Linking movement and population dynamics

(I wish…)

Juan Manuel Morales

INIBIOMA – CONICET

Universidad Nacional del Comahue

Bariloche, Argentina

What Behavioral Details Should be Considered to Understand and Predict Spatio-Temporal Population Dynamics?

What are the Effects of Landscape Heterogeneity on Population Dynamics?

Mixing

- Classic population models assume well mixed systems
- This allows to write stuff such as:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

- But:
  - Individuals are Discrete Entities
  - Most Ecological Interactions are Local
  - Landscapes are heterogeneous
- Hence:
  - Importance of spatial structure
  - Relevance of habitat fragmentation
  - Need to understand and predict movement

Movement could be the Bridge connecting Behaviour, Landscape Ecology and Population Dynamics

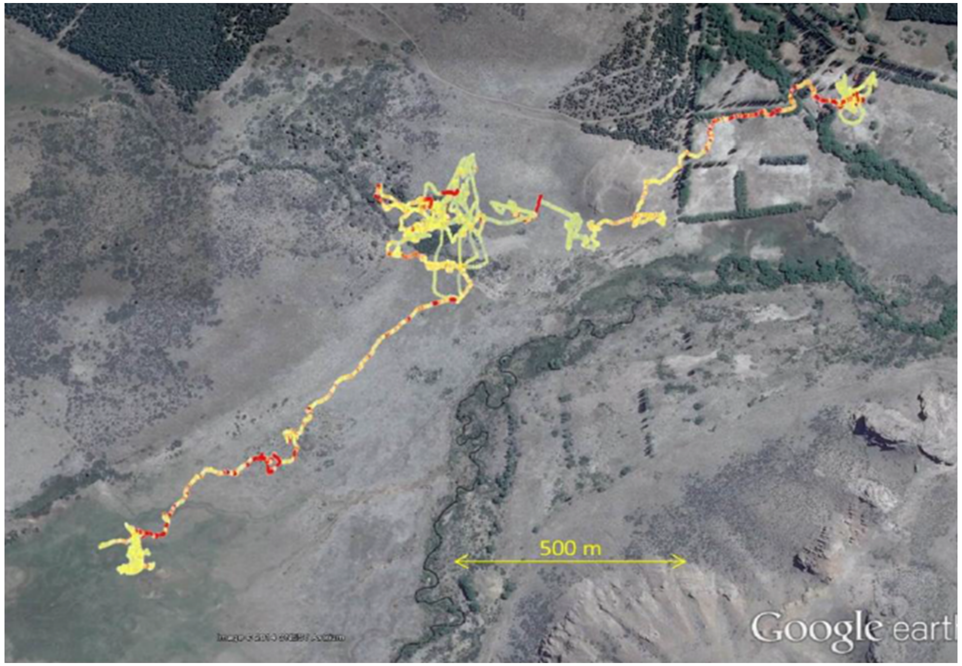
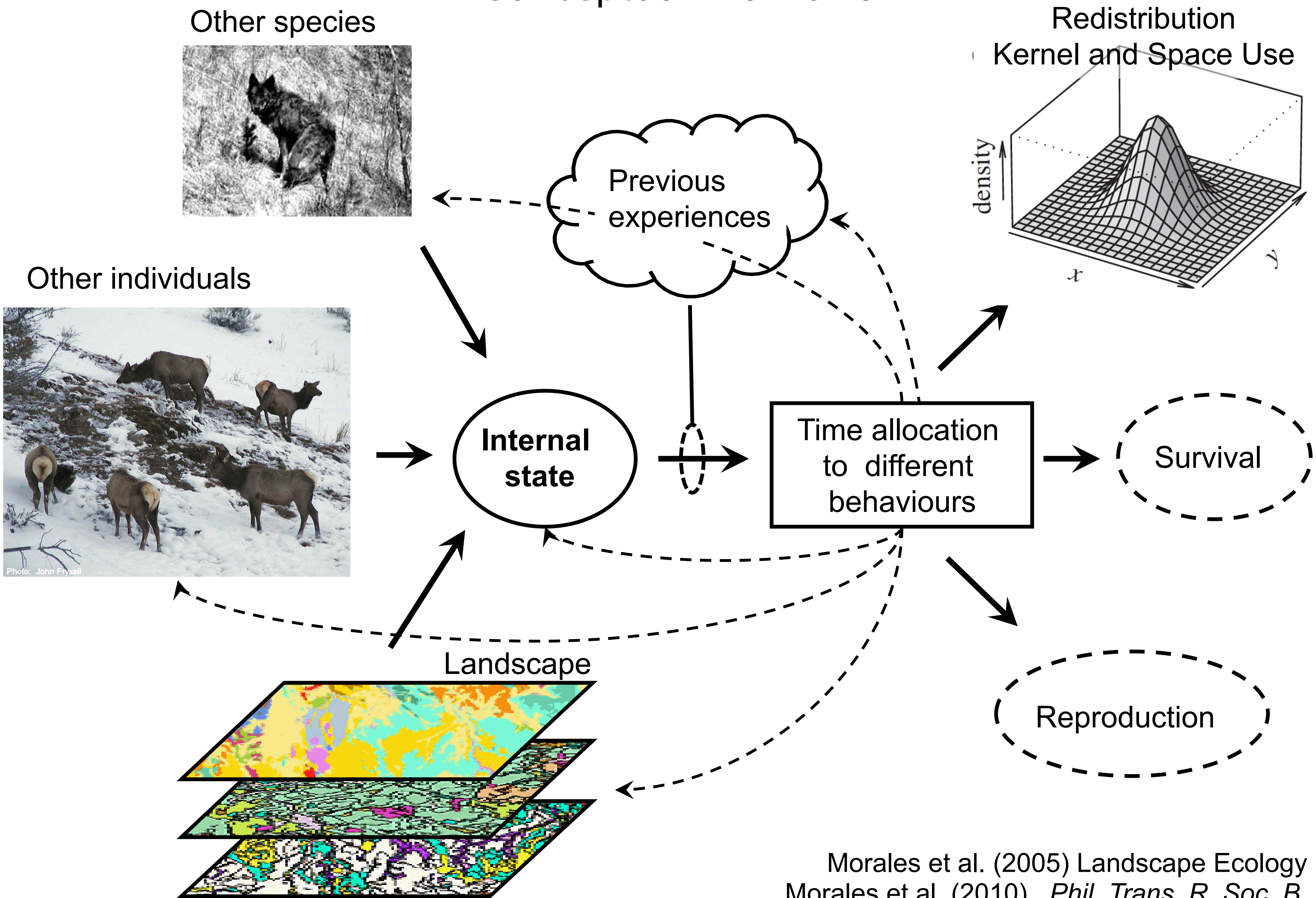


Photo Tomás Carlo

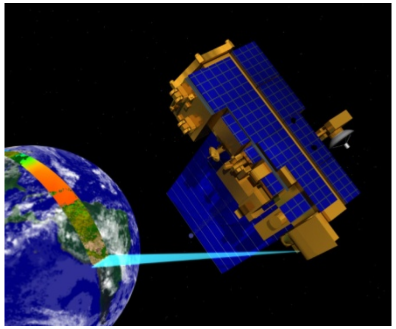
www.jessleephotos.com

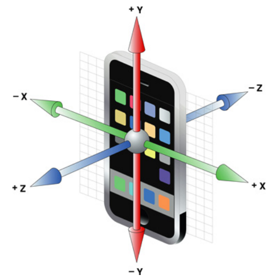
A Conceptual Framework



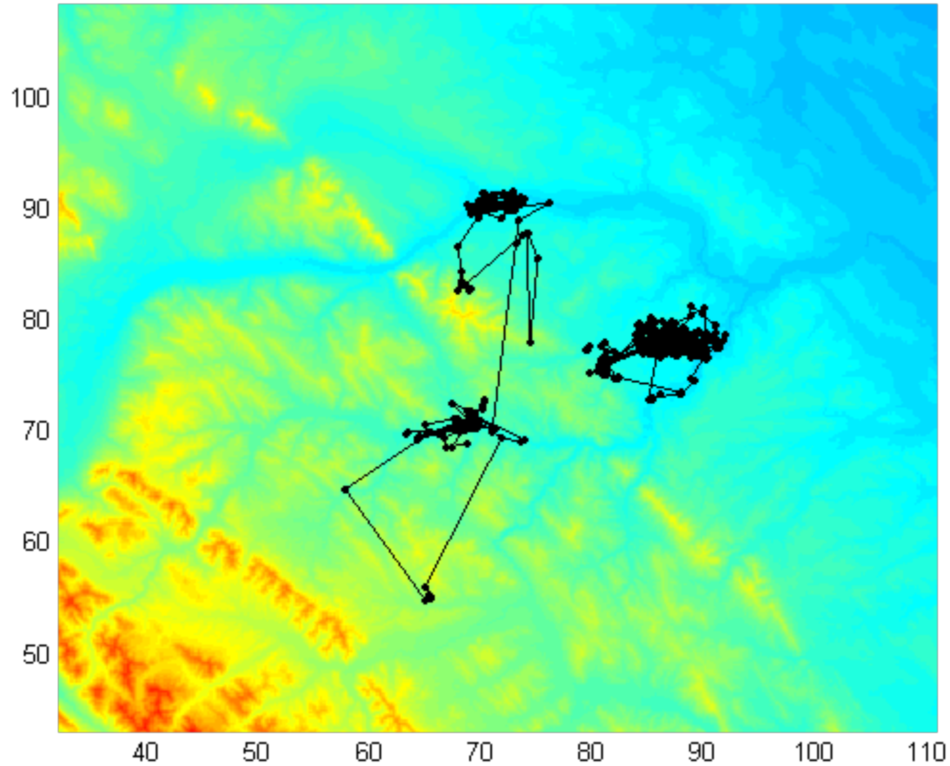
Morales et al. (2005) Landscape Ecology
Morales et al. (2010). *Phil. Trans. R. Soc. B.*

New and Better Technologies for Data Collection





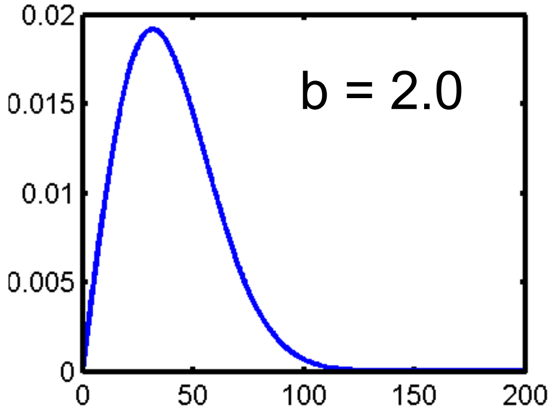
Animals not Always Move in the Same Way…



kilometers

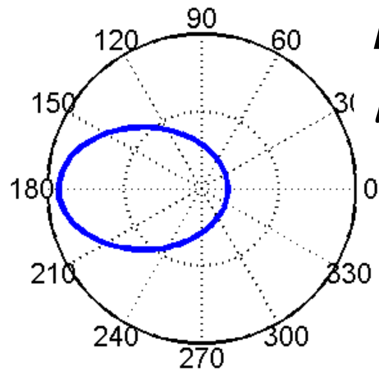
Probability Density Functions for Movement Components

Weibull



$$W(x) = abx^{b-1} \exp\left[-ax^{b}\right]$$

Wrapped Cauchy

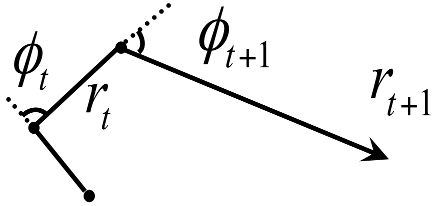


$\rho = 0.4$
$\mu = \pi$

$$C(\phi) = \frac{1}{2\pi} \frac{1-\rho^2}{1+\rho^2 - 2\rho\cos(\phi-\mu)}$$

$$0 \le \phi \le 2\pi, \quad 0 \le \rho \le 1$$

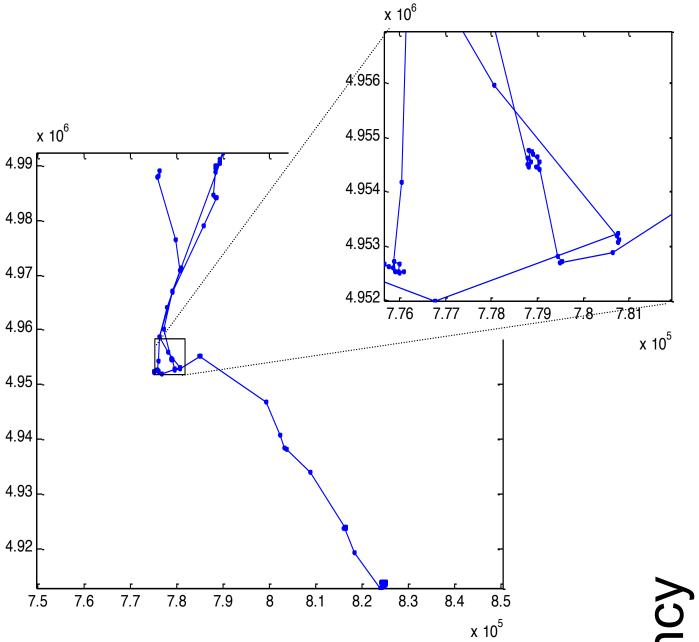
Likelihood Function for a Given State Indicator Vector $\mathbf{z}$



$$\boldsymbol{y} = \begin{pmatrix} r_1 & \phi_1 \\ r_2 & \phi_2 \\ \vdots & \vdots \\ r_T & \phi_T \end{pmatrix} \qquad \mathbf{z} = \begin{pmatrix} z_1 \\ z_2 \\ \vdots \\ z_T \end{pmatrix}$$

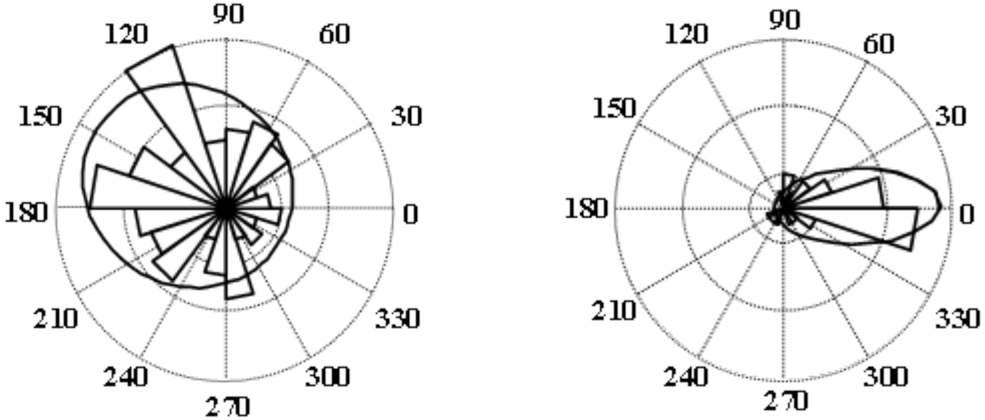
$$p\left(y \middle| a, b, \mu, \rho\right) = \prod_{t=1}^{T} W\left(r_t \middle| a_{z_t}, b_{z_t}\right) C\left(\phi_t \middle| \mu_{z_t}, \rho_{z_t}\right)$$

e.g. Model Fit for Elk 287



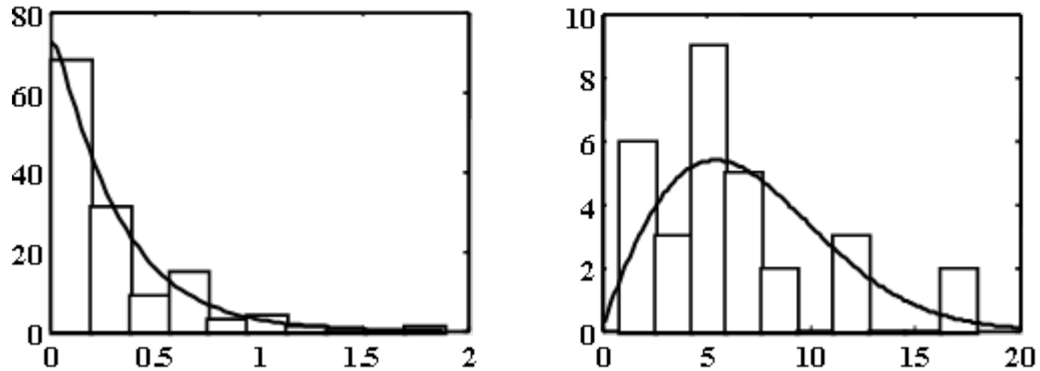
Encamped

Exploratory



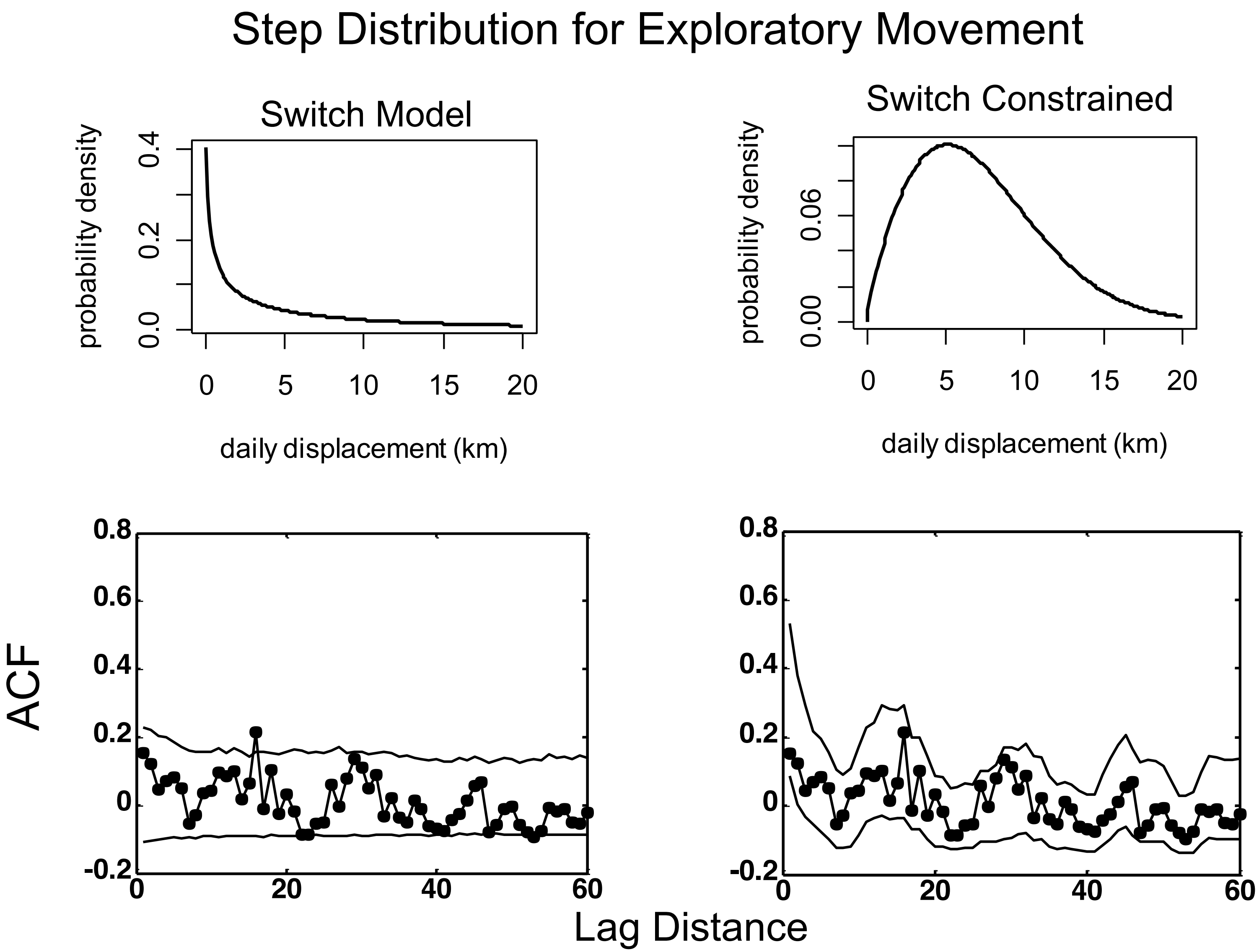
Turning Angles

Frequency



Daily Movement Rate (km)

Emergent Properties of Movement for Model Choice



Switching Among States

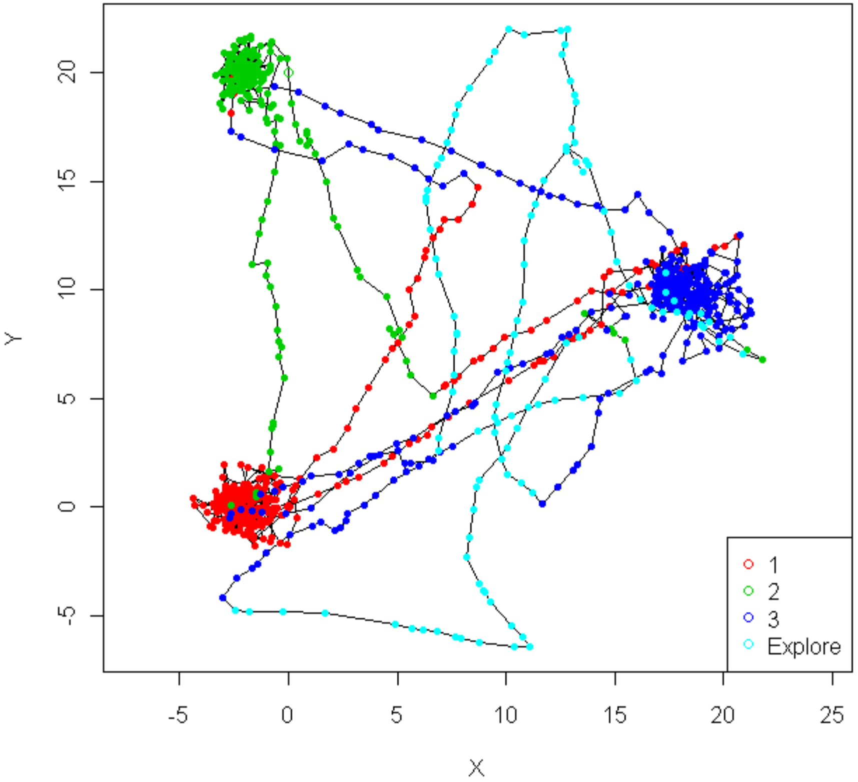
- Depending on:
  - Fixed probabilities
  - Where you are (habitat type)
  - Distance to habitat
  - Group size (Haydon et al. 2008)
  - Who is in the group (Ramos-Fernandez & Morales 2014)

- Probably realistic in many cases:
  - Time in current state
  - Distance to goal

Morales et al. (2004) *Ecology* . Haydon et al. (2008) *Proc. R. Soc. B.*
Ramos-Fernandez & Morales. (2014). *Behavioral Ecology and Sociobiology*

Incorporating Ecological Realism

- Movements may be biased, correlated, exploratory…



$$\phi_t \mid z_t \sim \text{wCauchy}\left(\lambda_t, \eta_t\right)$$

$$\lambda_t = \begin{cases} \phi_{t-1} & \text{if } z_t \text{ is exploratory} \\ \left(1-\rho_t\right)\phi_{t-1} + \rho_t \mu_t & \text{otherwise} \end{cases}$$

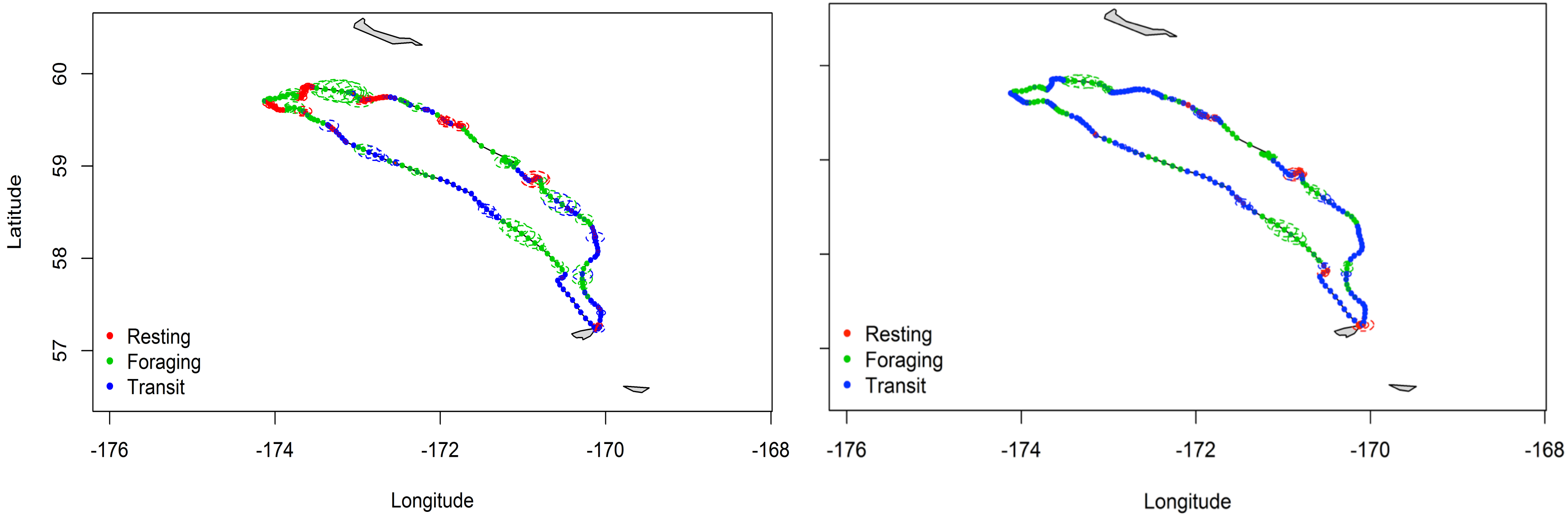
$$\eta_t = \begin{cases} \upsilon_e & \text{if } z_t \text{ is exploratory} \\ \tanh\left(r_{z_t}\delta_t\right) & \text{otherwise} \end{cases}$$

$$z_t \sim \text{Categorical}(\psi_1, \ldots, \psi_{c+1})$$

McClintock et al. (2012). *Ecological Monographs*

Similar But Different…
Continuous-Time RWs

- Continuous-time movement models more realistic. Especially to handle missing data and irregular observations.
- But autocorrelated velocity implies that long steps are associated with small turns. McClintock B.T. et al. (2014). *Movement Ecology*



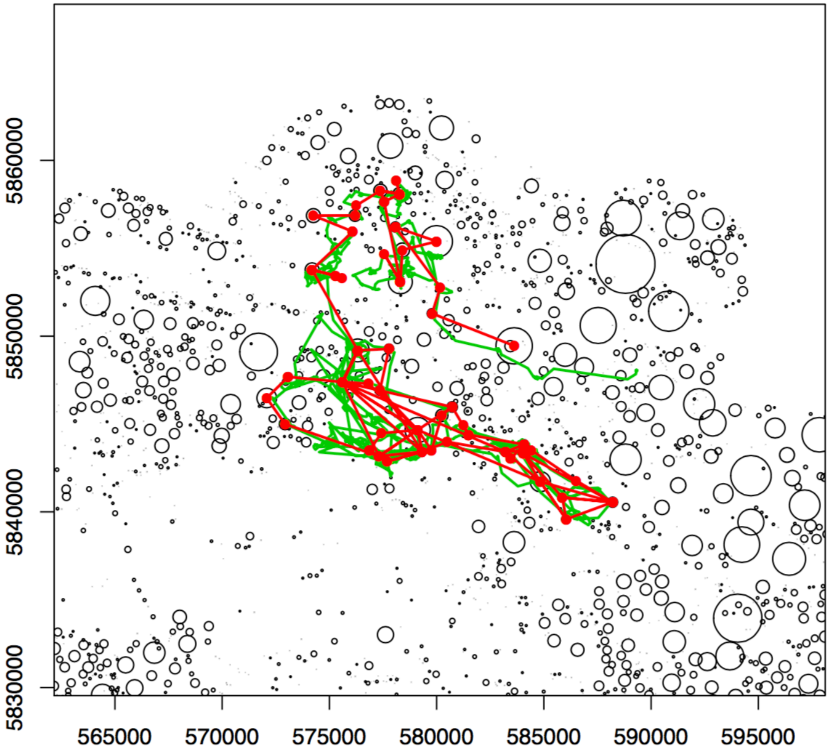
Including Memory in Movement Models

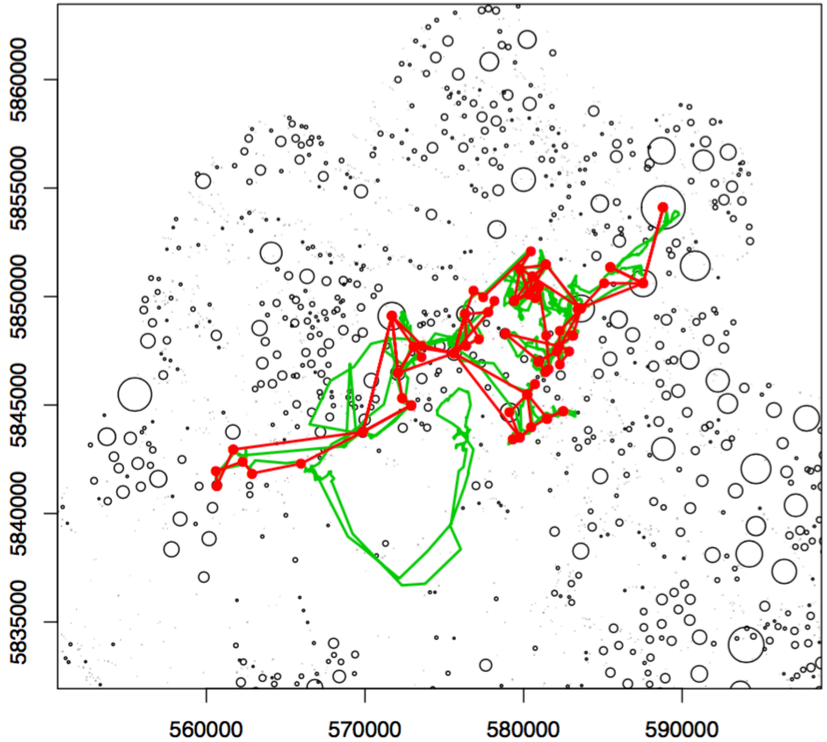
- 19 relocated elk in Alberta (Animals are new to the landscape)
- GPS location every 2 hours for up to 12 months

How do they update their movement decisions as they learn about the landscape?

- Several simplifications:
  - "Foraging Patches" identified from GIS and field work
  - Movement transformed into patch-to-patch plus "residence" and travel time

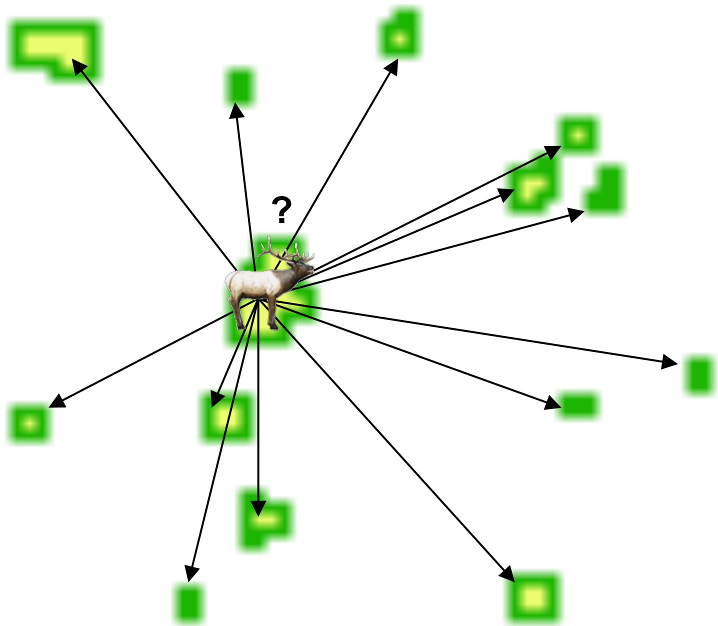
Relocated Elk in the Canadian Rockies





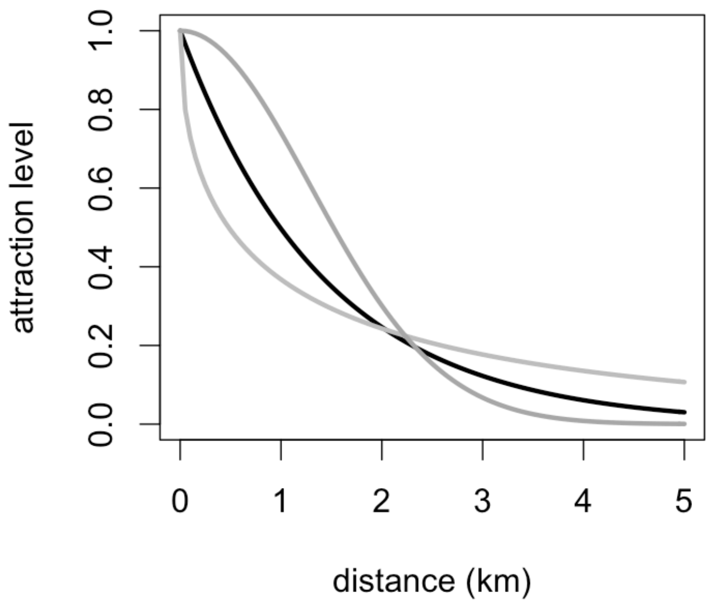
Where to go next?

Distance only

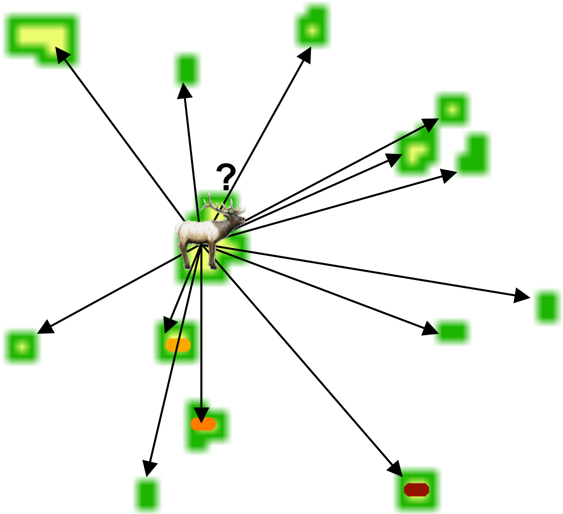


$$\delta_i = \exp\left(-a \times r_i^b\right),$$

$$D = \frac{\delta}{\sum \delta}$$



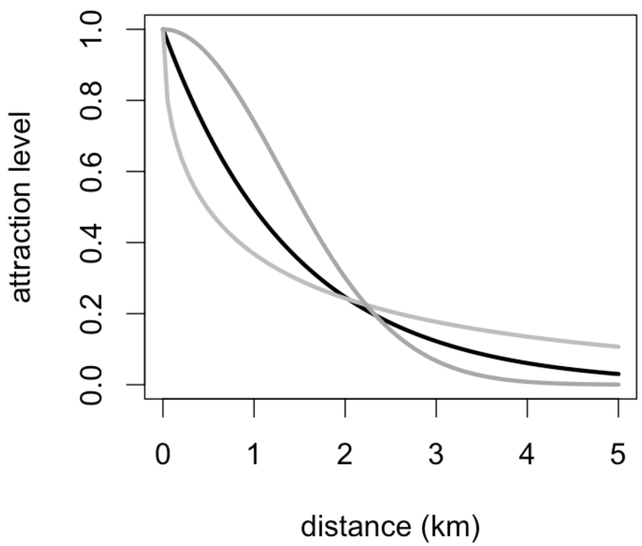
Distance and number of visits

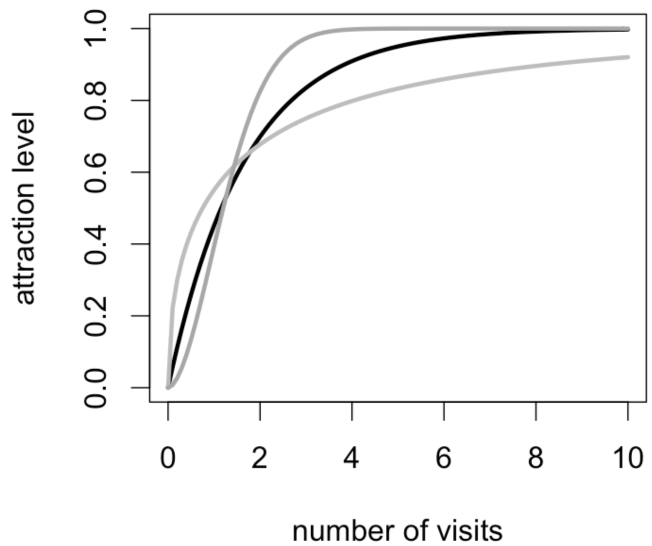


$$\delta_{ij} = \exp\left(-a r_{ij}^{b}\right),$$

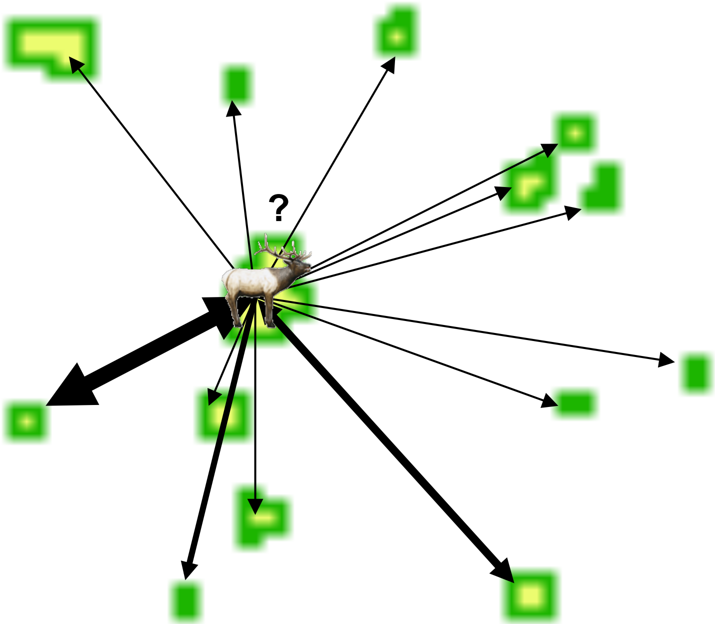
$$\mu_{ij} = \begin{cases} \exp\left(-ct\right) & \text{if } v_j = 0 \\ 1 - \exp\left(g v_j^{h}\right) & \text{otherwise} \end{cases}$$

$$D = \frac{\delta \times \mu}{\sum \delta \times \mu}$$





Distance and “edge” use



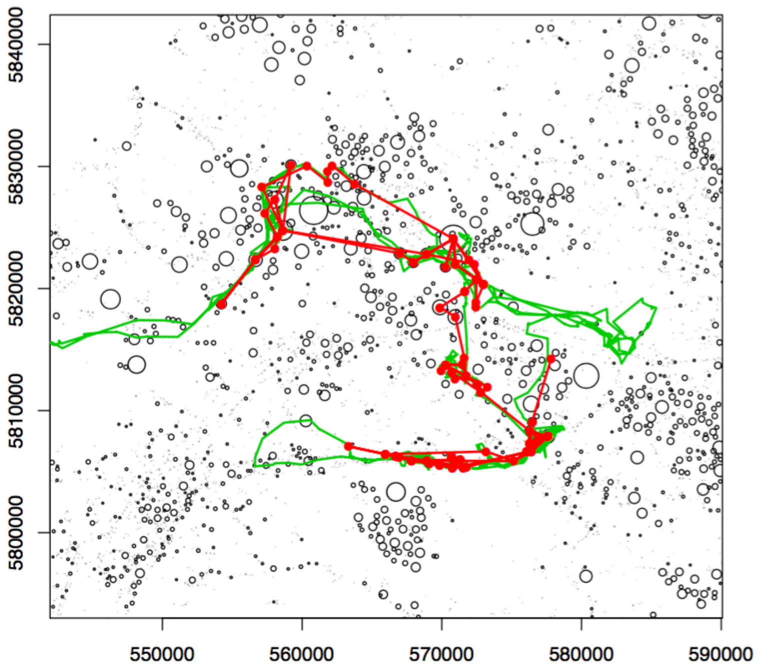
$$\delta_{ij} = \exp\left(-a r_{ij}^{b}\right),$$

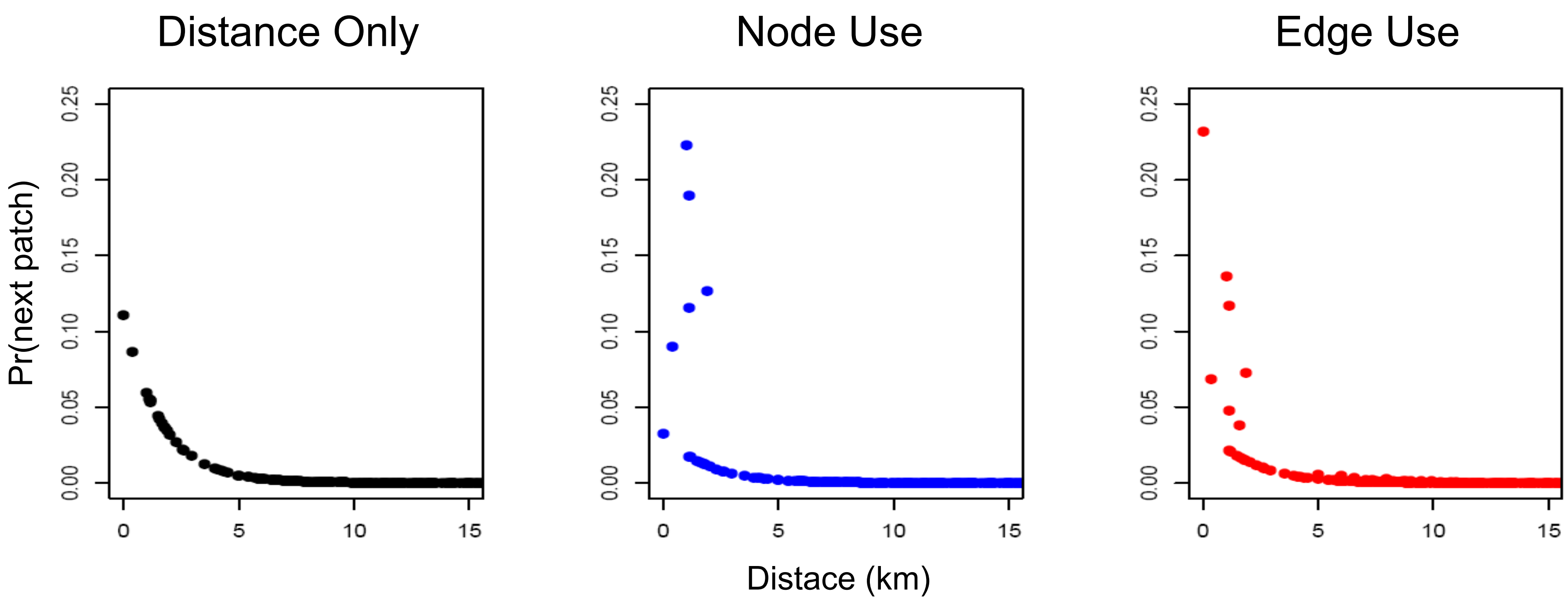
$$\mu_{ij} = \begin{cases} \exp\left(-ct\right) & \text{if } v_j = 0 \\ 1 - \exp\left(g v_j^{h}\right) & \text{otherwise} \end{cases}$$

$$D = \frac{\delta \times \mu}{\sum \delta \times \mu}$$

e.g. elk 4015

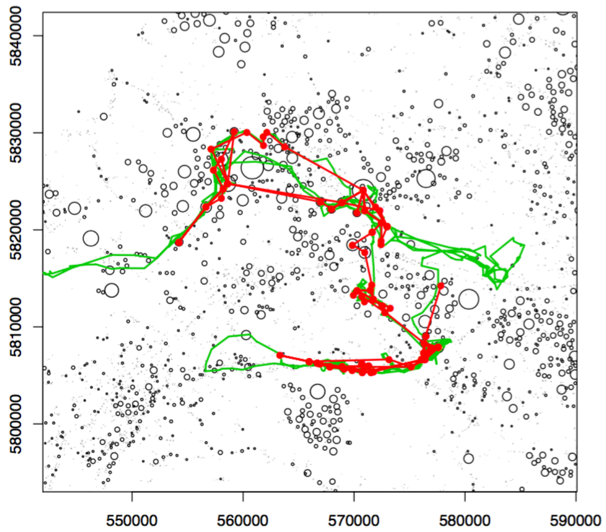
- Distribution of probabilities of being chosen for all patches at the last observed movement according to:

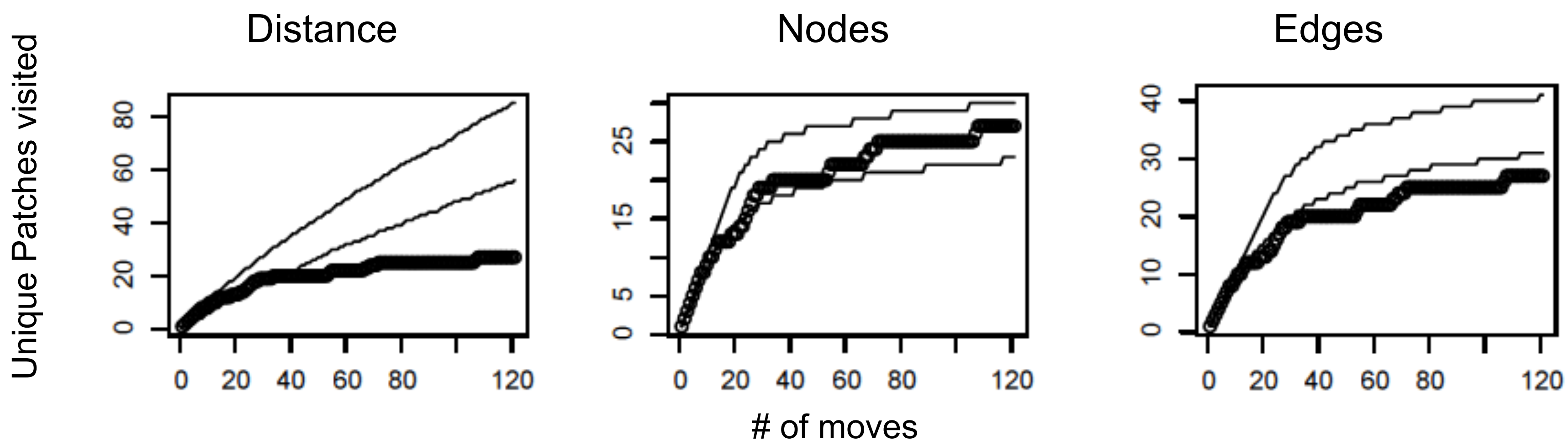




Checking Emergent Properties

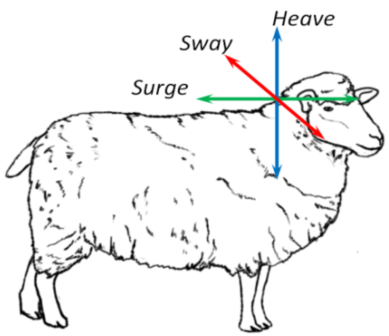
- Models fitted using Maximum Likelihood
- Model comparison using AIC shows that reinforcing "nodes" or "edges" fits equally well to the data
- But they are NOT equivalent!

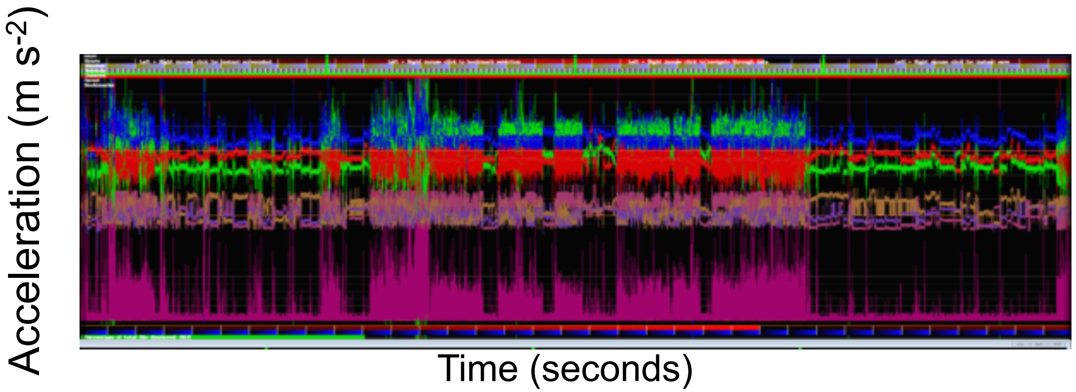




Even Bigger Models with More Sources of Data?

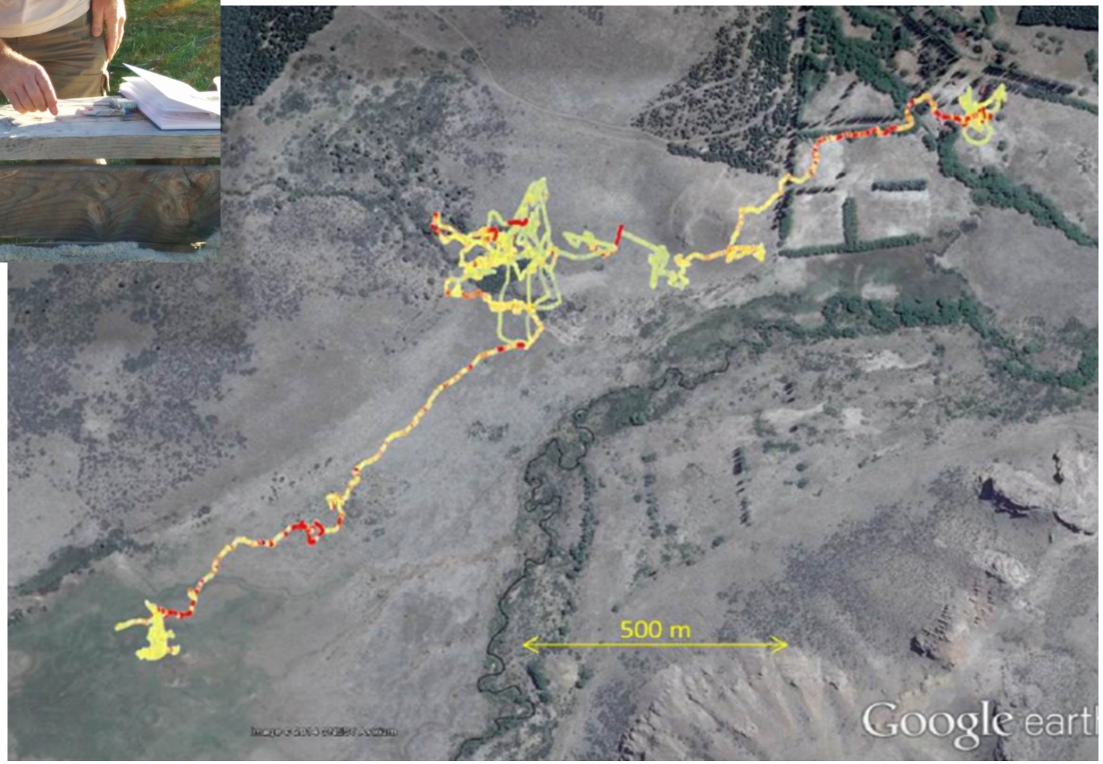
- Through **Biotelemetry** we can get lots of “extra” data
- For example, accelerometers can help in the identification of behavioral states

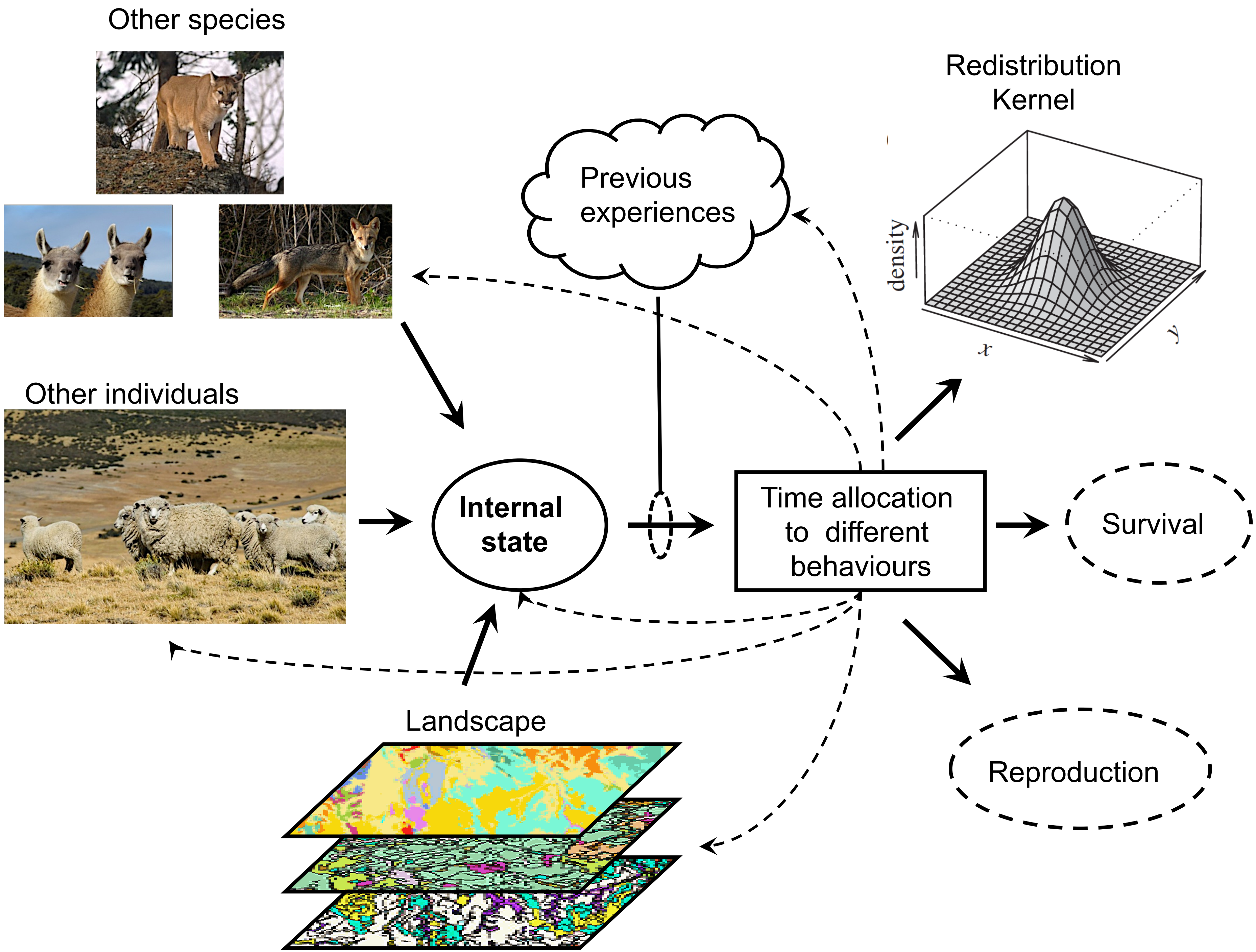




Accelerometers and GPS

Agustina diVirgilio
Sergio Lambertucci
Rory Wilson




Other species
Redistribution Kernel
Previous experiences
density
x
y
Other individuals
Internal state
Time allocation to different behaviours
Survival
Landscape
Reproduction


and now it's time for something completely different

Seed Dispersal by Thrushes in Northern Spain

- Collaboration with Daniel García (Universidad de Oviedo) and Tomás Carlo (Penn State)

Movement Sequences

T. iliacus

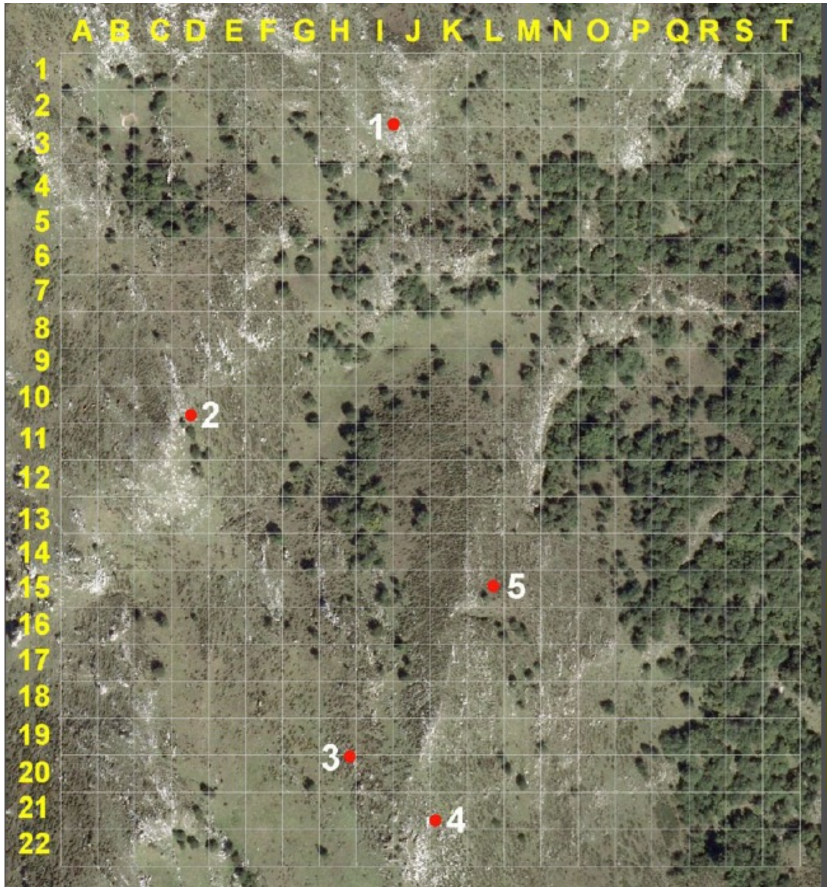
T. philomelos

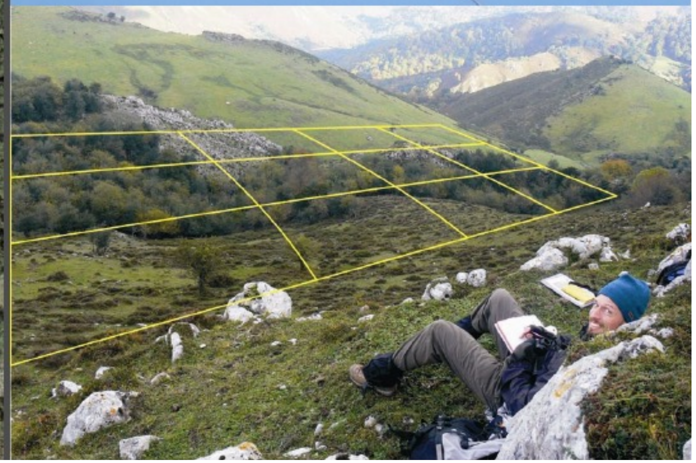
T. merula

T. pilaris

T. torquatus

T. viscivorus

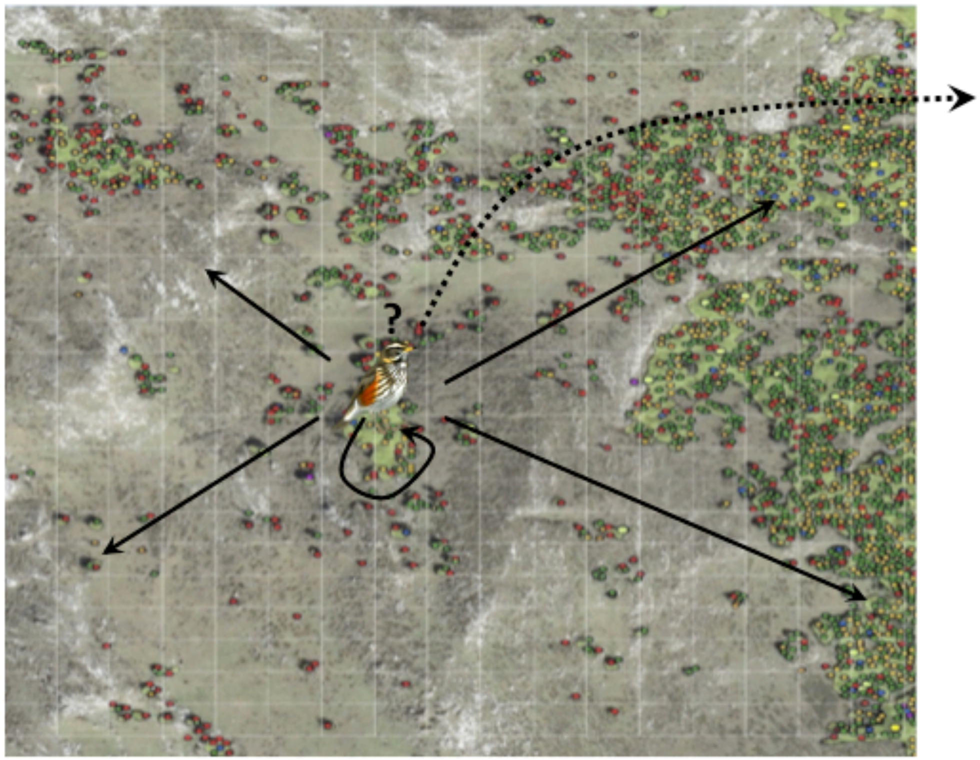




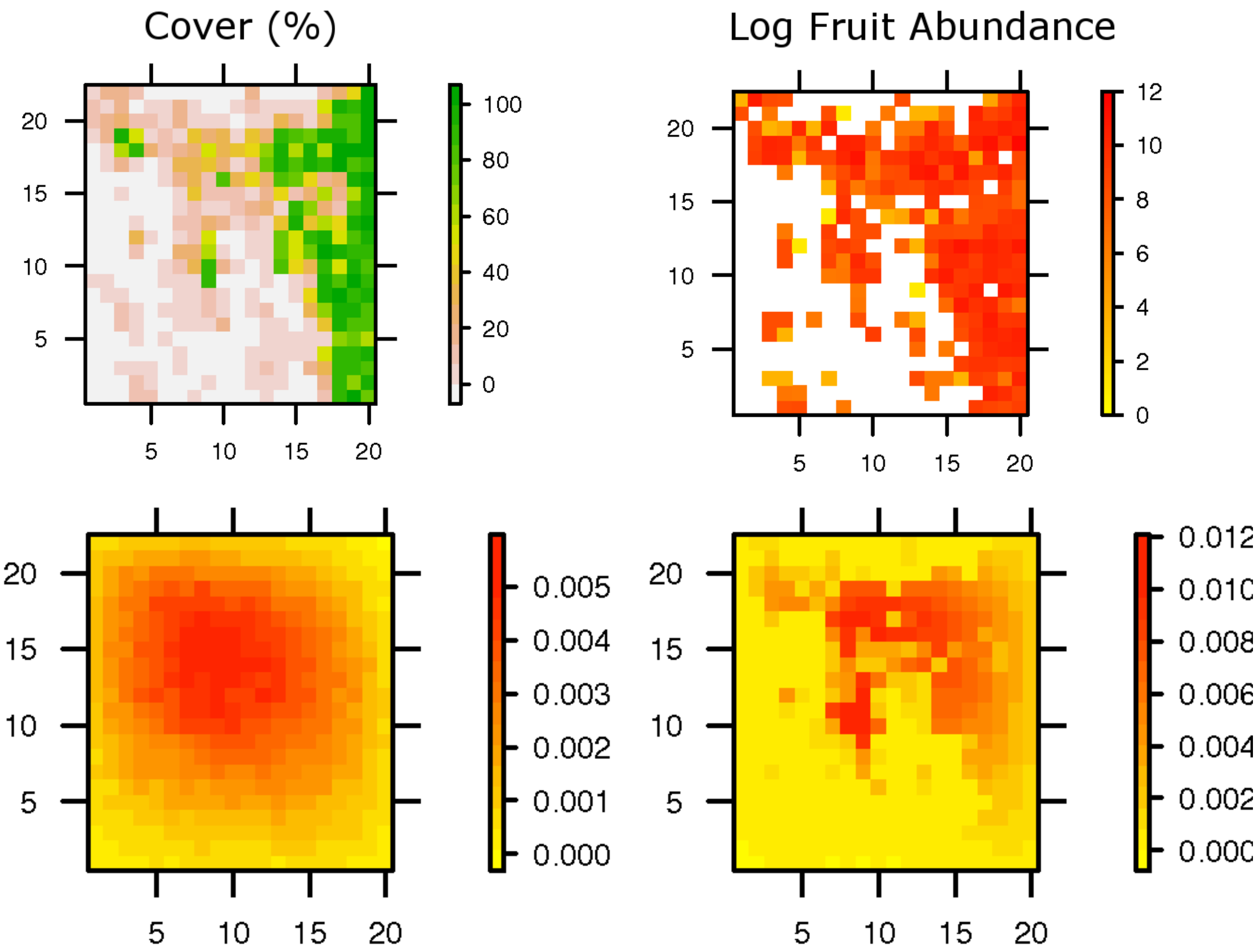
The Observers: Daniel García, José M. Herrera, Daniel Martínez and Javier Rodríguez-Pérez

Bird Movement and Seed Dispersal

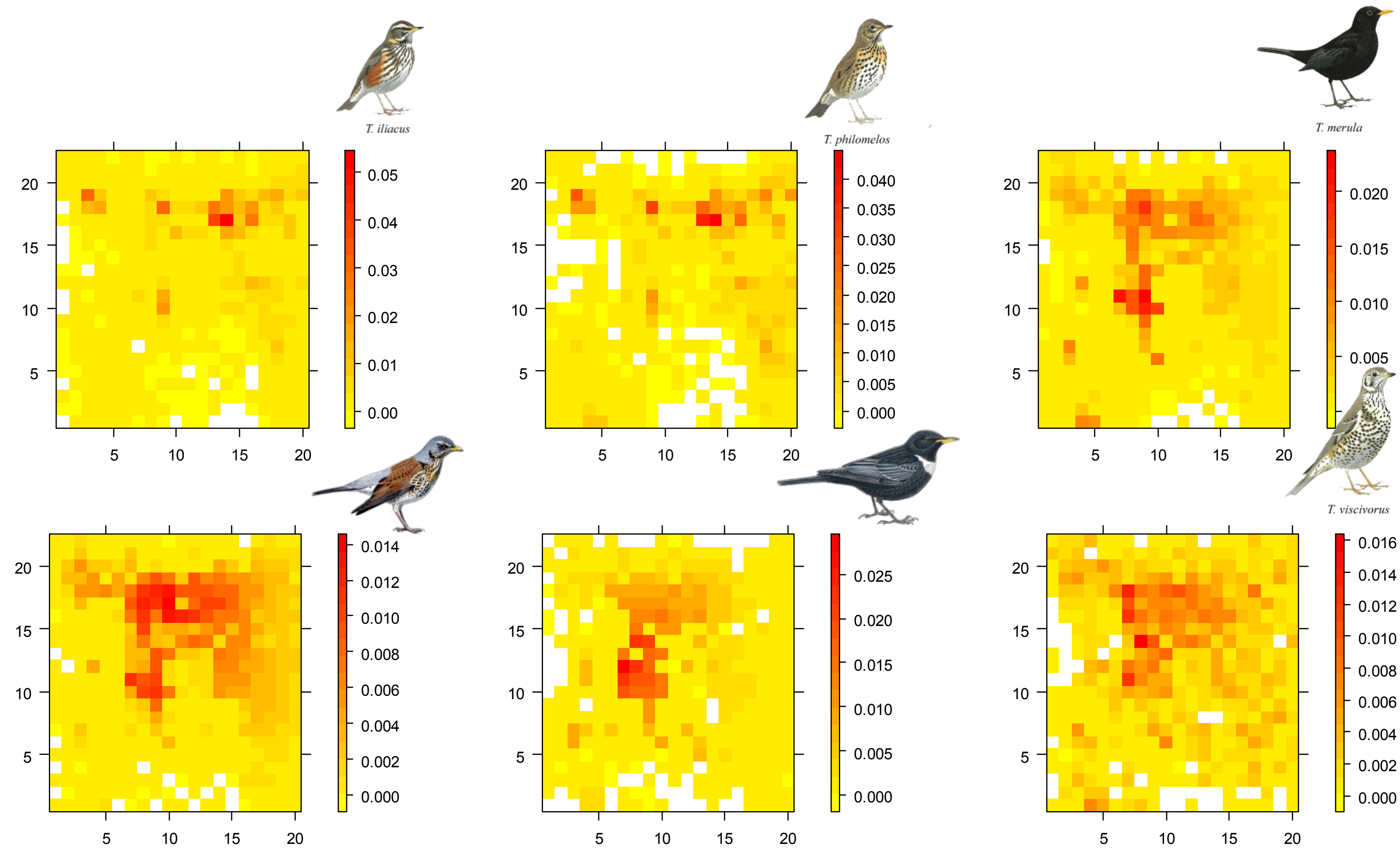
- Model:
  - Time perching
  - Fruit consumption
  - Gut passage time
  - Movement as function of distance, vegetation cover and fruit abundance
  - Movement time



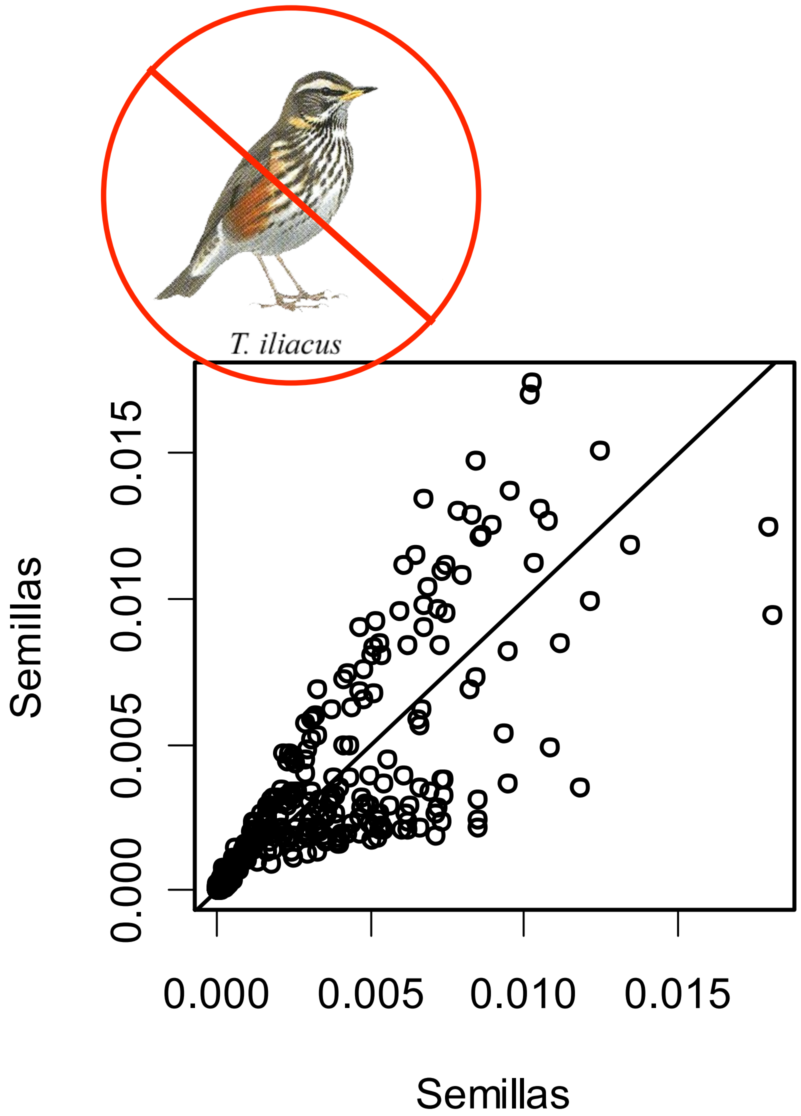
Importance of Bias

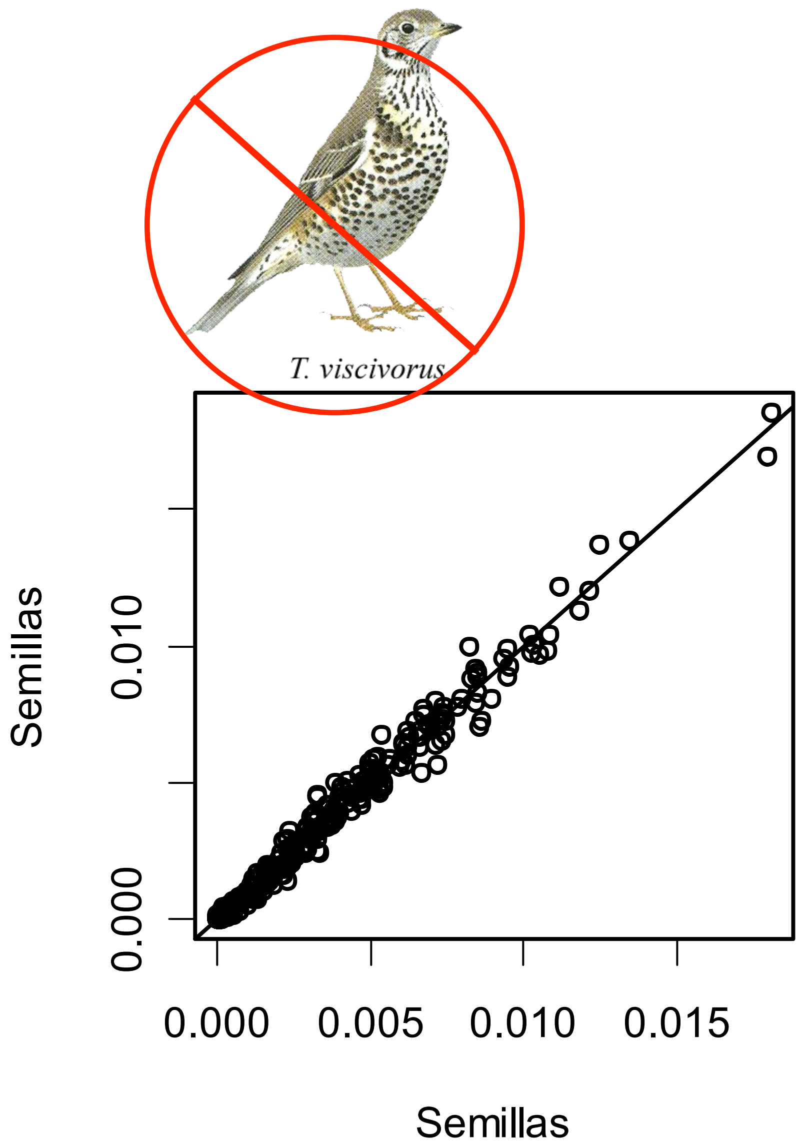


Seed Rain by Bird Species



Changes in the Community of Dispersers





Summary

- We should pay attention to different aspects of movement, including "emergent" properties

- Persistence might not be enough. Biased random walks more realistic in many conditions

- Memory (reinforcement) important for patterns of space use

Thanks!

https://sites.google.com/site/pajarom/