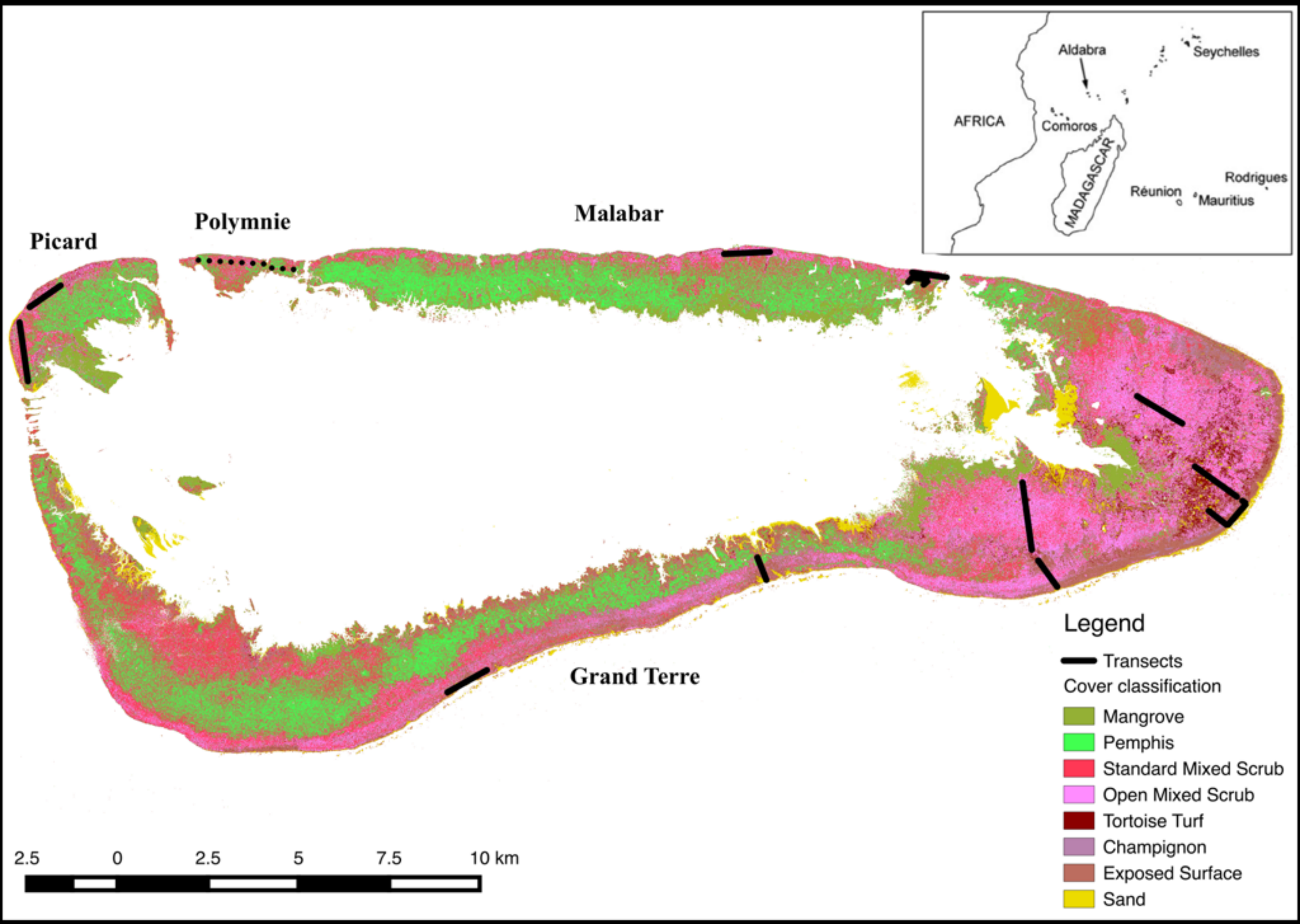
Continuous-time discrete-space models for animal movement

EM Hanks, MB Hooten & MW Alldredge (2015) *Ann. Appl. Stat.* 9(1): 145–165

Why this paper?

Seed dispersal on Aldabra Atoll


Aldabra
Seychelles
AFRICA
Comoros
MADAGASCAR
Réunion
Mauritius
Rodrigues
Picard
Polymnie
Malabar
Grand Terre
2.5 0 2.5 5 7.5 10 km
Legend
Transects
Cover classification
Mangrove
Pemphis
Standard Mixed Scrub
Open Mixed Scrub
Tortoise Turf
Champignon
Exposed Surface
Sand

Seed dispersal on Aldabra Atoll

Structure of the seed dispersal network

Factors influencing frugivore movement

Predicting animal-mediated seed deposition

Fruit bat

Fody

Turtledove

Bulbul

Giant tortoise

Blue pigeon

Land crab

A

P

Solanum aldabrense

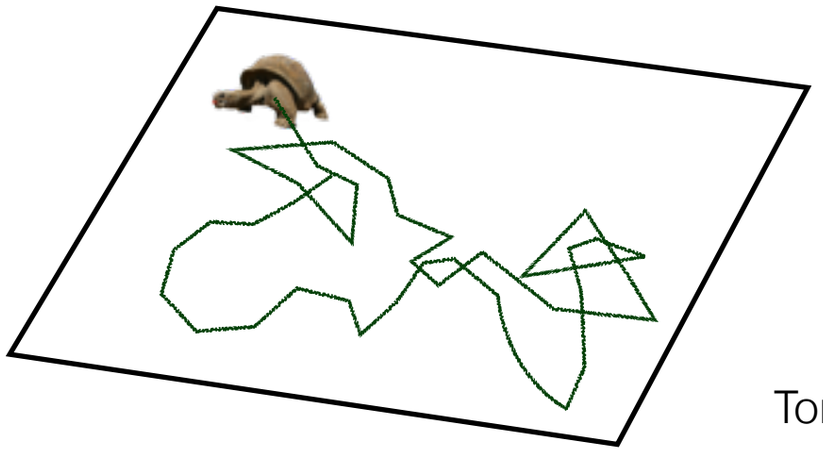
Seed dispersal on Aldabra Atoll

Structure of the seed dispersal network

Factors influencing frugivore movement

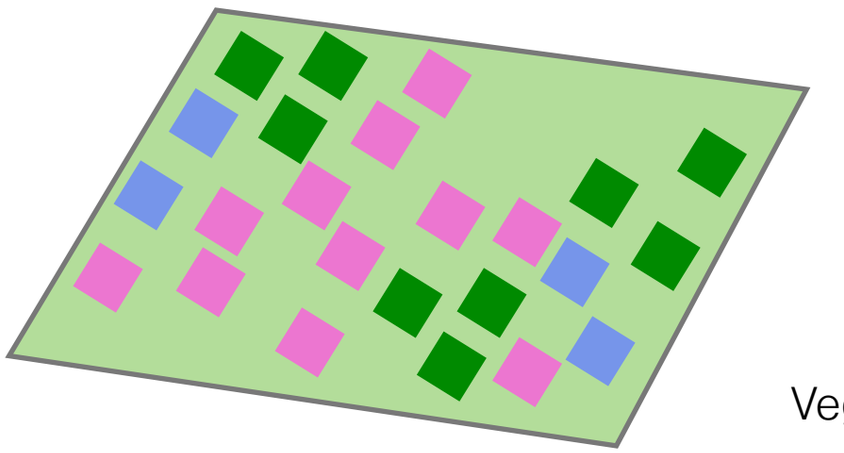
Predicting animal-mediated seed deposition

Data for model parameterisation



Tortoise movement

+



Vegetation map

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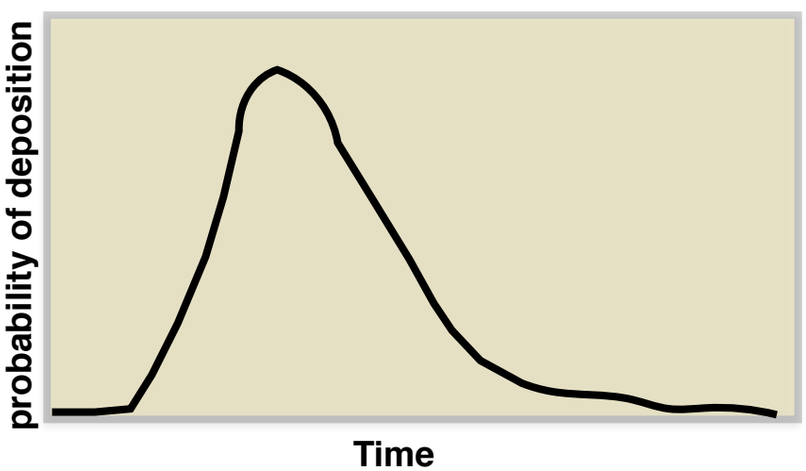
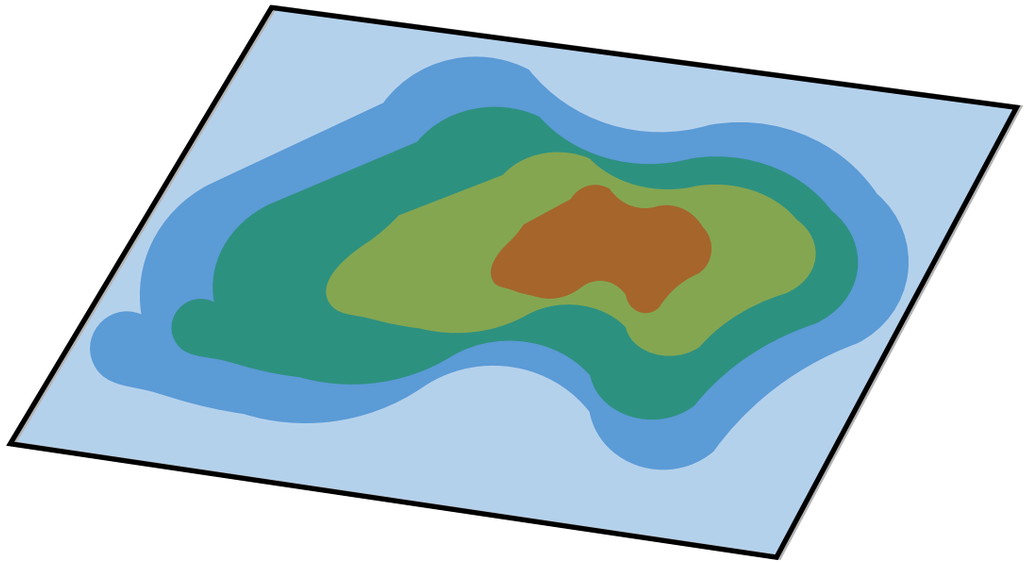
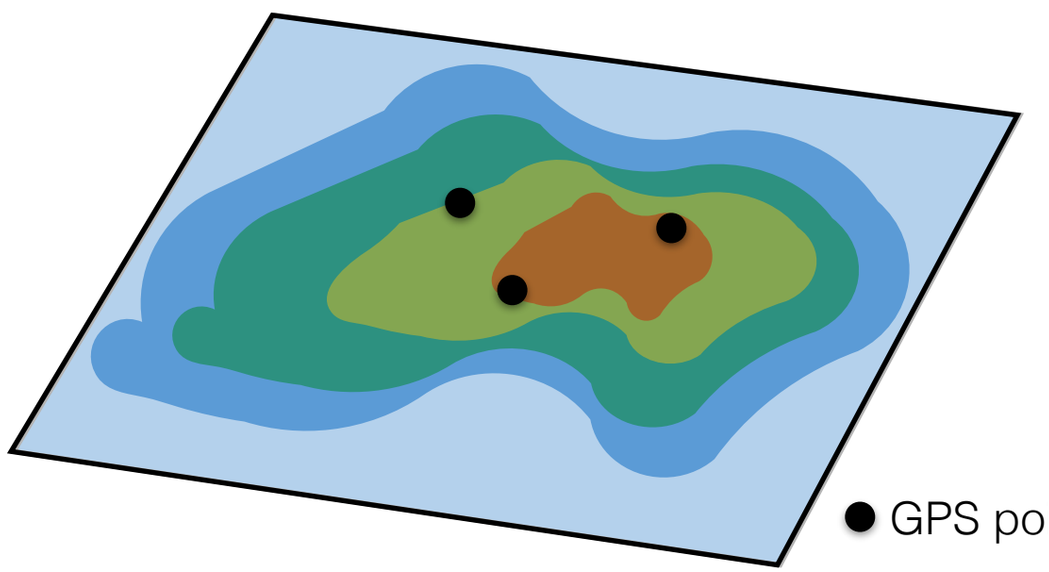


GRT

Seed deposition probability map

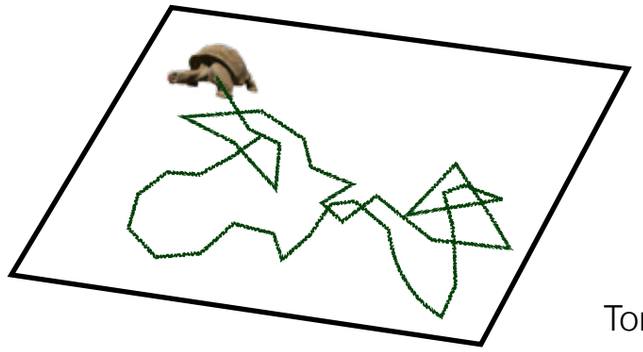


Model validation: Field test



So, I'm looking to integrate the following variables:

- **Habitat (vegetation)**
  - Discrete (cover type; 2 m^2 res.)
  - Temporal (?) (NDVI; 2-week res.)
- **Giant tortoise**
  - Movement behaviour (GPS-fixes; 1h res.)
  - Gut retention time (GRT; feeding trials)



Tortoise movement

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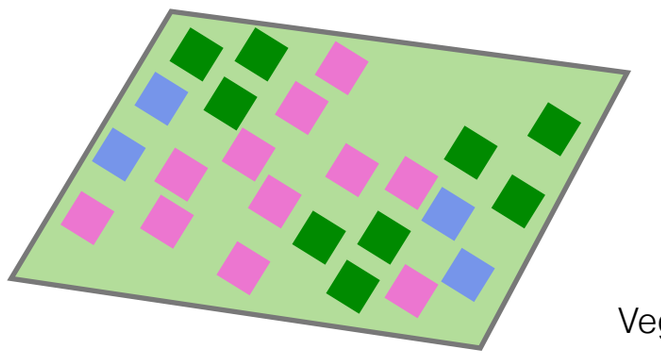

Vegetation map

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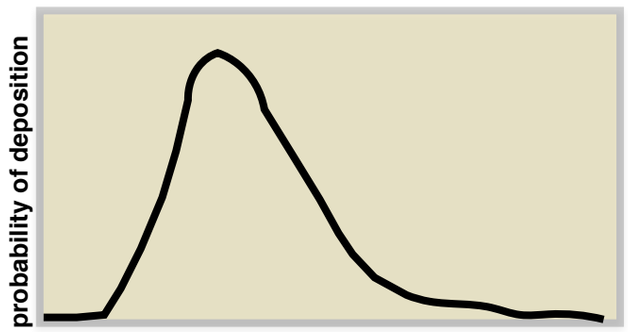

GRT

Back to the CTDS model…

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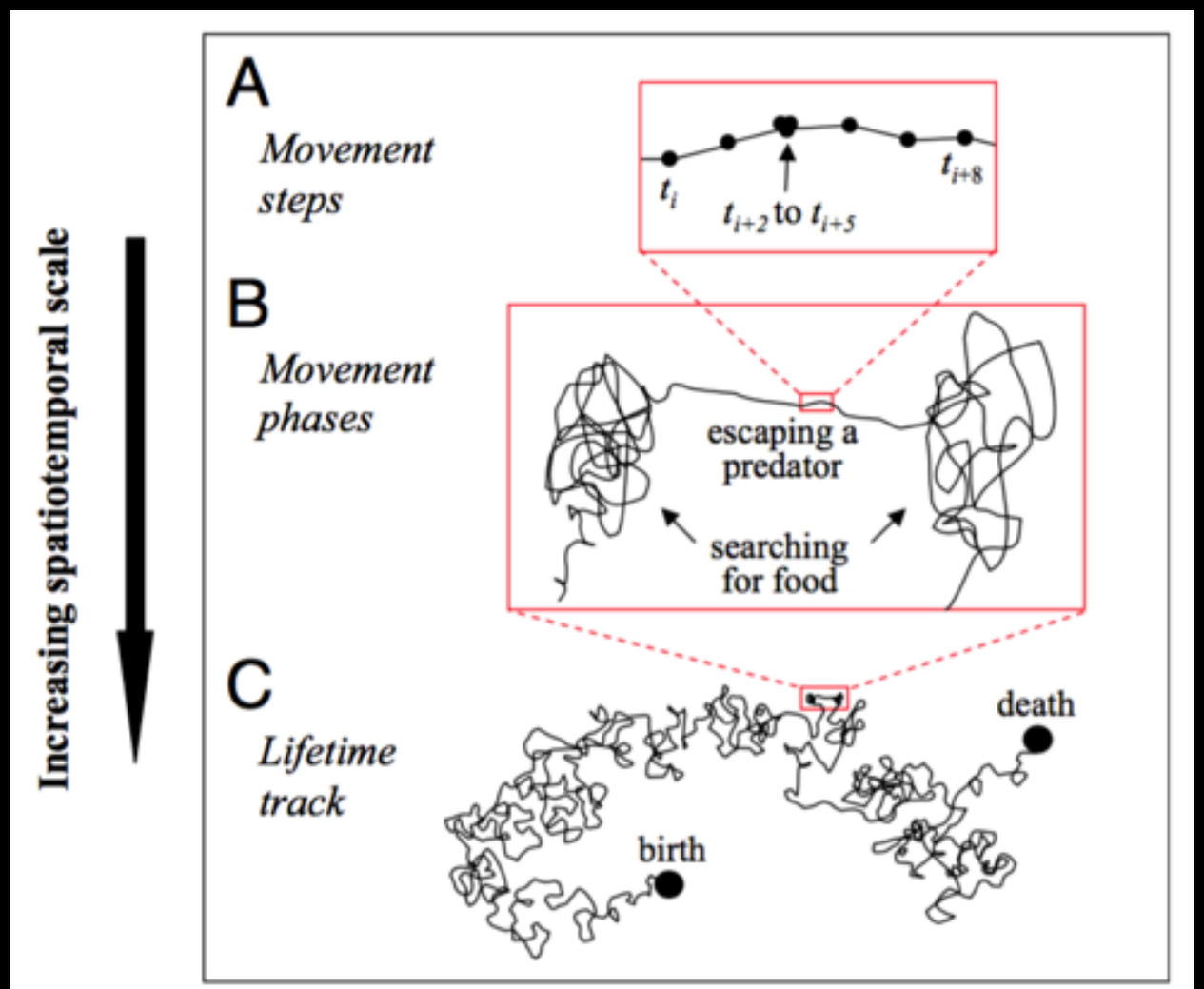
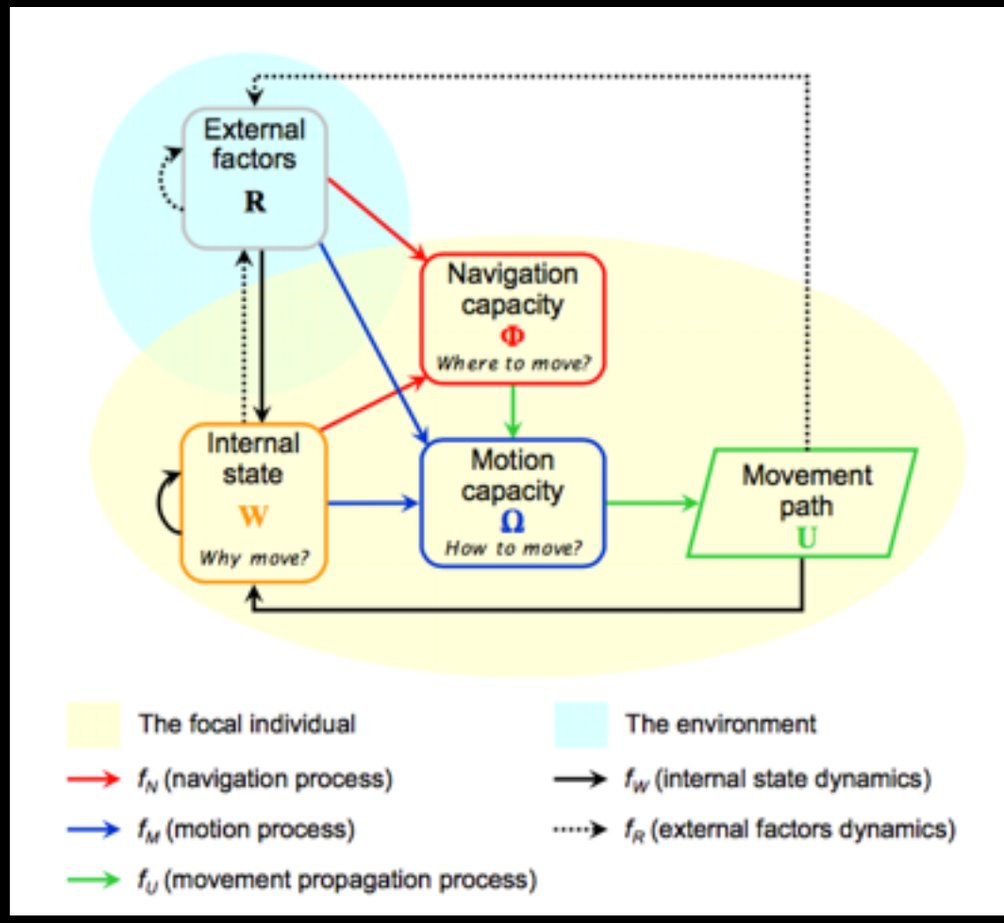
CONTINUOUS-TIME DISCRETE-SPACE MODELS FOR ANIMAL MOVEMENT

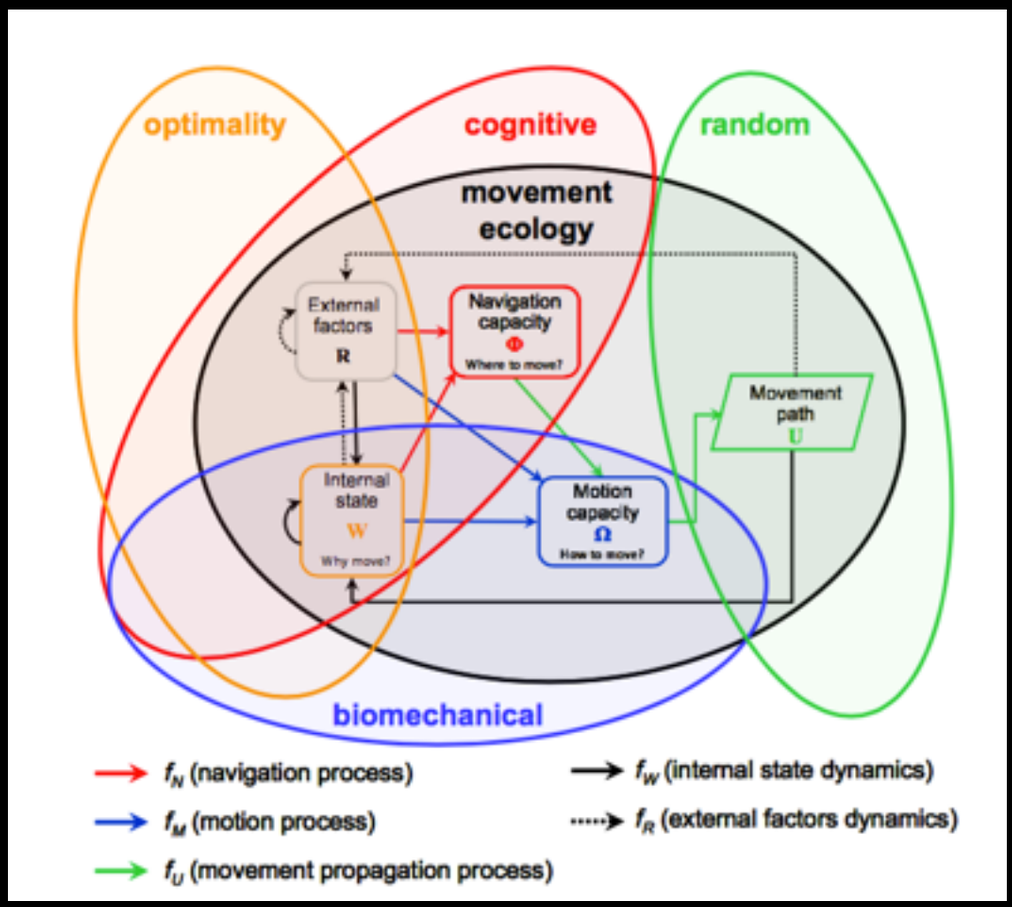
By Ephraim M. Hanks*, Mevin B. Hooten†,‡
and Mat W. Alldredge§

Animal movement behaviour:

☑ It's Complicated







Nathan *et al*. (2008) *PNAS* 105(49): 19052–19059

The framework:

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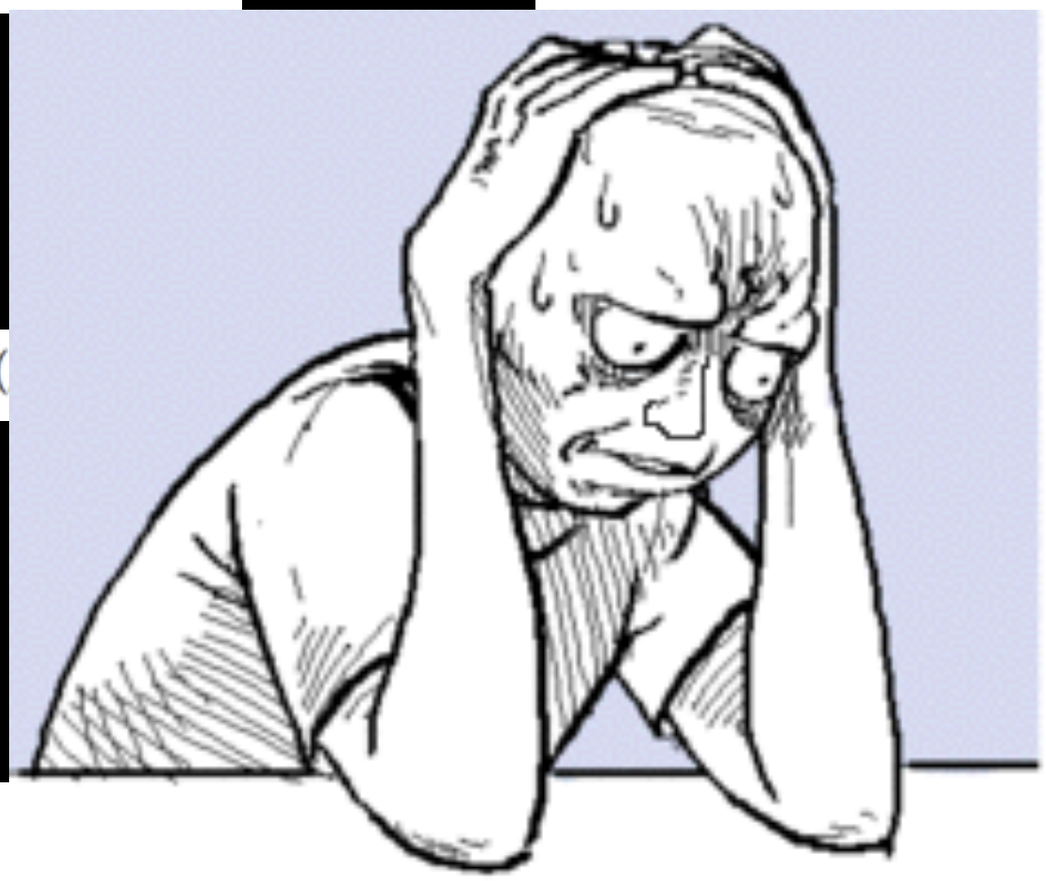
CONTINUOUS-TIME DISCRETE-SPACE MODELS FOR ANIMAL MOVEMENT

I

$$\lambda_{i_t j_t}(\boldsymbol{\beta}) = \exp\{\mathbf{x}'_{i_t j_t}\boldsymbol{\beta}\},$$

$$[\tau_t|\boldsymbol{\beta}] = \lambda_{i_t}(\boldsymbol{\beta})\exp\{-\tau_t\lambda_{i_t}(\boldsymbol{\beta})\}.$$



II

$$[z_{i_t j_t}, \tau_t|\boldsymbol{\beta}] \propto \lambda_{i_t j_t}^{z_{i_t j_t}} \exp\{-\tau_t\lambda_{i_t j_t}($$

$$] = [\mathbf{Z}, \boldsymbol{\tau}|\boldsymbol{\beta}] \propto \prod_{t=1}^{T}\prod_{i_t \sim j_t} [\lambda_{i_t j_t}^{z_{i_t j_t}}(\boldsymbol{\beta})\exp\{-\tau_t\lambda_{i_t j_t}(\boldsymbol{\beta})\}],$$

$$\alpha_k\phi_k(t)\Big\}$$

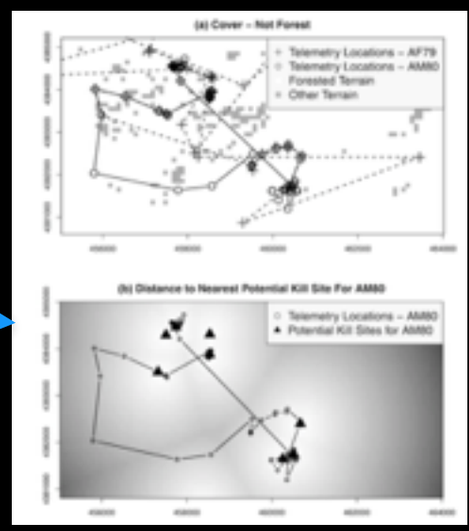
III

$$E(\boldsymbol{\beta}|\mathbf{S}) \approx E_{\tilde{\mathbf{S}}|\mathbf{S}}(E(\boldsymbol{\beta}|\tilde{\mathbf{S}}))$$

$$\mathrm{Var}(\boldsymbol{\beta}|\mathbf{S}) \approx E_{\tilde{\mathbf{S}}|\mathbf{S}}(\mathrm{Var}(\boldsymbol{\beta}|\tilde{\mathbf{S}})) + \mathrm{Var}_{\tilde{\mathbf{S}}|\mathbf{S}}(E(\boldsymbol{\beta}|\tilde{\mathbf{S}})).$$

$$s(t) = s(0) + \int_0 v(u)\,du,$$

$$\hat{\boldsymbol{\alpha}}_{\text{lasso}} = \max_{\boldsymbol{\alpha}}\left\{\log[\mathbf{Z}, \boldsymbol{\tau}|\boldsymbol{\alpha}] - \gamma\sum_{k=1}^{K}|\alpha_k|\right\}$$



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CONTINUOUS-TIME DISCRETE-SPACE MODELS FOR ANIMAL MOVEMENT

1. Continuous-time Markov chain models for animal movement

    - And GLM representation & analysis

2. Inference on CTDS model parameters using telemetry data

3. Time-varying behaviour & variable selection

4. Drivers of animal movement

Continuous-time Markov chain models

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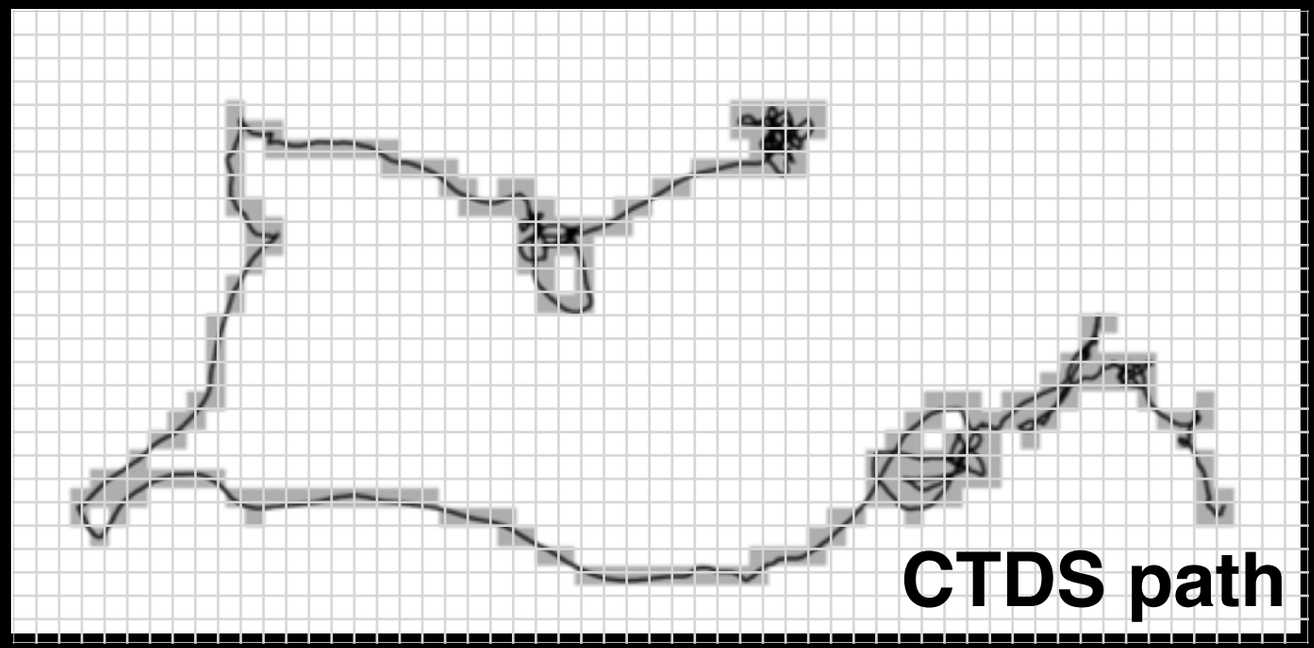
CONTINUOUS-TIME DISCRETE-SPACE MODELS FOR ANIMAL MOVEMENT

CTDS path, $\tilde{S} = (g, \tau)$

grid cells,
$\mathbf{g} = (G_{i1}, G_{i2}, \ldots, G_{it})$

residence time in g,
$\boldsymbol{\tau} = (\tau_1, \tau_2, \ldots, \tau_t)$



G_{it} to G_{jt} transition rate at time t, $\lambda_{itjt}(\beta) = exp\{x'_{itjt}\,\beta\}$

$\boldsymbol{x_{itjt}}$ is a vector containing covariates related to drivers of movement specific to cells G_{it} & G_{ij}

$\boldsymbol{\beta}$ is a vector of parameters that define how each of the covariates $\boldsymbol{x_{itjt}}$ are correlated with animal movement

Latent variable representation for GLM analysis

Example with mountain lion (*Puma concolor*)

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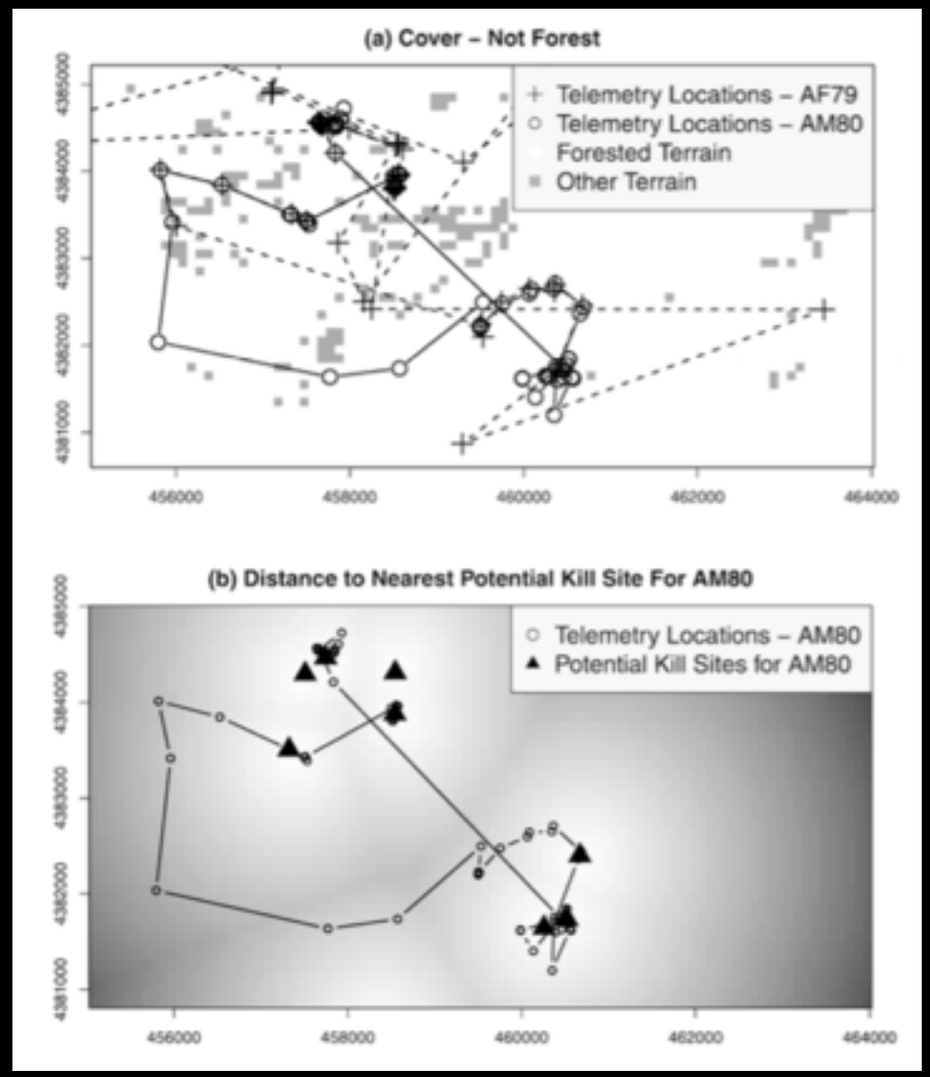
CONTINUOUS-TIME DISCRETE-SPACE MODELS FOR ANIMAL MOVEMENT

- **CTDS**
  - 2-week GPS-location data
  - Land cover (vegetation)
  - Kill site (directional)
  - Recent movement (directional)
- **CTCRW model fit**
- **Simulation study**



CTDS: What's new?

Modelling

1. Builds on the use of Bayesian approaches for modelling animal movement

2. Continuous-time Markov Chain Model => Generalised Linear Model via latent variable representation

3. Joint modelling of location-based & directional drivers of movement

4. Use of time-varying coefficient instead of state-switching to Δbehaviour~time

5. Variable selection using lasso penalty (regularisation)

CTDS: What's new?

Advantages

- More computationally efficient than currently available models (great for big data!)
- Data for reproducibility available
    - transferable to other systems
- Authors are reachable (EM Hanks)

So…