Model complexity and model choice for animal movement models

Ben Bolker, McMaster University

Departments of Mathematics & Statistics and Biology

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Outline

1. Animal movement
2. Florida panthers
3. Hidden Markov models
4. Basic analysis (van de Kerk et al., 2015)
5. Incorporating diurnal variation (Li, 2015)
6. Broader issues/outlook

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Animal movement: data

- observations:
  e.g. mass mark-recapture, longitudinal density, direct observation, telemetry (VHF, GPS)
- most methods provide a sequence of times and locations for each individual

(sequence pix)

- summaries:
  - home range (convex hull, kernel density estimate, etc.)
  - root-mean-squared displacement
  - step length and turning angle
- covariates:
  e.g. habitat map,
  individual characteristics
  (sex, age, weight . . .)

(step length/turning angle pix)

Animal movement: questions

- simple description
- how do animals' movements change as a function of their (internal or external) environment?
  what does that tell us about their biology?
- how might animals' distributions, etc. change when conditions (density, habitat, ...) change?

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Biological/conservation issues

- Florida panther: *Puma concolor coryi*
- endangered subspecies
- severely reduced habitat
- small, isolated population
- currently recovering

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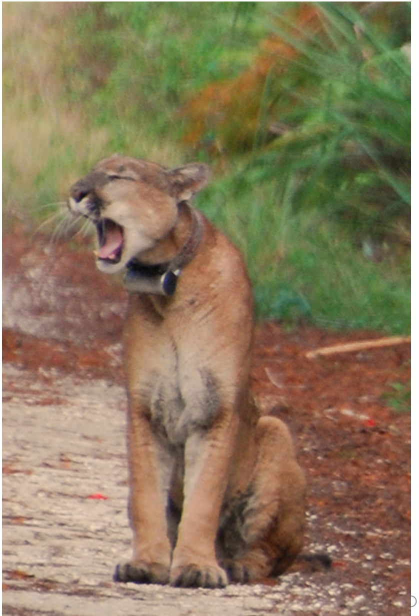
Panther movement questions

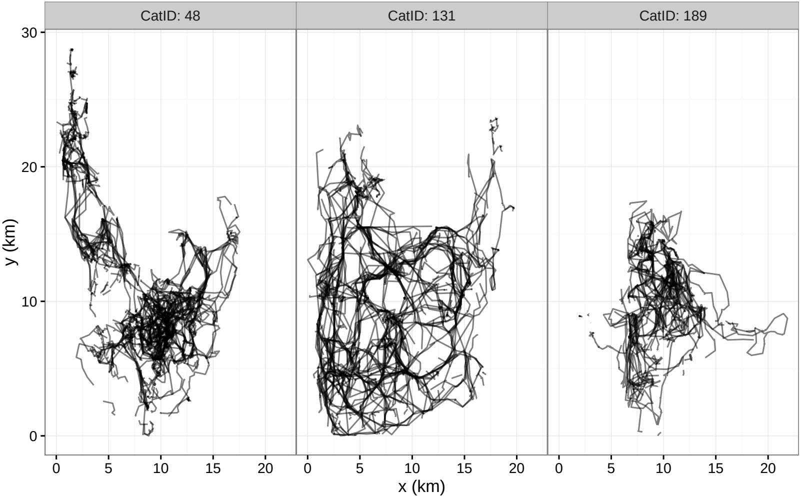
- movement variation by sex and life history stage (juvenile, adult, mom with kittens ...)
- effects of movement on threats (intraspecific aggression, roadkill) ?
- predicting the effects of future changes in population density / population structure / habitat

Panther movement data

- panthers tracked, captured
- GPS collars
- 18 males (13 male, 5 female, 1-15 years old)
- 3200 panther days, hourly/bihourly; 49000 locations
- ?? per panther



example movement tracks



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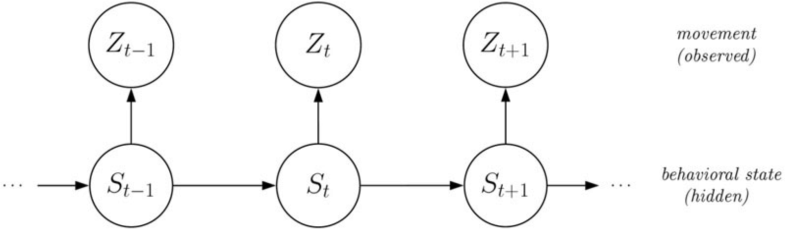
Hidden Markov models

- finite mixture model with temporal dependence
- discrete time steps
- discrete latent state; *transition matrix*
- observations from *emission distributions* (continuous or discrete, univariate or multivariate)
- **multiphasic movement** (Fryxell et al., 2008; Langrock et al., 2012)



Hidden Markov models (cont.)

state:

$$S_t \sim \mathrm{Multinomial}(S_{t-1}, \mu_{S,t})$$
$$\mu_{S,t} = \text{multi-logistic}(\mathbf{X}_{S,t}\boldsymbol{\beta}_S)$$

emission:

$$\mathbf{Z}_t \sim \{\mathrm{Dist}_1(\mu_{Z_1,S_t}), \ldots, \mathrm{Dist}_n(\mu_{Z_n,S_t})\}$$
$$\mu_{Z_i,S_t} = g^{-1}\left(\mathbf{X}_{Z_i,t}\boldsymbol{\beta}_{Z_i,S_t}\right)$$

Hidden Markov models (part 3)

- *forward-backward algorithm* for estimating parameters
- *Viterbi algorithm* for estimating most probable state sequences
- `depmixS4` package (Visser and Speekenbrink, 2010) (also `moveHMM` (Michelot et al., 2016))
- hidden *semi-Markov* models: allow for non-geometric *dwell distributions* (Langrock, 2011; Augustine, 2016): `move.HMM`

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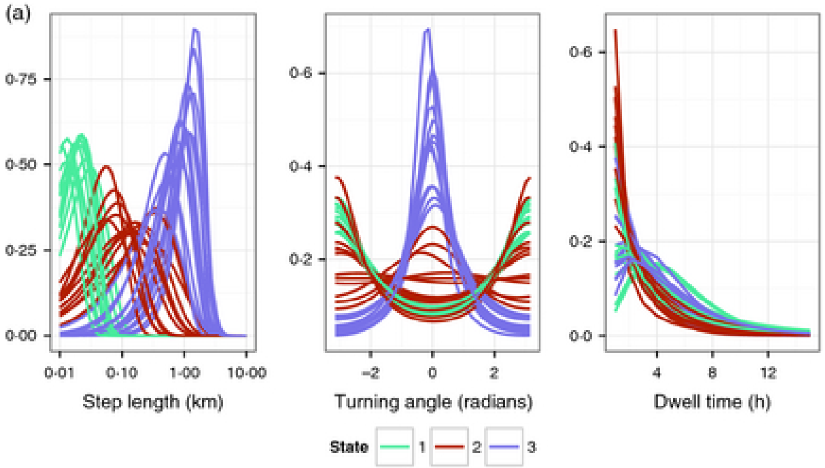
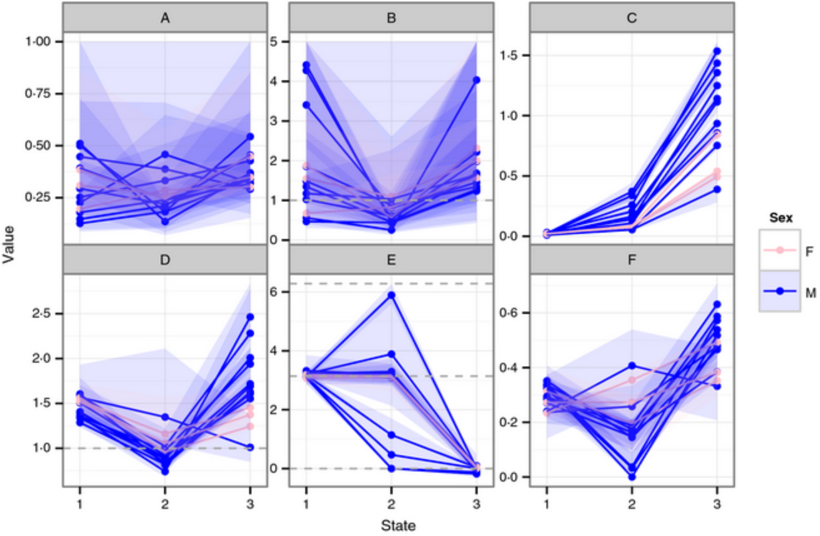
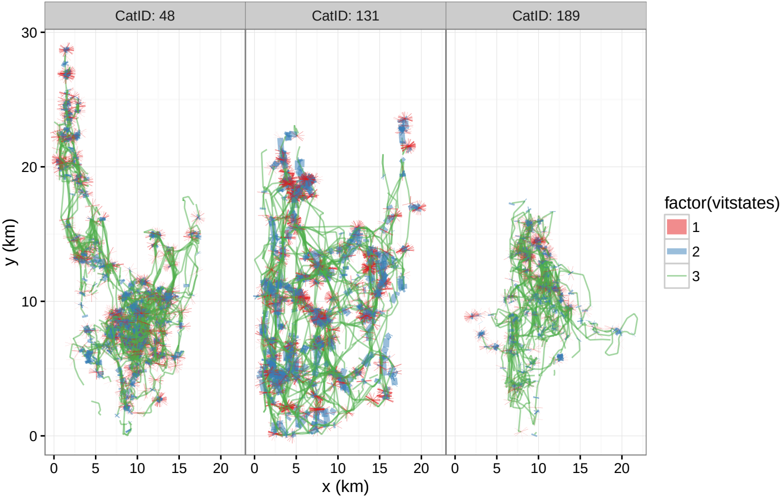
State distributions



Parameter estimates



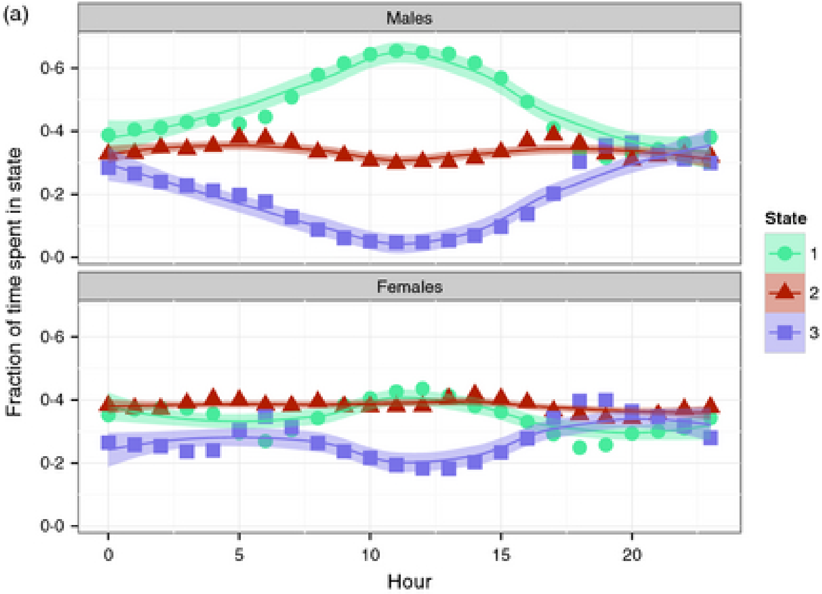
Tracks with Viterbi estimates



Transition parameters

picture/table here of transition parameters (network diagram??)

Diurnal variation



what can we conclude so far?

good news

- basic biology: males move faster, farther
- three states are identifiable, sensible
- dwell distributions approximately geometric (HSMM $\rightarrow$ HMM)

bad news

- diurnal variation in Viterbi results - but it's not in the model!
- estimates of model complexity are too high

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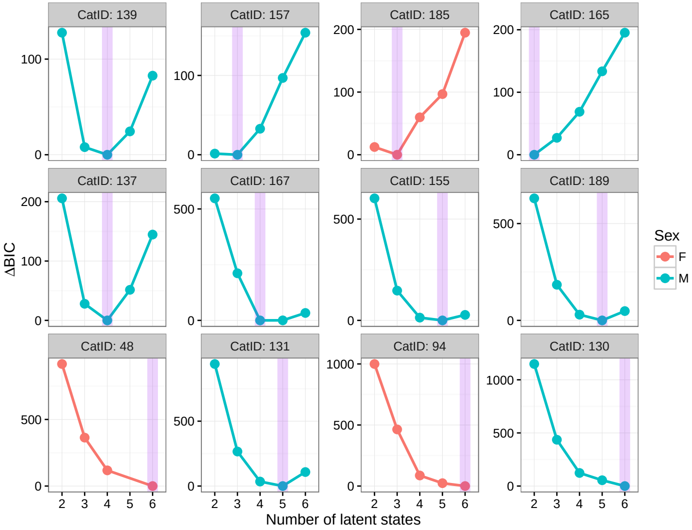
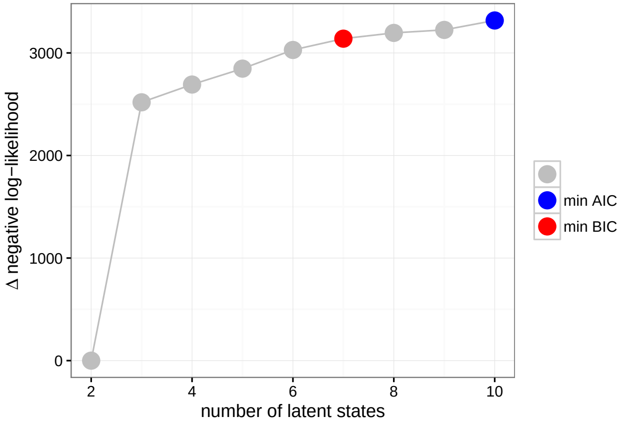
Model complexity



Model complexity (Manx shearwaters, Dean et al. (2013))



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Broadening the model

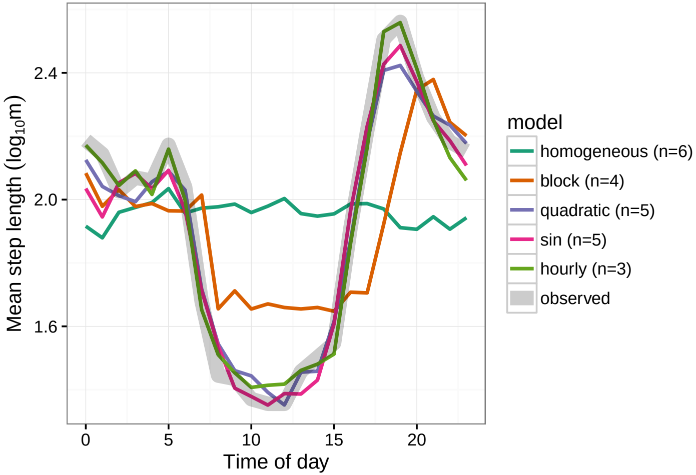
Attempting to fix these problems:

- extend the model to allow covariates
- specifically, allow for diurnal variation
  - simplify model (log-Normal step length only)
  - *fixed* state-specific emissions parameters (step length mean and std dev)
  - time-varying transition parameters
  - also try *finite mixture models* (independent occupancy)
- how much does this help?

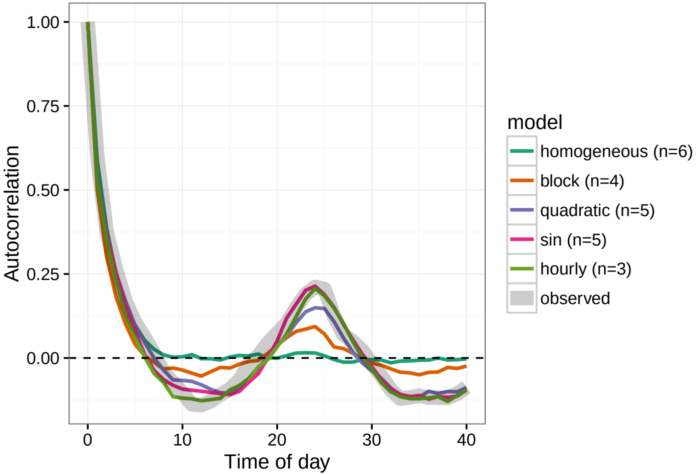
Temporal models

figure showing alternative temporal models

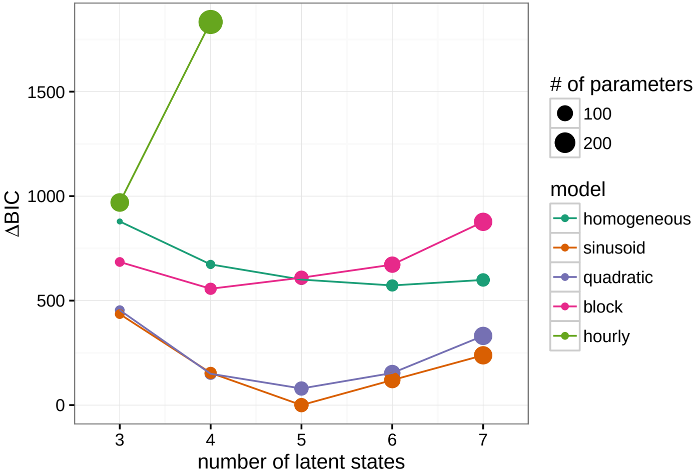
Temporal patterns (step length)



Temporal patterns (autocorrelation)



Goodness of fit/model complexity



Model complexity

Figure showing BIC plots for all cats tried

Model complexity

Simulation results

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Animal movement: open challenges

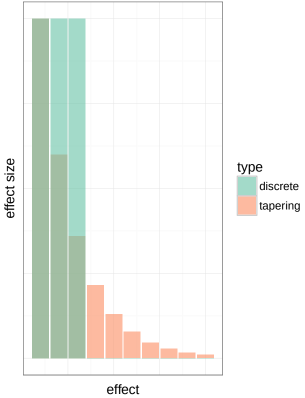
- Cognition
- Intraspecific interaction/collective movement (Delgado et al., 2014)
- Continuous-time movement models (Calabrese et al., 2016)
- Edges, barriers, and corridors (Beyer et al., 2016)
- Efficient (big-data) approaches (Brillinger et al., 2008)
- Putting it all together ...

Big data and small models

- simple model families +
  model misspecification $\rightarrow$
  overparameterization
- protocols and tools for model checking (Potts et al., 2014); score tests?
- flexible computational frameworks

an aside on AIC vs BIC

- “should I use AIC or BIC? I heard that AIC is inconsistent ...”
- complexity penalty = 2 (AIC) vs $\log(n)$ (BIC)
- best prediction vs. model identification (Yang, 2005)
- importance of *effect size spectrum*: tapering or discrete?



Tools needed

- cross-validation (Wenger and Olden, 2012)
- diagnostic plots
- score tests?

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