Estimating Seasonal Behavior States from Bio-logging Sensor Data

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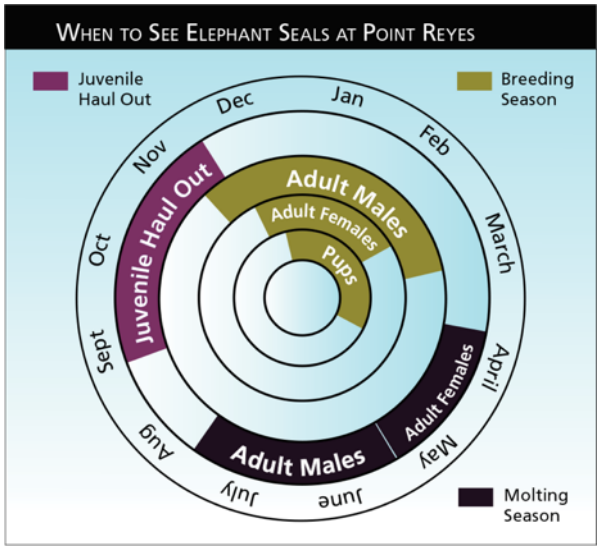
NMFS Research Permit: 15126

BOEM
Bureau of Ocean Energy Management

The Importance of Seasons

The seasonal timing of key, annual life history events is an important component of many species' ecology.

The Importance of Seasons



Point Reyes National Seashore, National Park Service

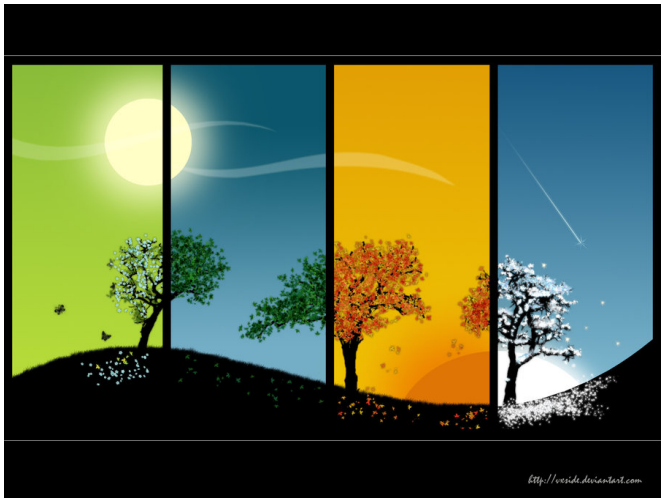
The timing of key life history events is well documented only for species found in accessible rookeries, breeding areas, or migratory corridors.

Our knowledge of seasonal timing for species widely dispersed in inaccessible or remote habitats is poor.

Expected Change in Arctic Species

Key life-history events in Arctic species are often closely tied to sea-ice, weather, ocean productivity, and a range of other factors predicted to change dramatically

Seasonal Misalignment



Seasonal periods important to marine mammals often do not align well with typical labels.

Data From Bio-loggers

- Fine-scale observations
- Deployment lengths of several months
- Record both movement and behavior

- Data can be noisy
- Large datasets
- Position Error
- Irregular in Time
- Missing Data

Hidden Markov Models

- Pattern recognition in noisy time series
- Previously used to identify behavioral states
  (e.g. foraging, transit, resting)
- Widely used; existing tools

- Behavioral states are, typically, shorter time steps
- Duration in a state is not dependent on time already spent in a state

Multivariate Hidden Semi-Markov

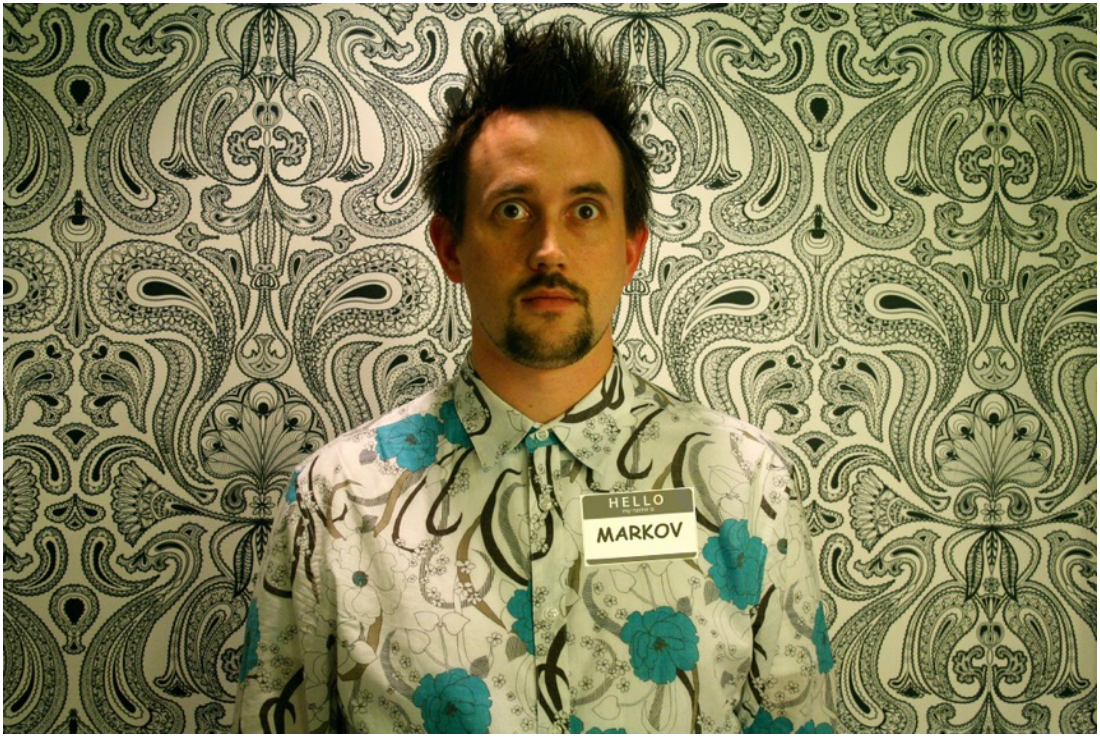


Photo Adapted From Ben Husmann

Multivariate Hidden Semi-Markov

Hidden Semi-Markov models allow an arbitrary sojourn distribution

R package `mhsmm`

Jared O'Connell, Soren Hojsgaard (2011). Hidden Semi Markov Models for Multiple Observation Sequences: The mhsmm Package for R. Journal of Statistical Software, 39(4), 1-22. URL http://www.jstatsoft.org/v39/i04/.

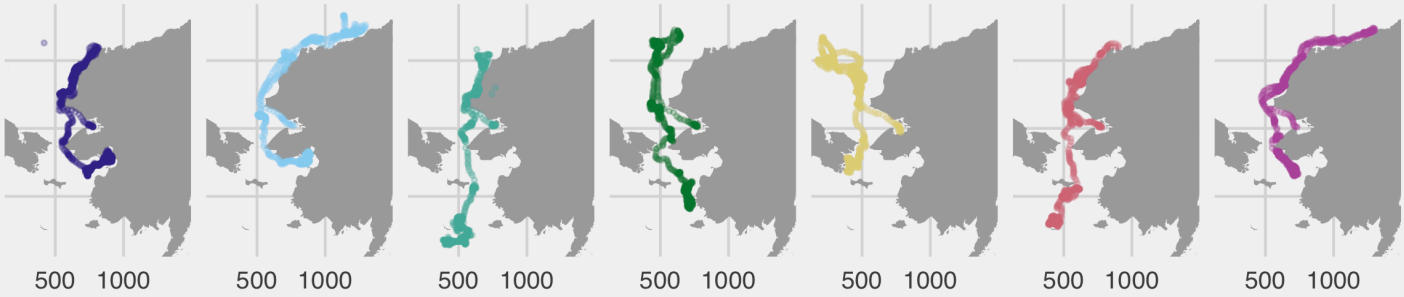
Animal Movement Model

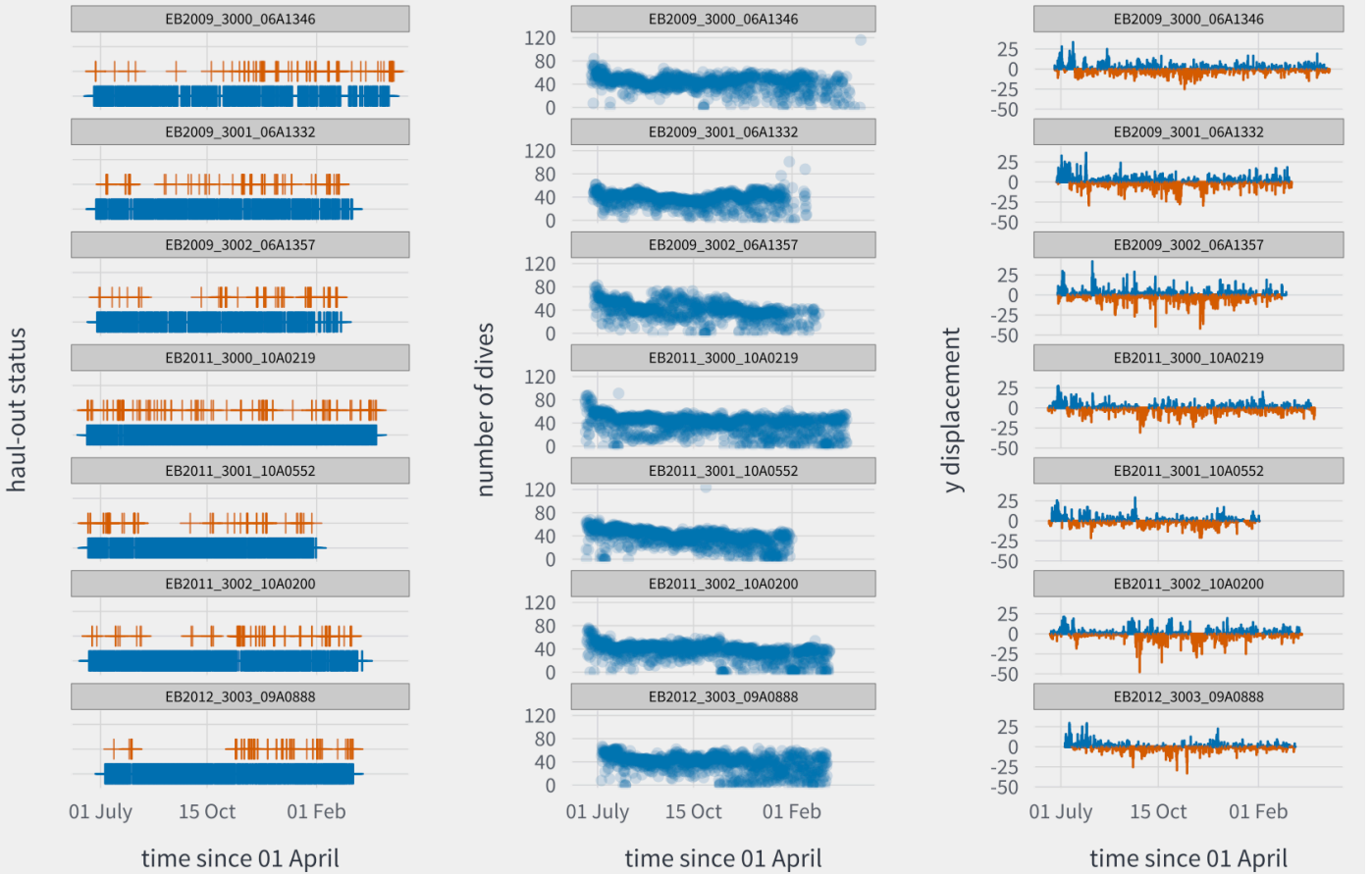
Predict locations at regular time steps that align with behavioral observations

R package `crawl`

Devin S. Johnson (2015). crawl: Fit Continuous-Time Correlated Random Walk Models to Animal Movement Data. R package version 2.0 (development branch available on Github).

Predicted Movements of 7 Adult Bearded Seals in the Bering and Chukchi Seas (2009 - 2013)




EB2009_3000_06A1346
EB2009_3001_06A1332
EB2009_3002_06A1357
EB2011_3000_10A0219
EB2011_3001_10A0552
EB2011_3002_10A0200
EB2012_3003_09A0888
haul-out status
number of dives
y displacement
120
80
40
0
25
0
-25
-50
01 July
15 Oct
01 Feb
time since 01 April

mhsmm Parameters

- Haul-out status (6 hours)
  - Bernoulli (initial value: 0.1 for each state)
- Number of Dives (6 hours)
  - Poisson (initial value: 30 for each state)
- XY-Displacement (6 hours)
  - Multivariate Normal (initial value: 0,0; 20,20)

- Sojourn Time
  - Poisson (initial value: mean = n/#States; shift by 0)

Number of States

- Unknown, but we have some prior knowledge
  - seals captured towards end of molt
  - summer/fall = open water, less ice
  - winter/spring = ice advances south
- More states, less seasonal time scale
  - 4-6 states seems reasonable
- Model Selection or Pick a Value

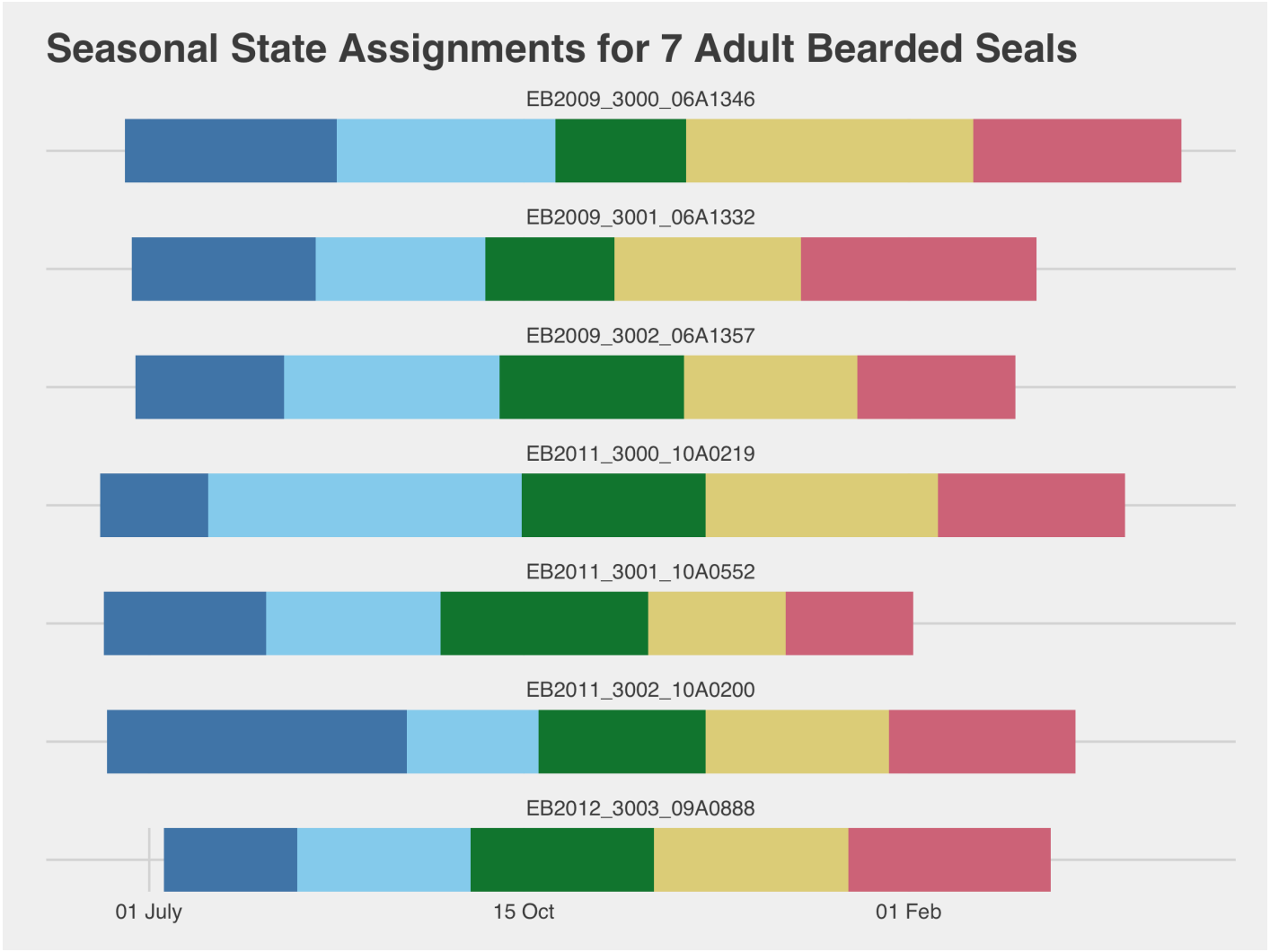
5 Seasonal States

1. Molt Transition Period
2. Open Water
3. Migration South w/ Ice Advance
4. Winter Site Fidelity
5. Early Stages of Pupping/Breeding

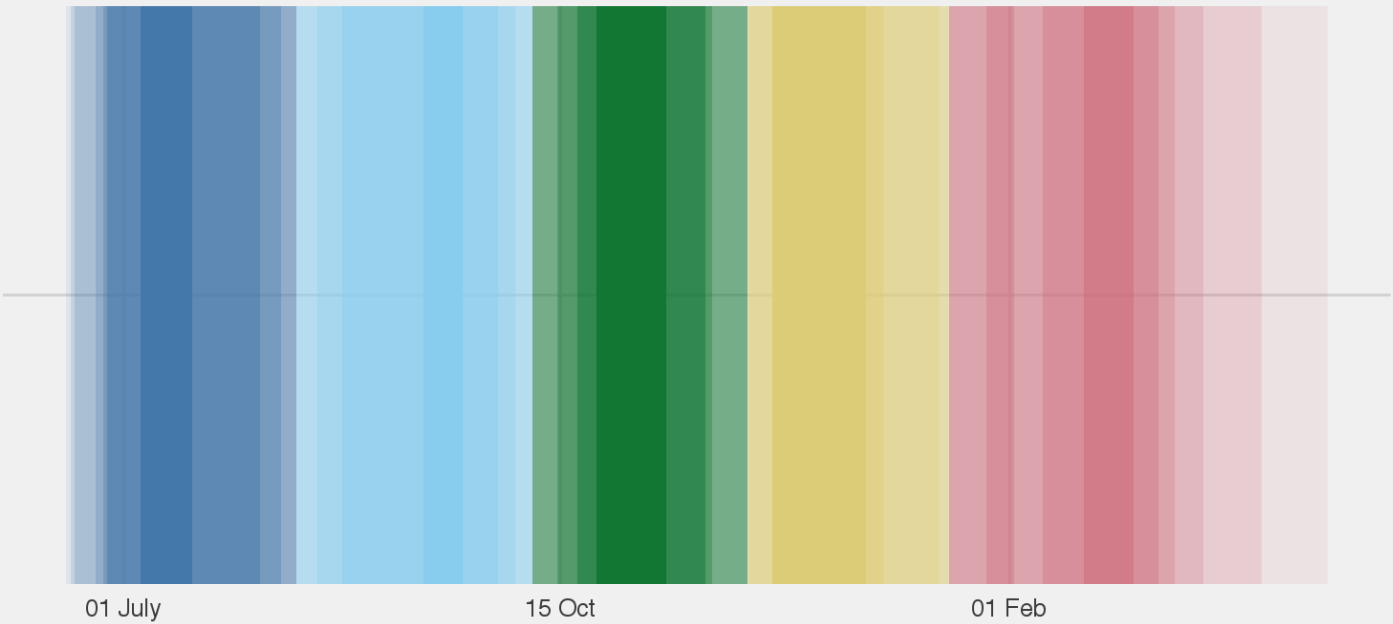
Transition Matrix

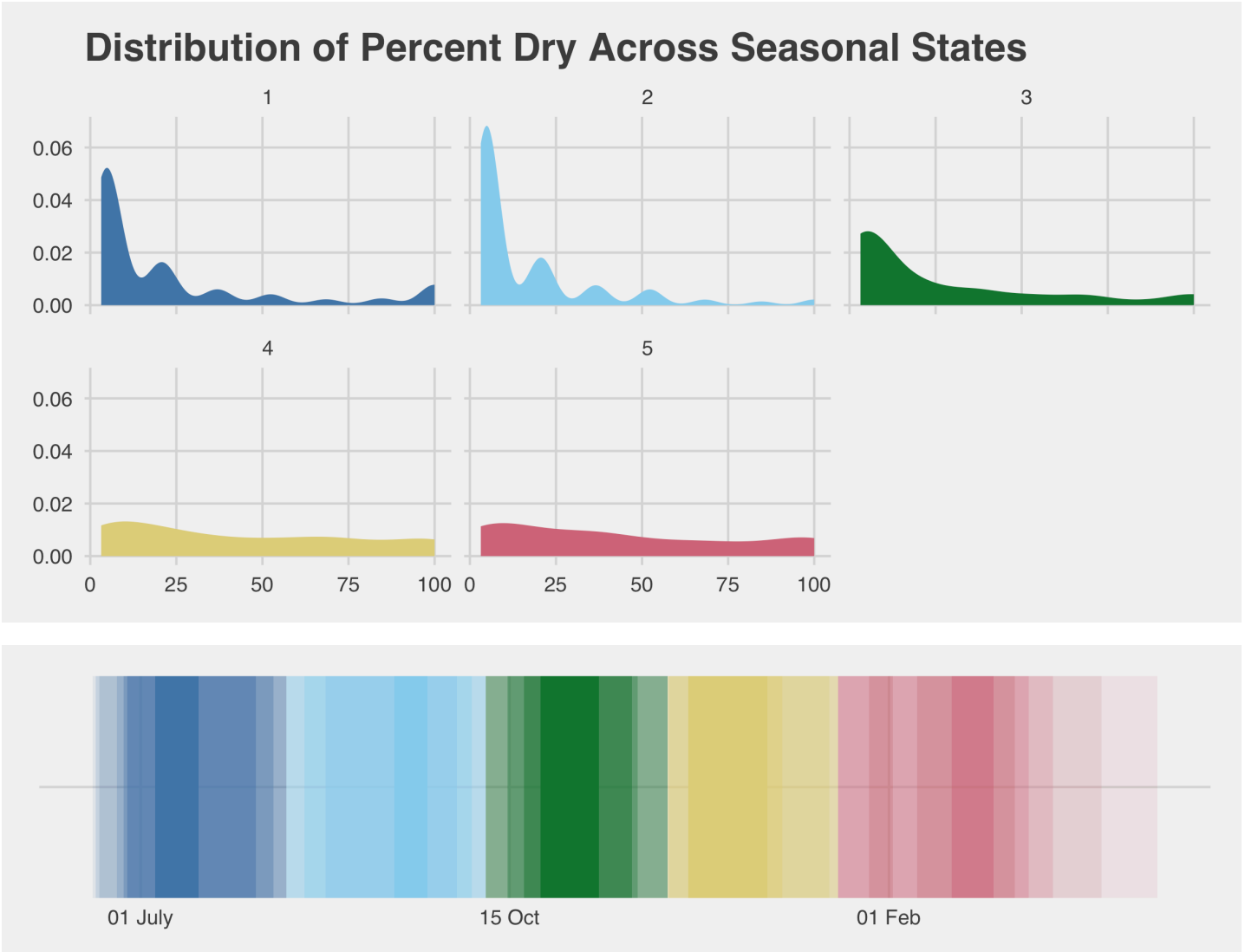
$$\begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

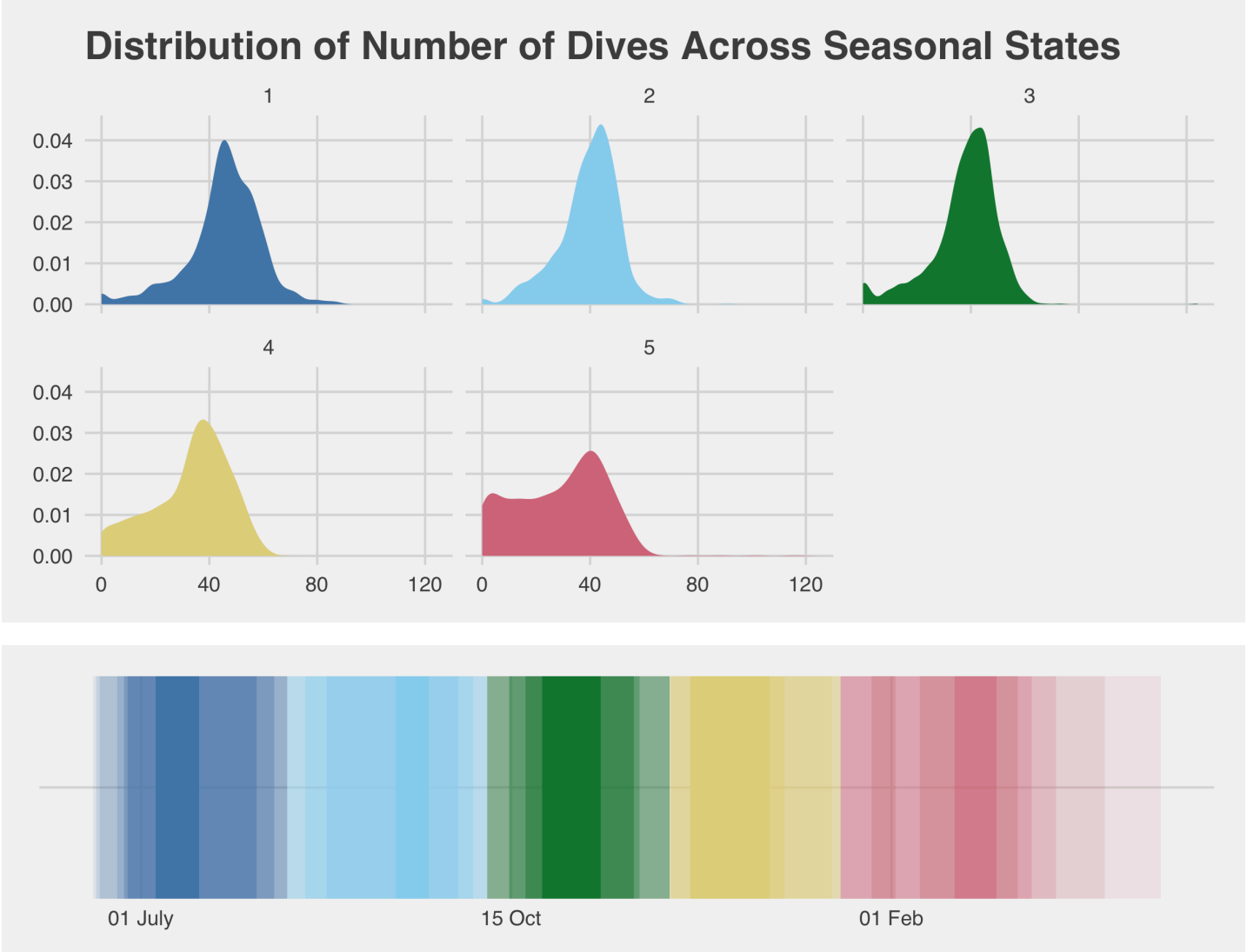
- Mimic the Seasonal Progression
- Start at State 1
- Super-diagonal Entries set to 1
- Transition Matrix is Locked (not re-estimated)


Seasonal State Assignments for 7 Adult Bearded Seals
EB2009_3000_06A1346
EB2009_3001_06A1332
EB2009_3002_06A1357
EB2011_3000_10A0219
EB2011_3001_10A0552
EB2011_3002_10A0200
EB2012_3003_09A0888
01 July
15 Oct
01 Feb

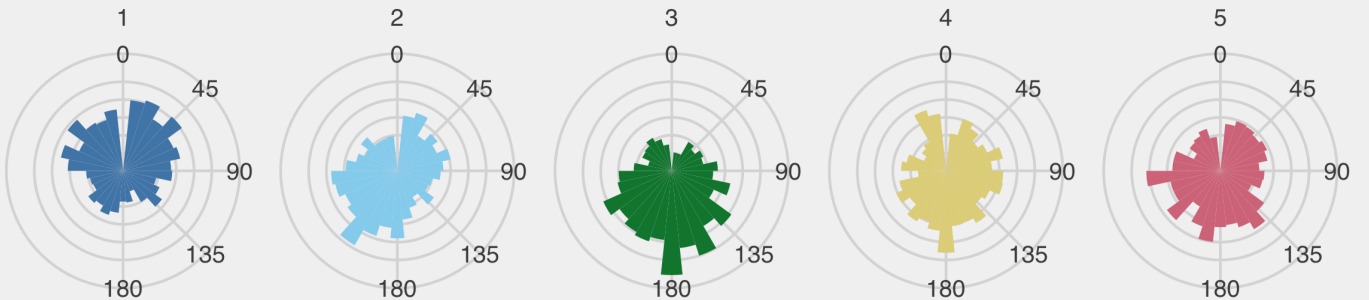
Combined Seasonal State Assignments

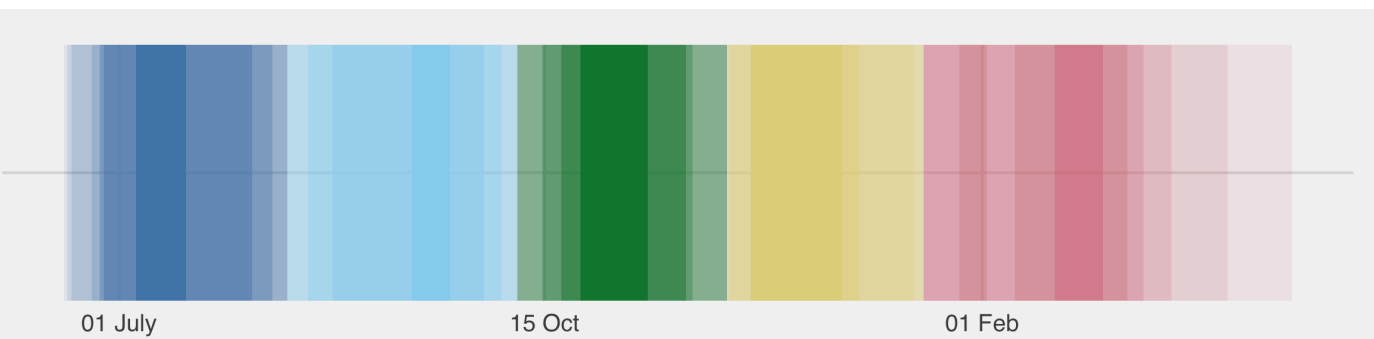



Distribution of Percent Dry Across Seasonal States
1
2
3
4
5
0.06
0.04
0.02
0.00
0
25
50
75
100
01 July
15 Oct
01 Feb

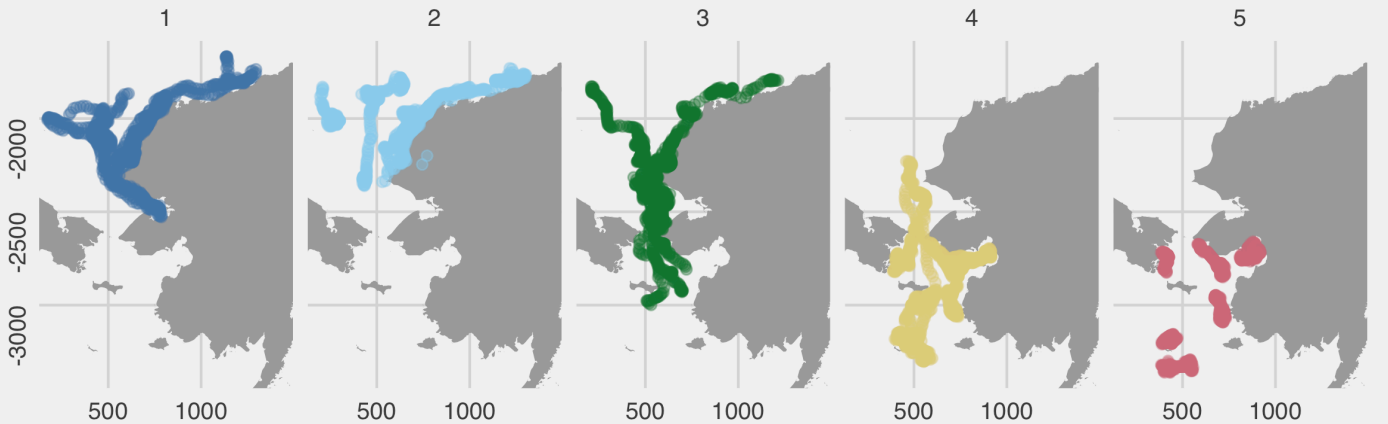

Distribution of Number of Dives Across Seasonal States
1
2
3
4
5
0.04
0.03
0.02
0.01
0.00
0
40
80
120
01 July
15 Oct
01 Feb

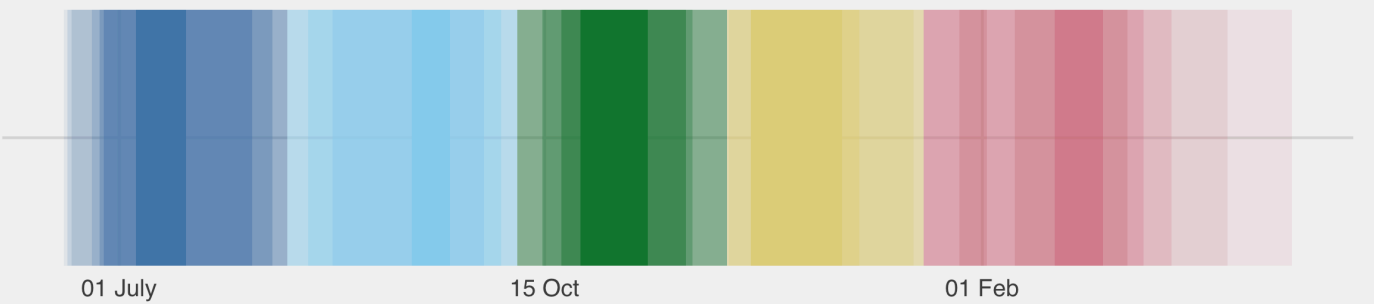
Distribution of Movement and Compass Bearing Across Seasonal States





Predicted Movements of Bearded Seals by Assigned Seasonal State





Bearded seal results tell a nice story and aligns with our understanding of their ecology

Expanding to other species and larger, more complex datasets may not be as nice

Future Considerations

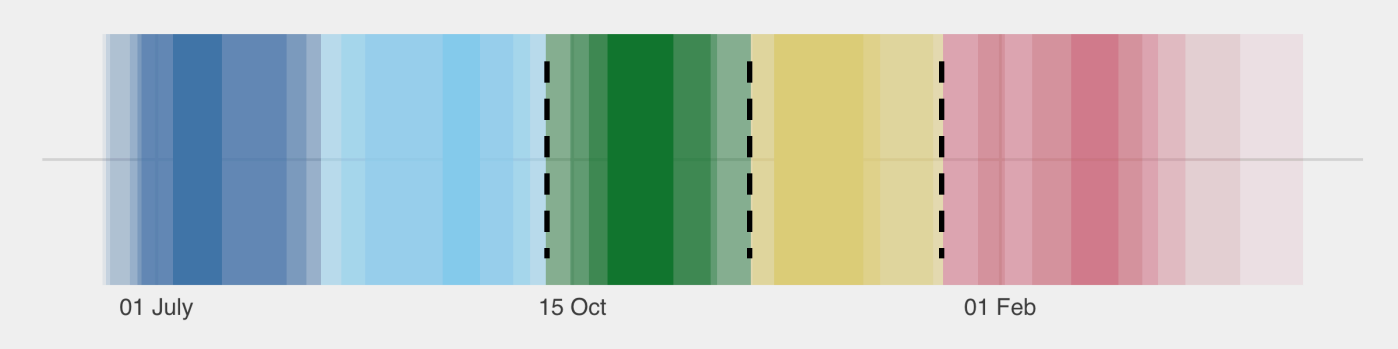
- Still just a ‘proof of concept’

- Model selection for optimal number of states
- Metrics for evaluating model performance
- Explore other time steps for observations
- Explore additional sensor data

Conclusions

Bio-logging provides our best insight into the seasonal timing of key life-history events

Could prove a useful tool for measuring change in remote, less accessible species



Questions

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