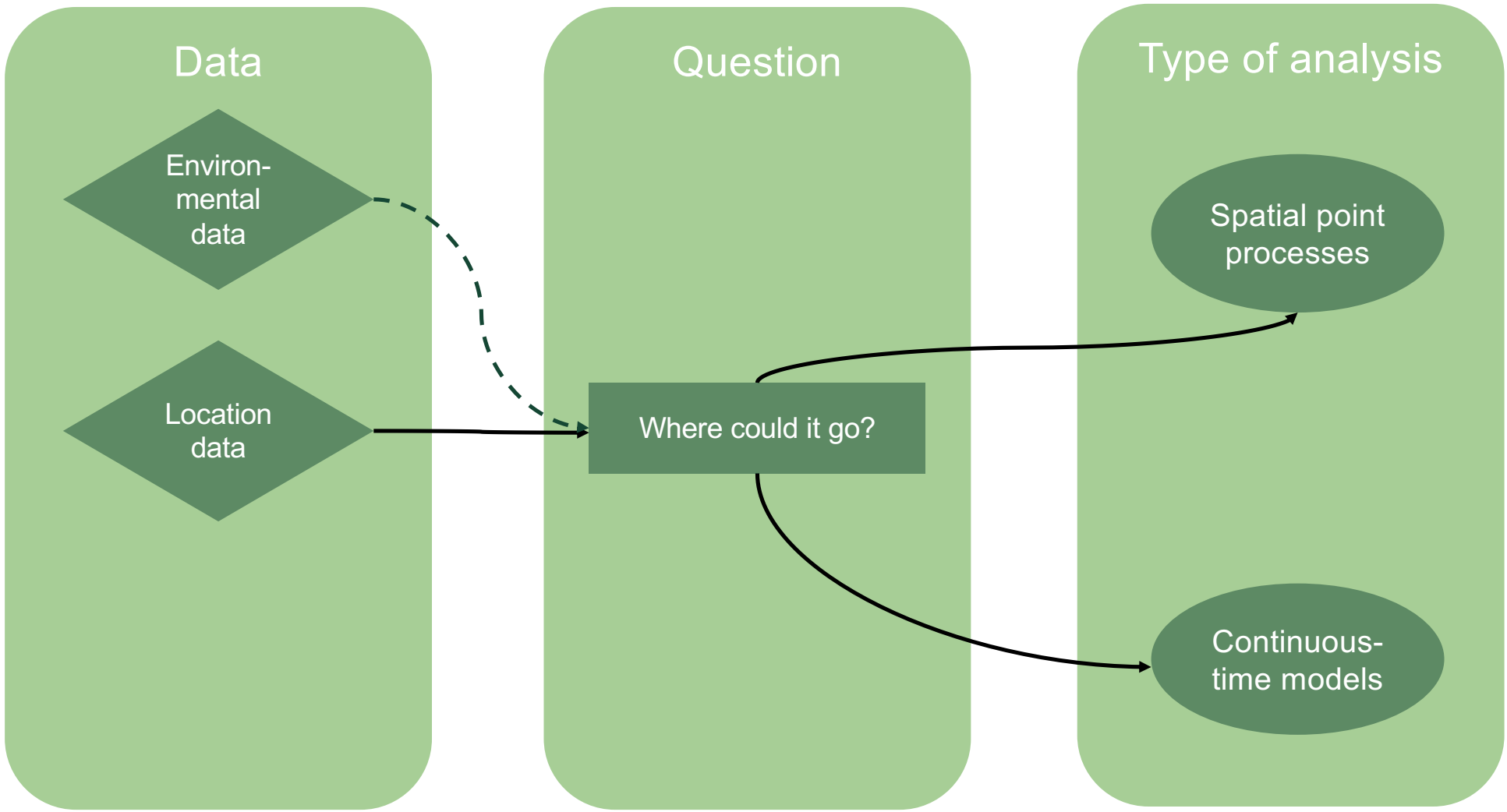


FIGURE 4 Grey seal track, off the East coast of Great Britain, coloured by posterior state probabilities

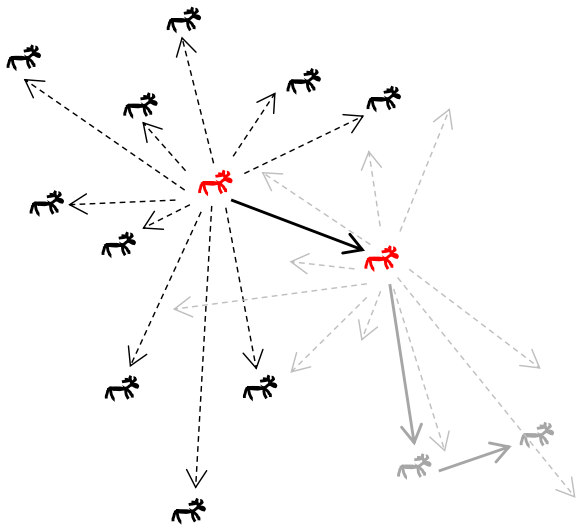
Continuous-time correlated random walks

Michelot and Blackwell 2019 https://doi.org/10.1111/2041-210X.13154

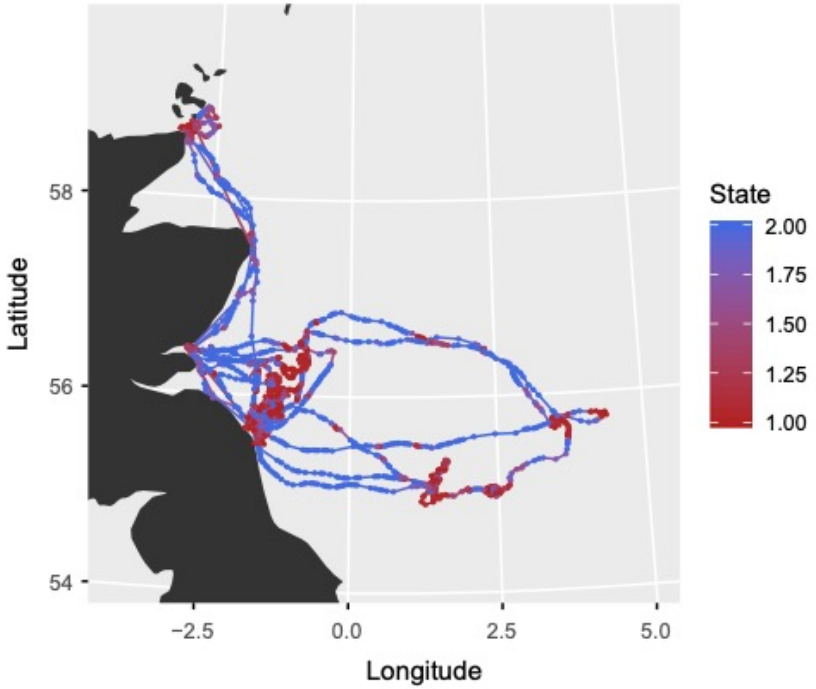


From Hooten et al. 2021 (Figure 1.1)

Movement



Step selection functions – Spatial point processes
Fortin et al. 2005 – early study



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Step selection

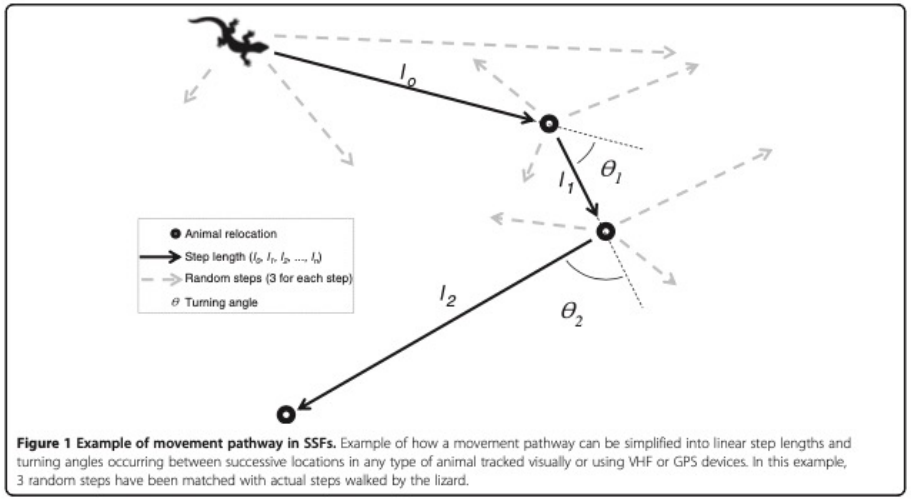
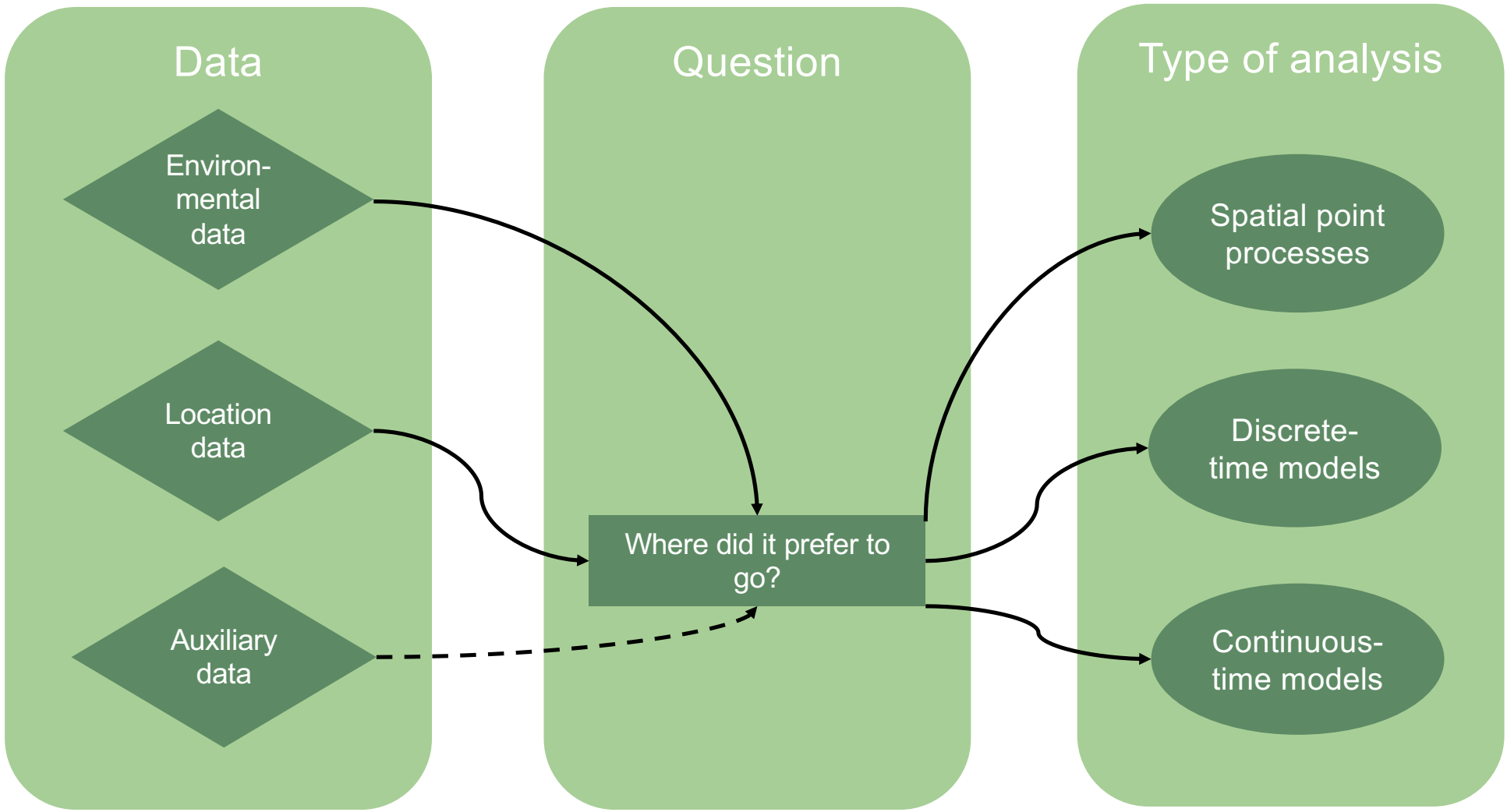


Figure 1 Example of movement pathway in SSFs. Example of how a movement pathway can be simplified into linear step lengths and turning angles occurring between successive locations in any type of animal tracked visually or using VHF or GPS devices. In this example, 3 random steps have been matched with actual steps walked by the lizard.

- Compare between steps
- Selection of end or start points in relation to a number of random available points
- Good when high resolution can take into account some of the serial autocorrelation

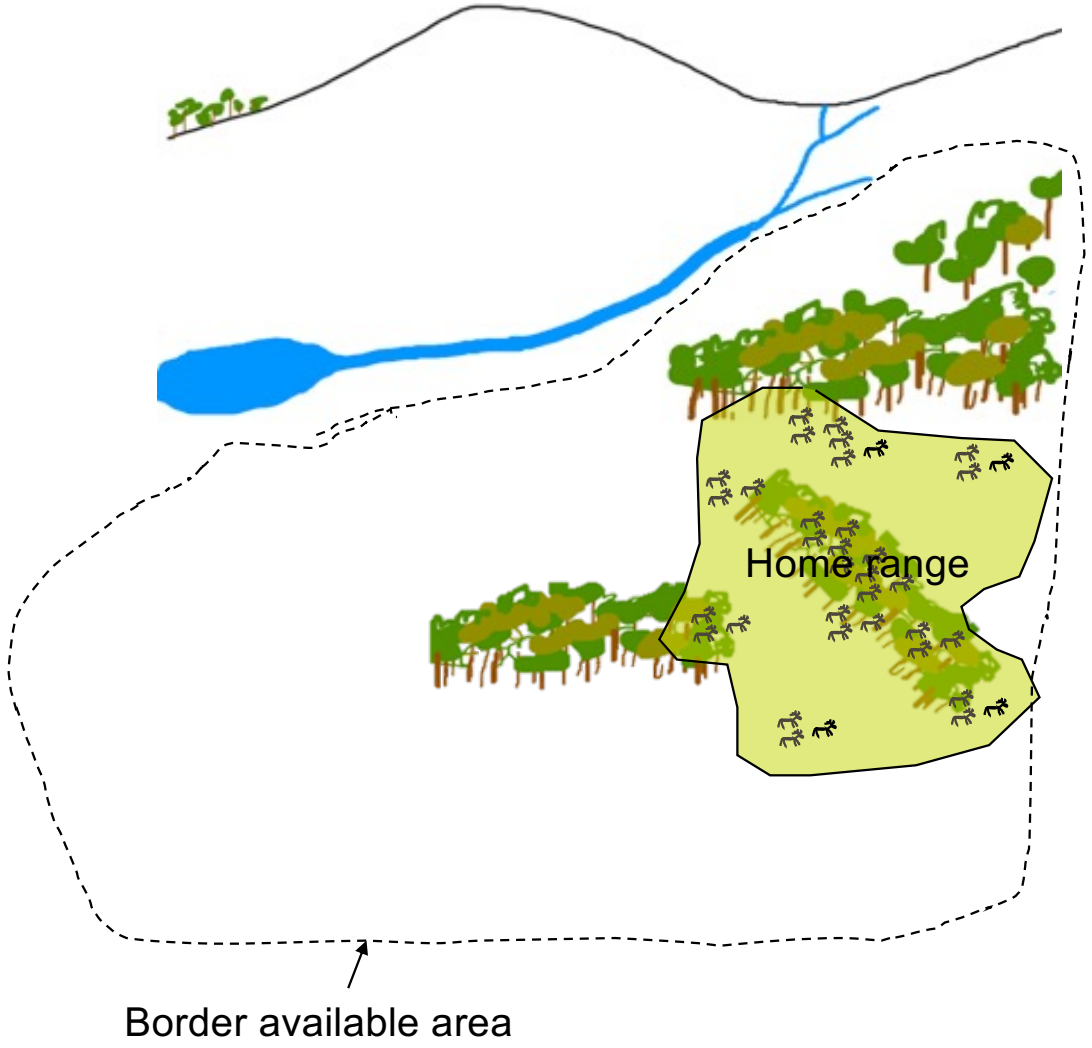
Thurfjell et al. 2014



From Hooten et al. 2021 (Figure 1.1)

Habitat selection

- Where did it prefer to go?
- What is available?
- What resources are selected – resource selection
- “selective if components are used disproportionately to their availability”
- Different scales of selection - Johnson 1980
  - First ➔ fourth order of selection



Habitat

- How do you define a habitat?

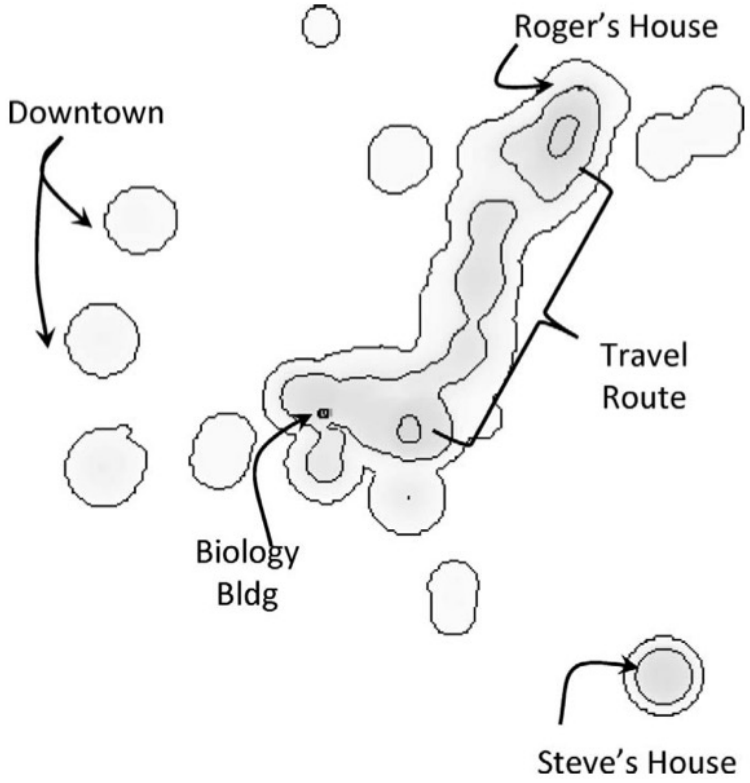
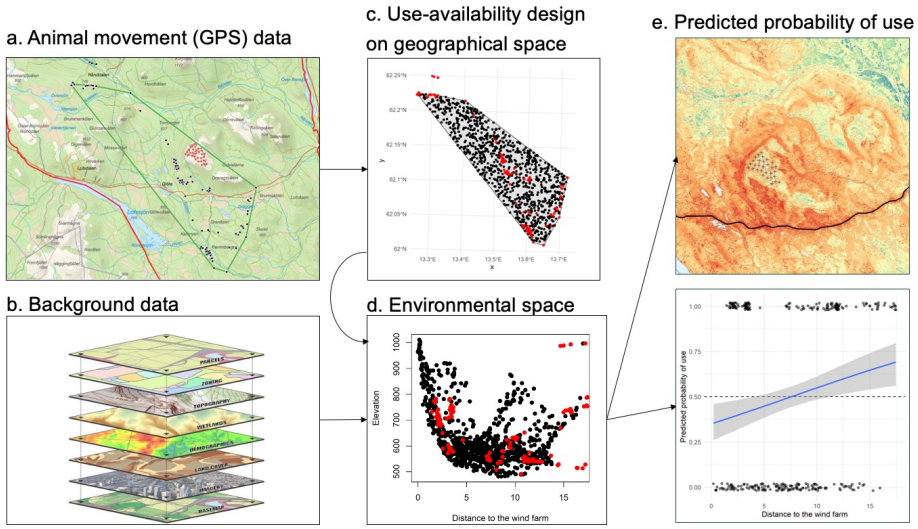


FIG. 1.—The 95% kernel estimate of Roger's home range in Laramie, Wyoming, where he spent sabbatical at the University of Wyoming in 1990–1991. Roger's house, the Biology Building on the university campus, Steve Buskirk's (a friend) house, and areas in downtown Laramie frequented by Roger are noted.

Powell & Mitchell 2012

Resource/habitat selection



Resource/Habitat selection function – Spatial point process

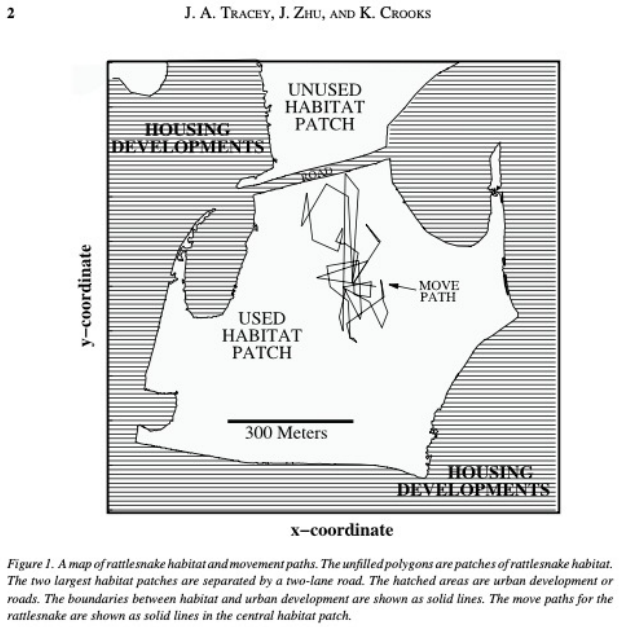
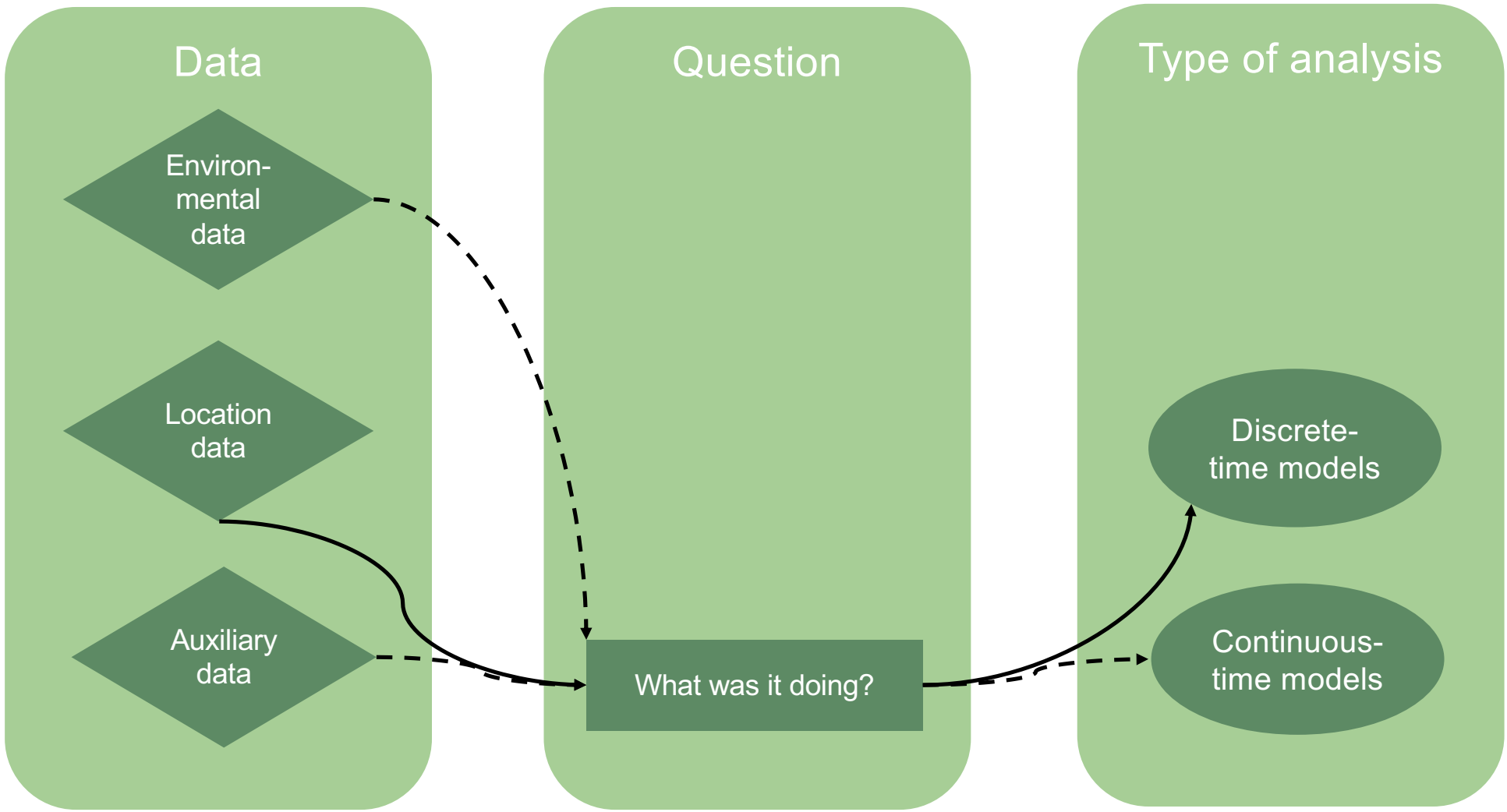


Figure 1. A map of rattlesnake habitat and movement paths. The unfilled polygons are patches of rattlesnake habitat. The two largest habitat patches are separated by a two-lane road. The hatched areas are urban development or roads. The boundaries between habitat and urban development are shown as solid lines. The move paths for the rattlesnake are shown as solid lines in the central habitat patch.

Discrete time model taking into account landscape variables - Tracey et al. 2005



From Hooten et al. 2021 (Figure 1.1)

Behavioural states

- Definition of different behaviours – what are they doing?
- How to separate foraging from resting? As the trajectories can look very similar.
- Increased possibility to detect fine-scale behaviour with accelerometer sensors

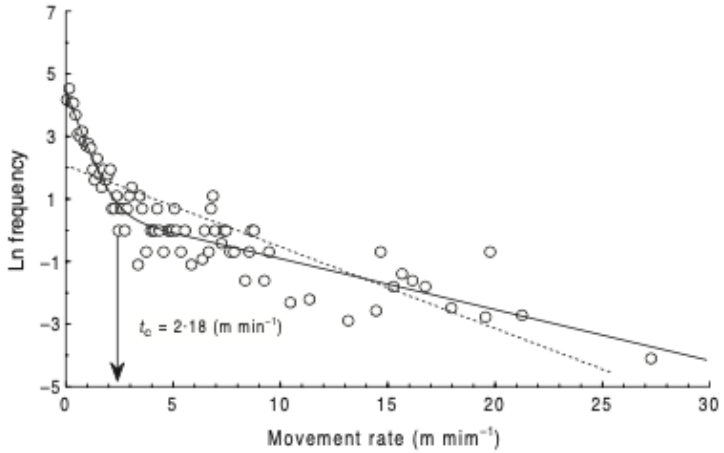


Fig. 1. Example of log, frequency distribution of movement rates by caribou 042B during winter (December 1997–April 1998). A non-linear two-process model was fit (equation 2) and the scale criterion (equation 3; r_c) was calculated using the parameters of the fitted equation. For comparison, a linear regression (dashed line) serves as the null model of a nonscalar response.

Johnson et al. 2002

Behavioural states

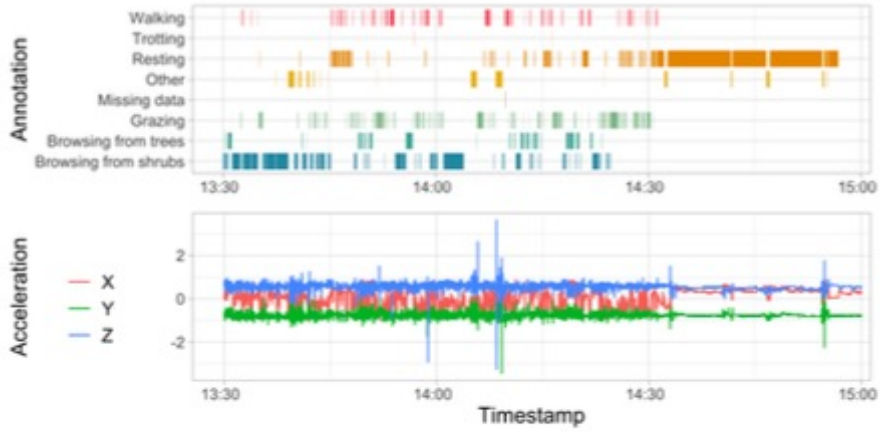
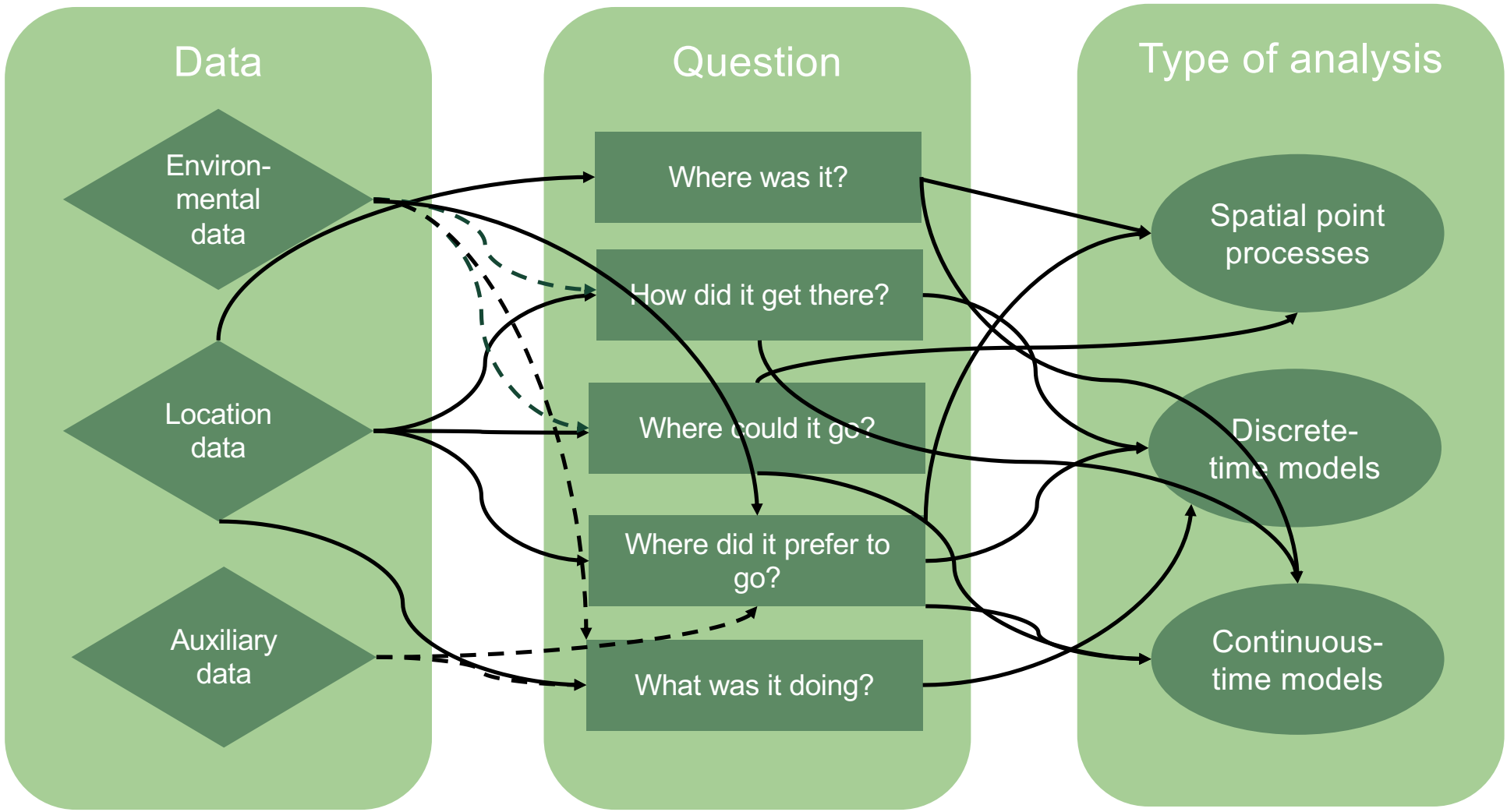
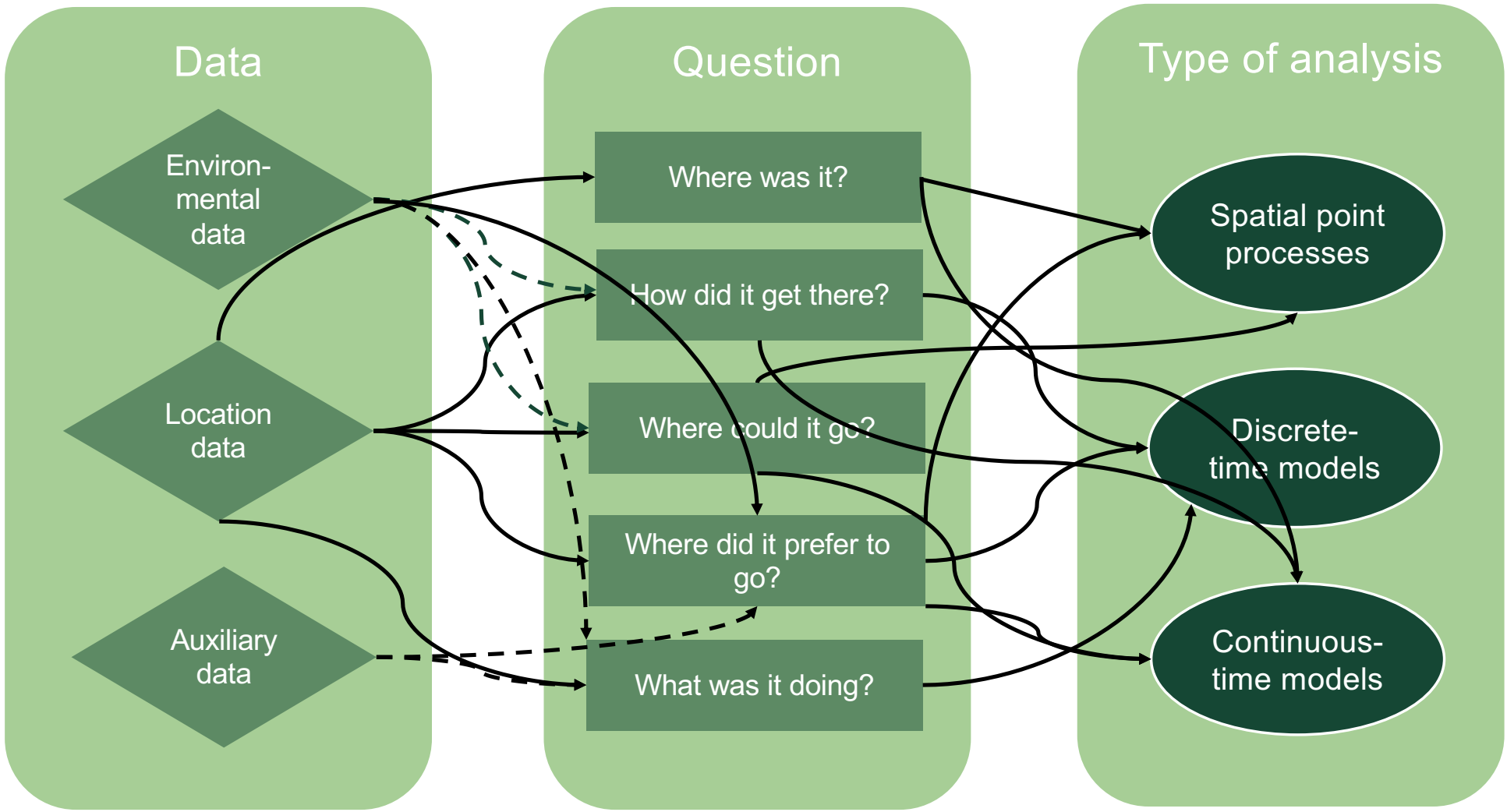


Figure 6. Illustration of time matching of behaviours from video recordings and acceleration data to create a labelled data set in paper II.



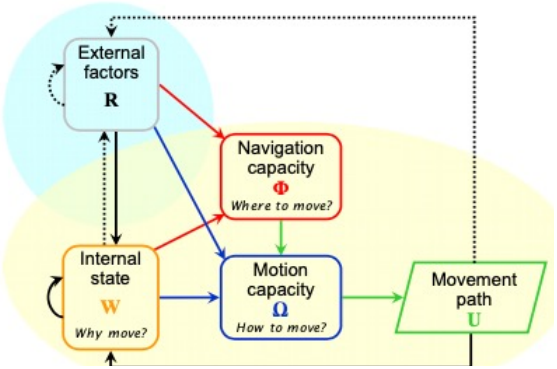
From Hooten et al. 2021 (Figure 1.1)

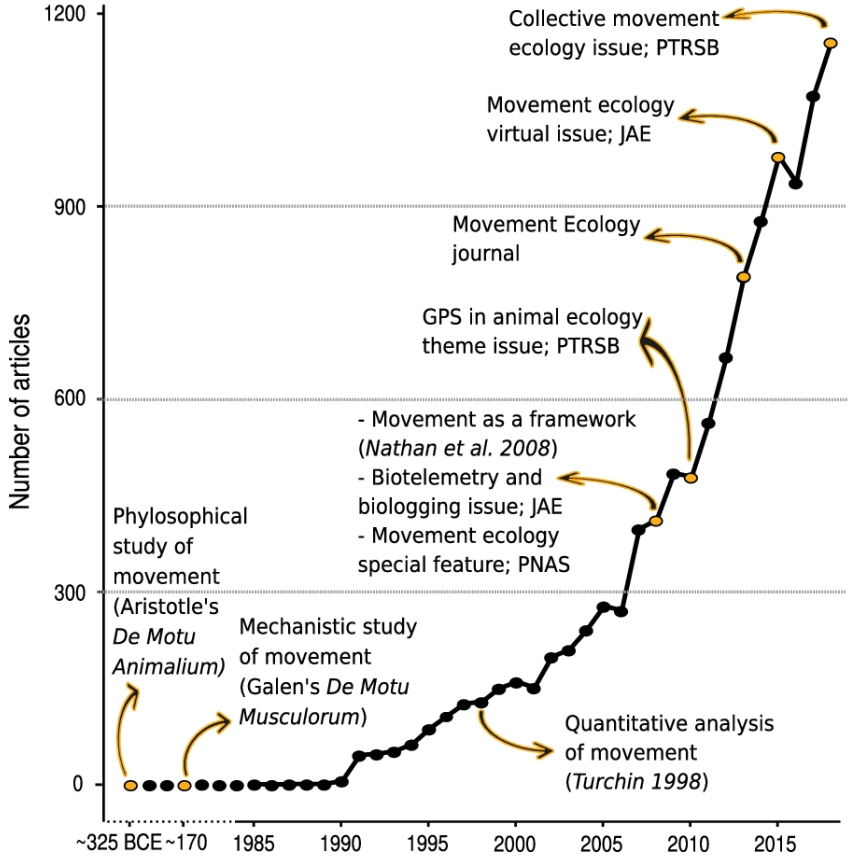


From Hooten et al. 2021 (Figure 1.1)

Movement ecology studies over time

- Review using Nathans Movement Ecology Framework (MEF)





Joo, R., Picardi, S., Boone, M.E. *et al.* (2022)
https://doi.org/10.1186/s40462-022-00322-9

Number of articles published each year until 2018 in movement ecology of animals and human mobility.

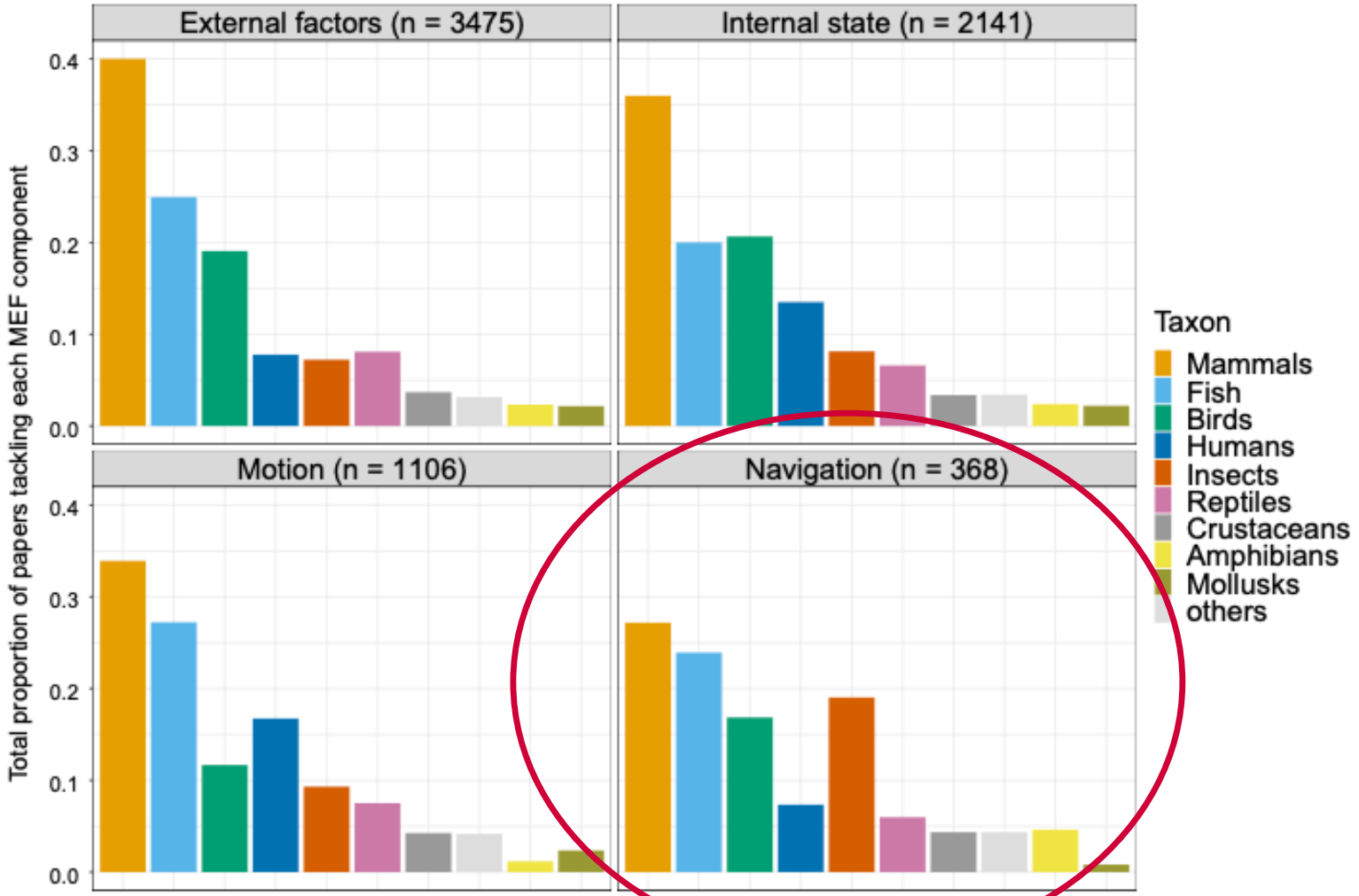


Fig. 9 Proportion of articles in movement studying each taxonomic group for each component of the Movement Ecology Framework from 2009 to 2018. Humans were extracted from mammals. Articles associated to several components were accounted for in each relevant frame. See alt-text in the Alt-text section of the manuscript

With increased resolution we can test cognition in animals

- Do they remember their environment? Yes we know this but at what scale?
- Reindeer herders tell stories about reindeer - migrating along the exact same routes
- With more detailed data and advanced models we can test animal memory also in nature

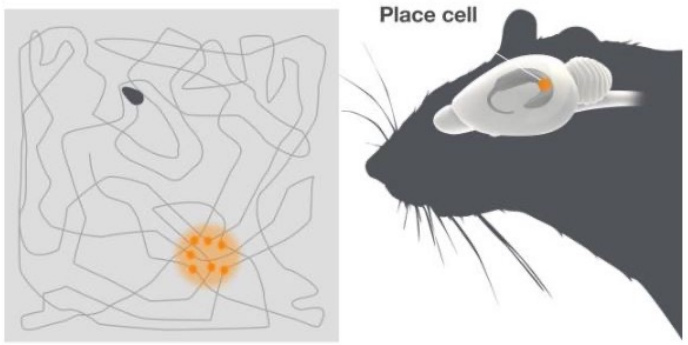


Figure 1. Place cells. To the right is a schematic of the rat. The hippocampus, where the place cells are located is highlighted. The grey square depicts the open field the rat is moving over. Place cells fire when the animal reaches a particular location in the environment. The dots indicate the rat's location in the arena when the place cell is active. Different place cells in the hippocampus fire at different places in the arena.

The 2014 Nobel Prize in Physiology or Medicine is awarded to Dr. John M. O'Keefe, Dr. May-Britt Moser and Dr. Edvard I. Moser for their discoveries of nerve cells in the brain that enable a sense of place and navigation.

Spatial redistribution

- Landscape connectivity – how organisms (can) move in the landscape, are there barriers etc?
- How species spread and use the landscape
- Depend on phenotype – preconditions
- For example - net square displacement (NSD) can be used to illustrate the possibility to move in the landscape.

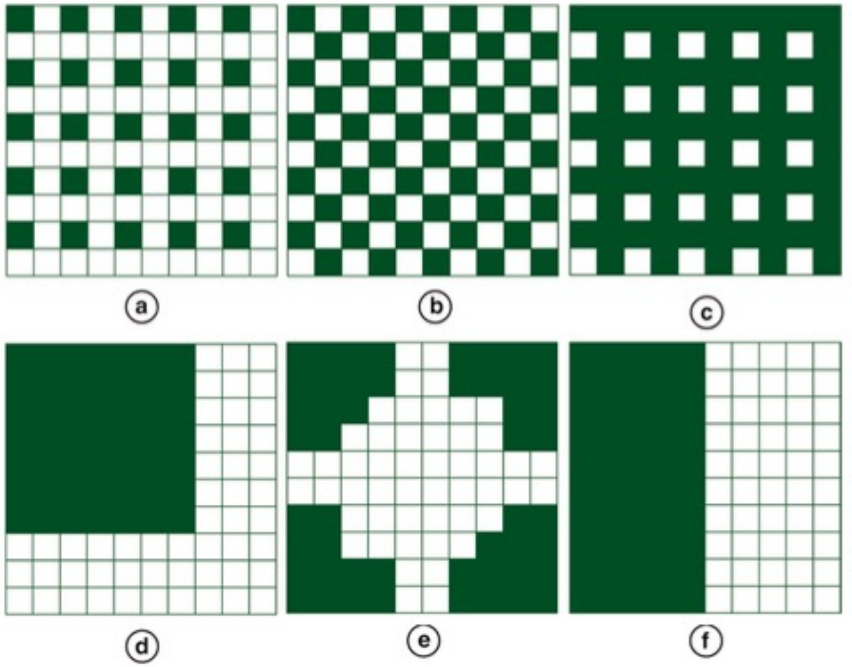
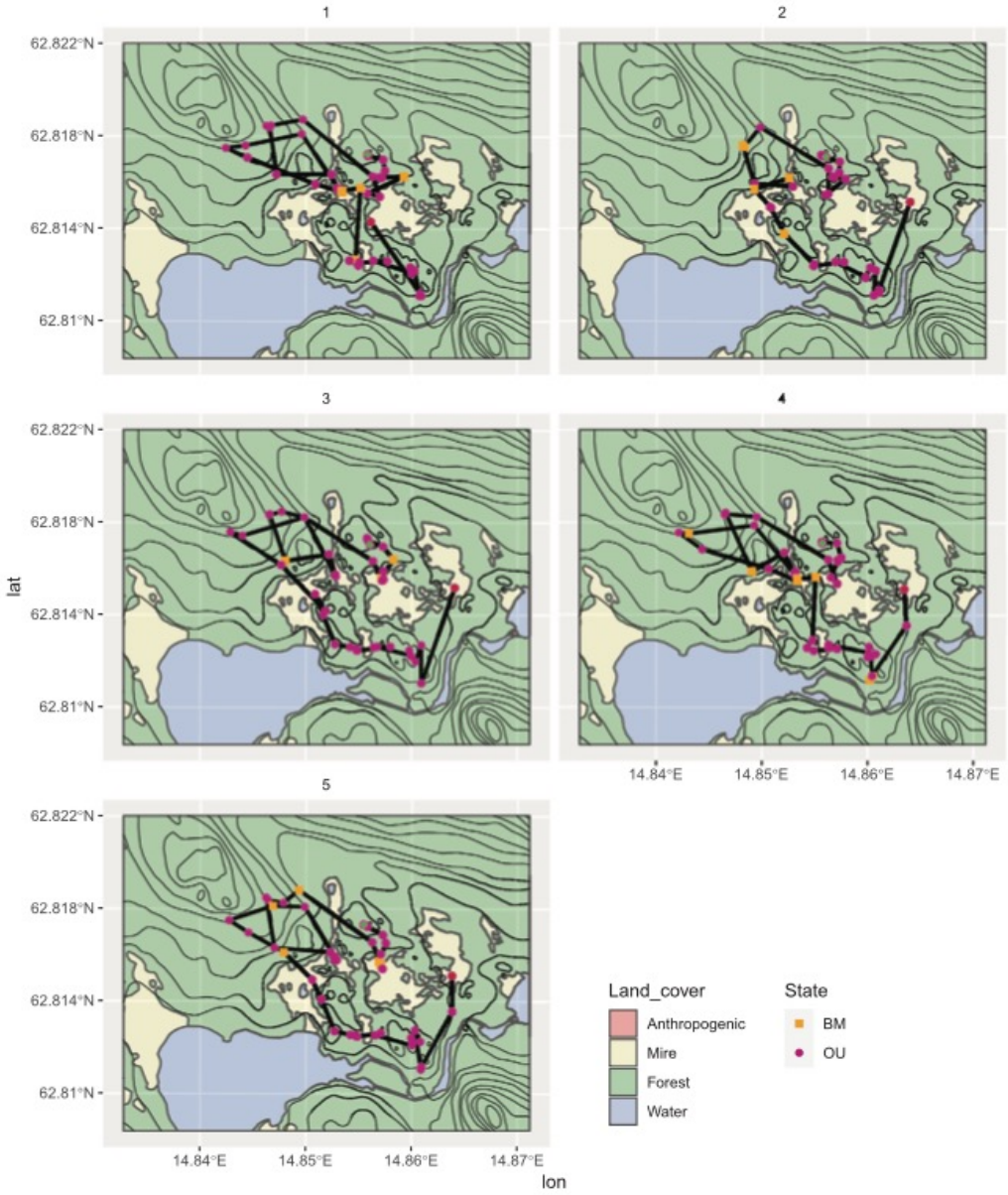


FIGURE 6.7.
Patterns of clearcutting developed under various models by Franklin and Forman (1987). In (**a–c**), a dispersed cut pattern is used in which the amount of cutover area (*black*) varies but there is a regular distribution across the landscape. In (**d–f**), the cutover area is 50 % but it is arranged as a single nucleus, four-nucleus, or progressive parallel cutting system.
ADAPTED FROM FRANKLIN AND FORMAN (1987)

Social interaction - group movement

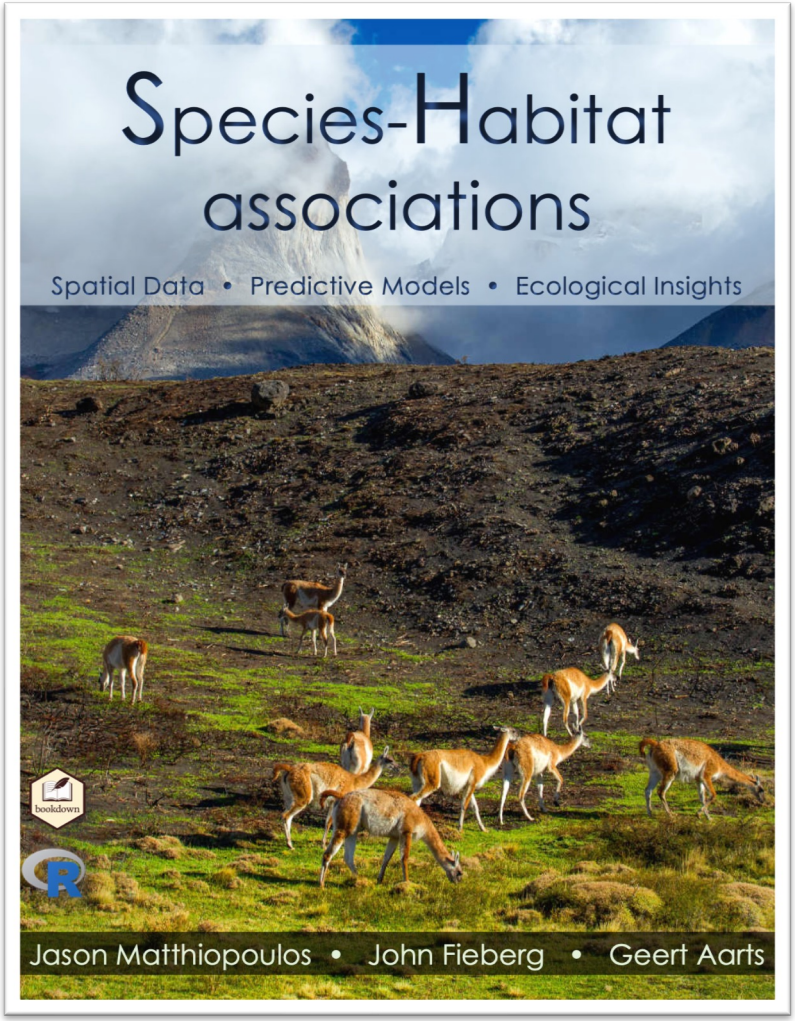
- Possibilities to estimate when animals are grouping and when the movement are independent
- Ornstein-Uhlenbeck (OU) process - group movement
- Brownian motion (BM) - independent movement
  - In forests with lichen

Niu et al. 2020 Biometrics



Population dynamics

- Link between behaviour, habitat selection and population dynamics
- Which habitats is best and give high survival and fitness?

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Establishing the link between habitat selection and animal population dynamics

Jason Matthiopoulos, John Fieberg, Geert Aarts, Hawthorne L. Beyer, Juan M. Morales, Daniel T. Haydon

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