# Estimating Seasonal Behavior States from Bio-logging Sensor Data


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NMFS Research Permit: 15126

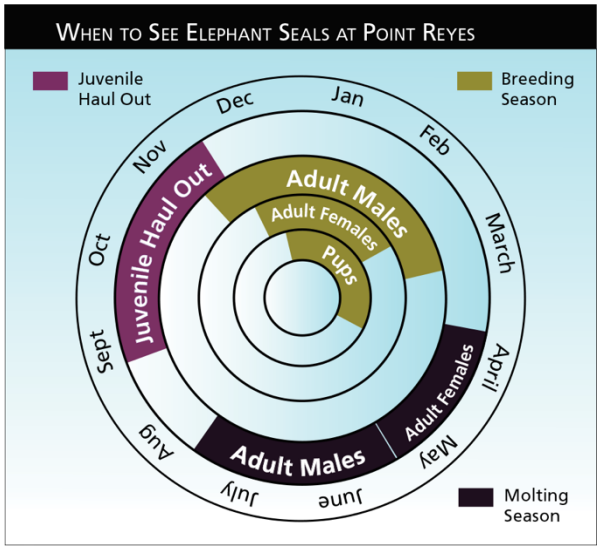
Please cite this presentation as:

London, Josh M., D.S. Johnson, P.B. Conn, B.T. McClintock, M.F. Cameron, and P.L. Boveng (2015, December). Estimating Seasonal Behavior States from Bio-Logging Sensor Data. Oral presentation at the 22nd Biennial Conference on the Biology of Marine Mammals. San Francisco, California, USA. 10.6084/m9.figshare.2057928

# 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

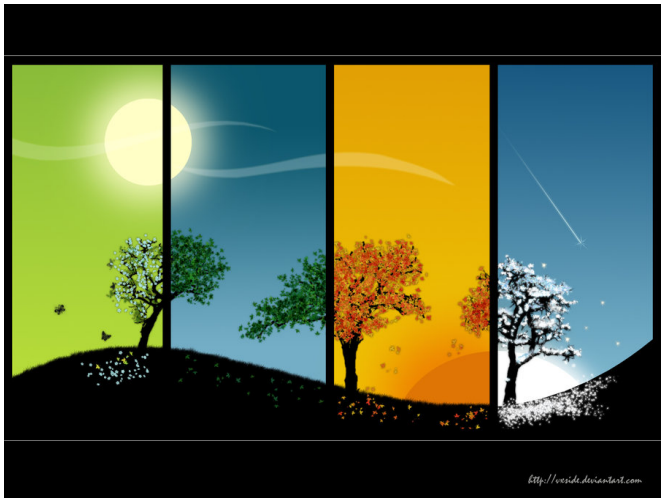
*The timing of key life history events is well documented only for species found in accessible rookeries, breeding areas, or migratory corridors.*

*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

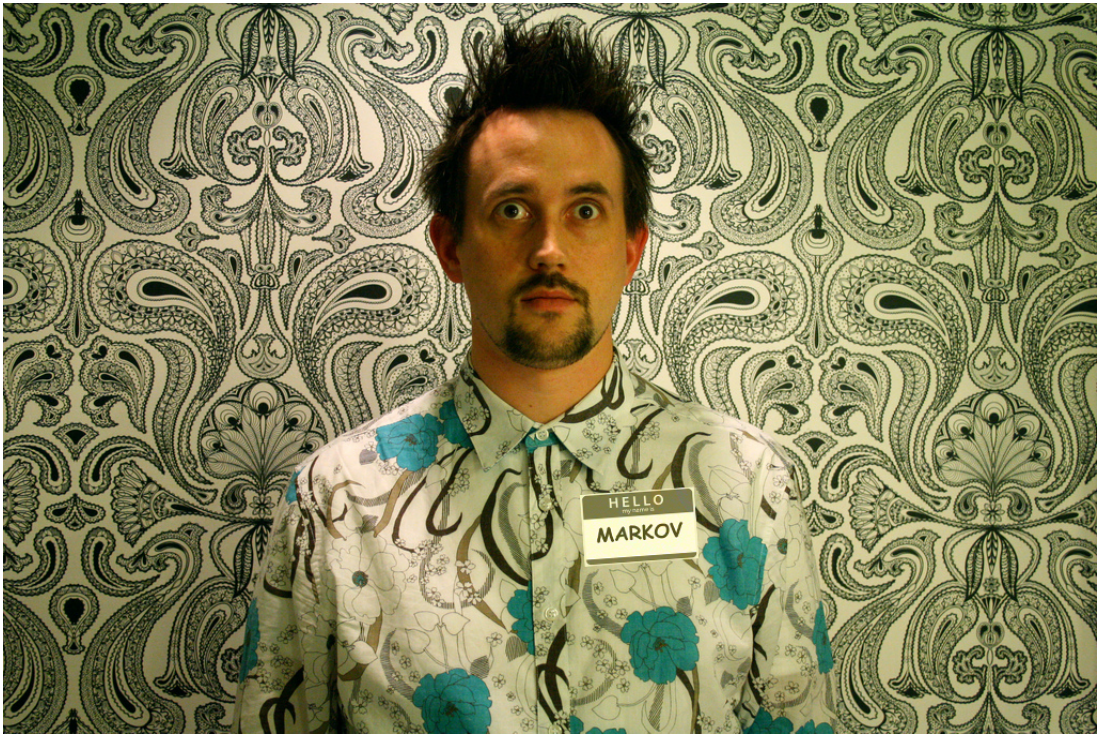



Photo Adapted From Ben Husmann

# 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 Bearded, Ribbon, and Spotted Seals in the Bering Sea and North Pacific

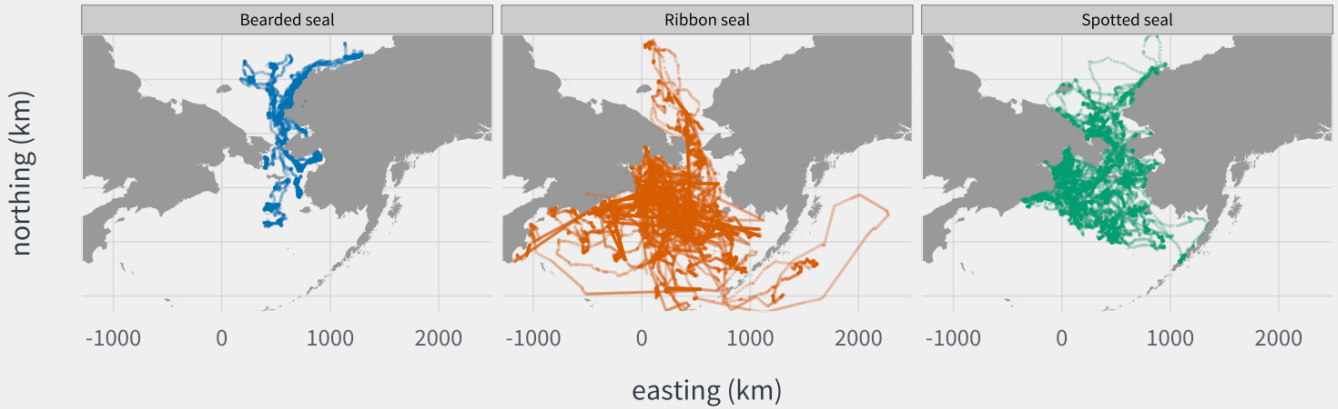
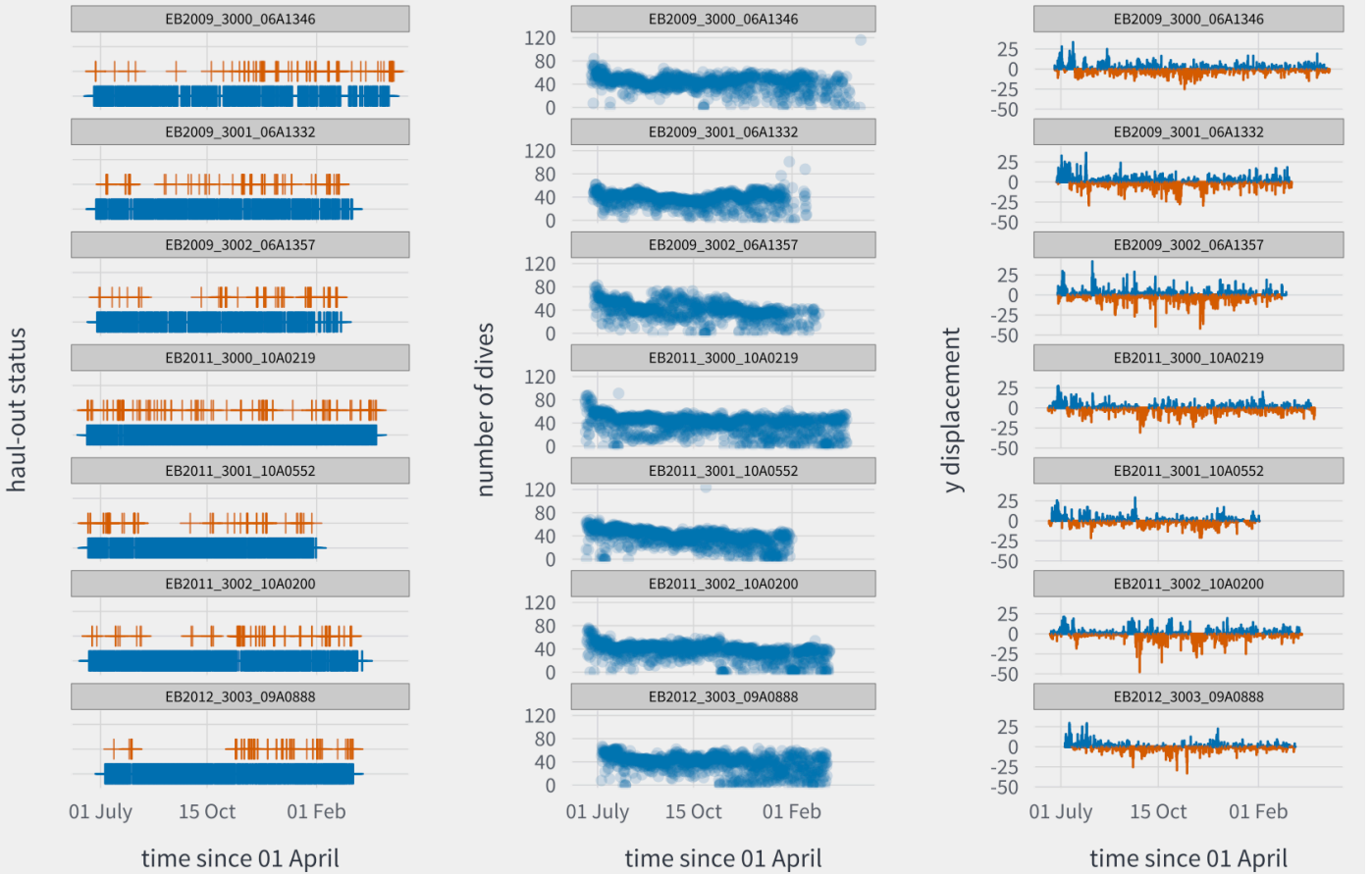


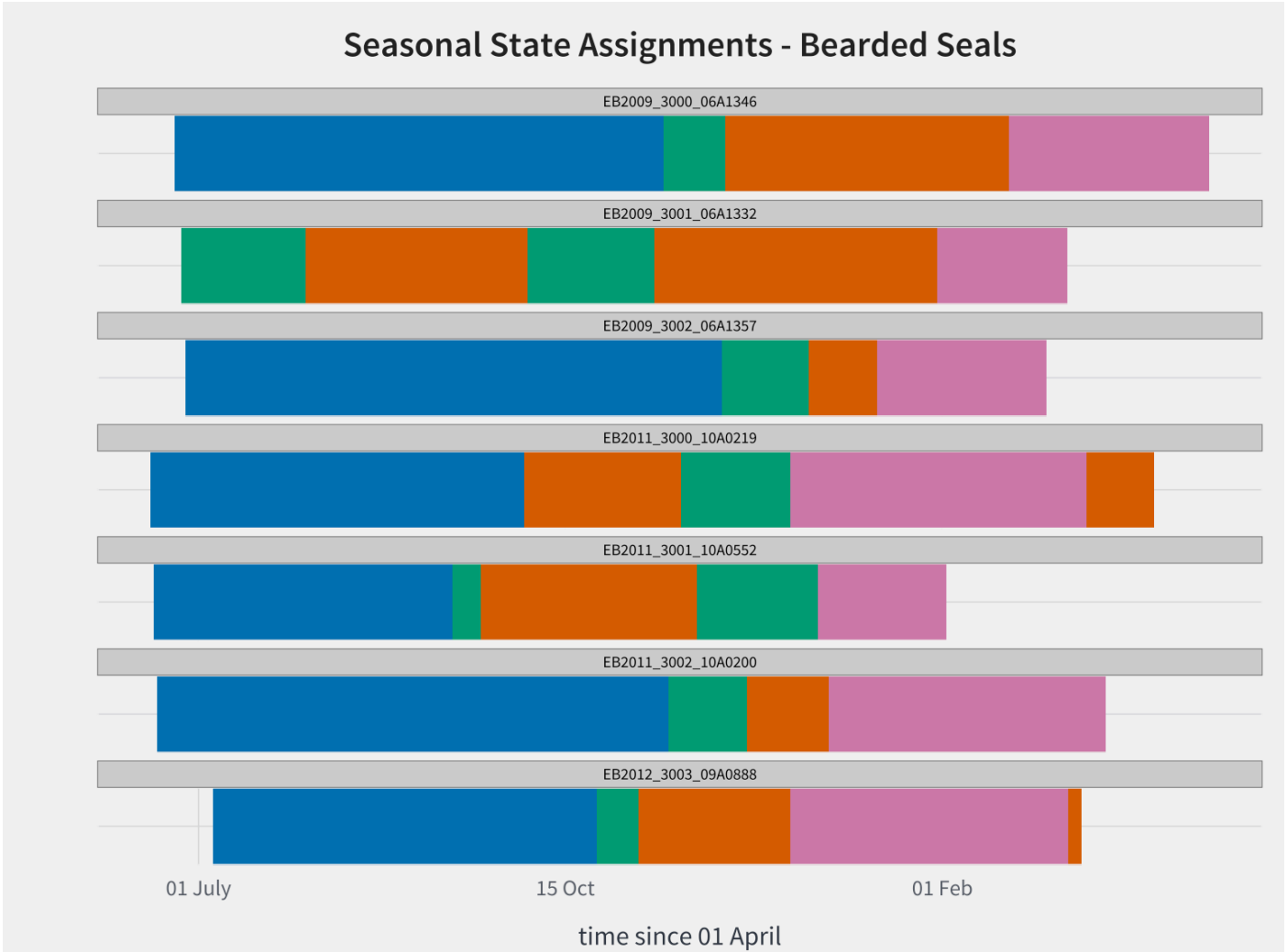

photo credit: John Jansen, Josh London


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

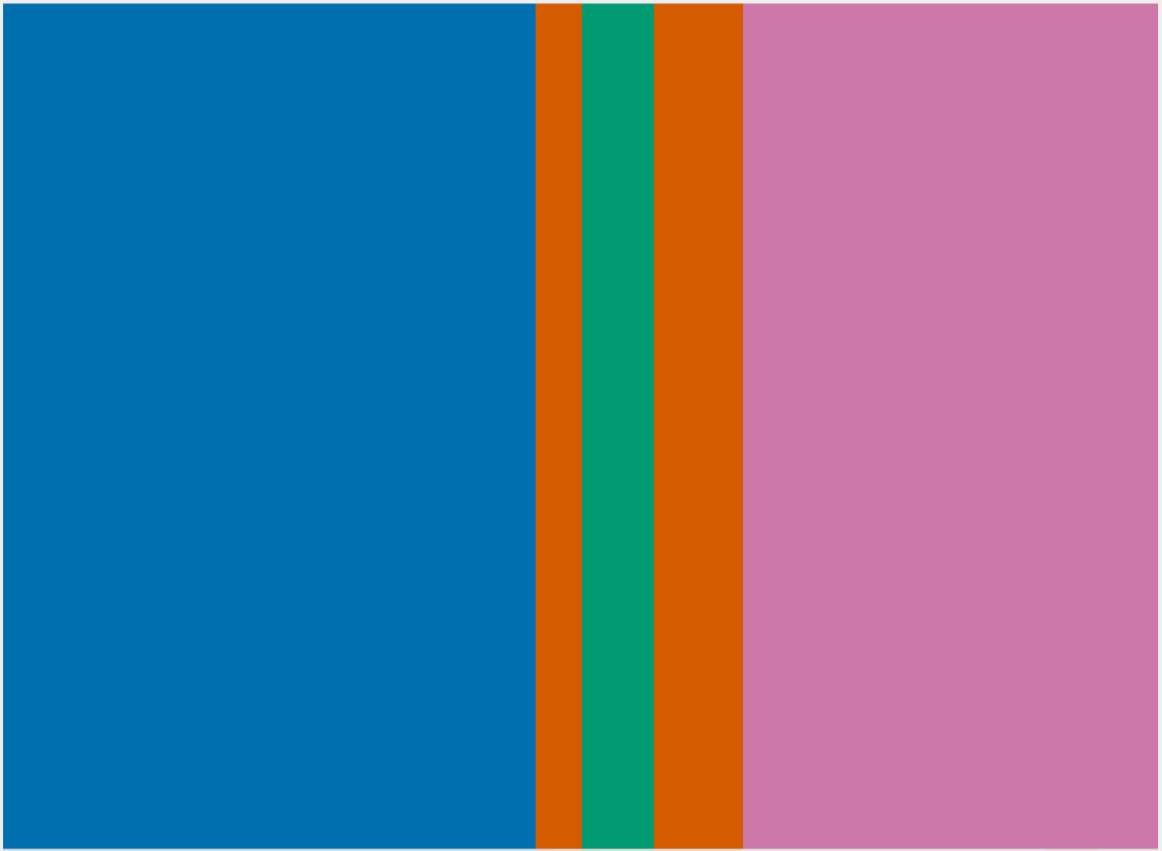
# mhsmm Parameters

- 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)

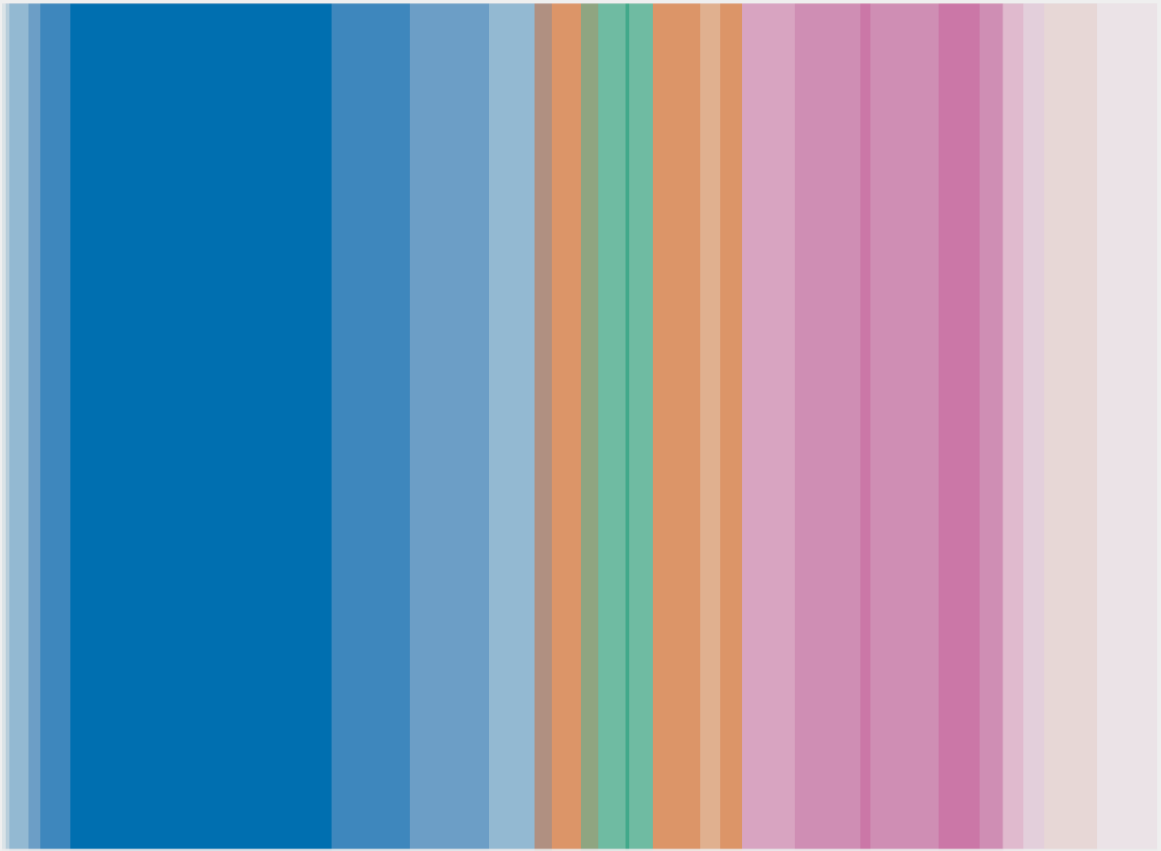
- Sojourn Time
  - Poisson (initial value: mean = 150; shift by 200)

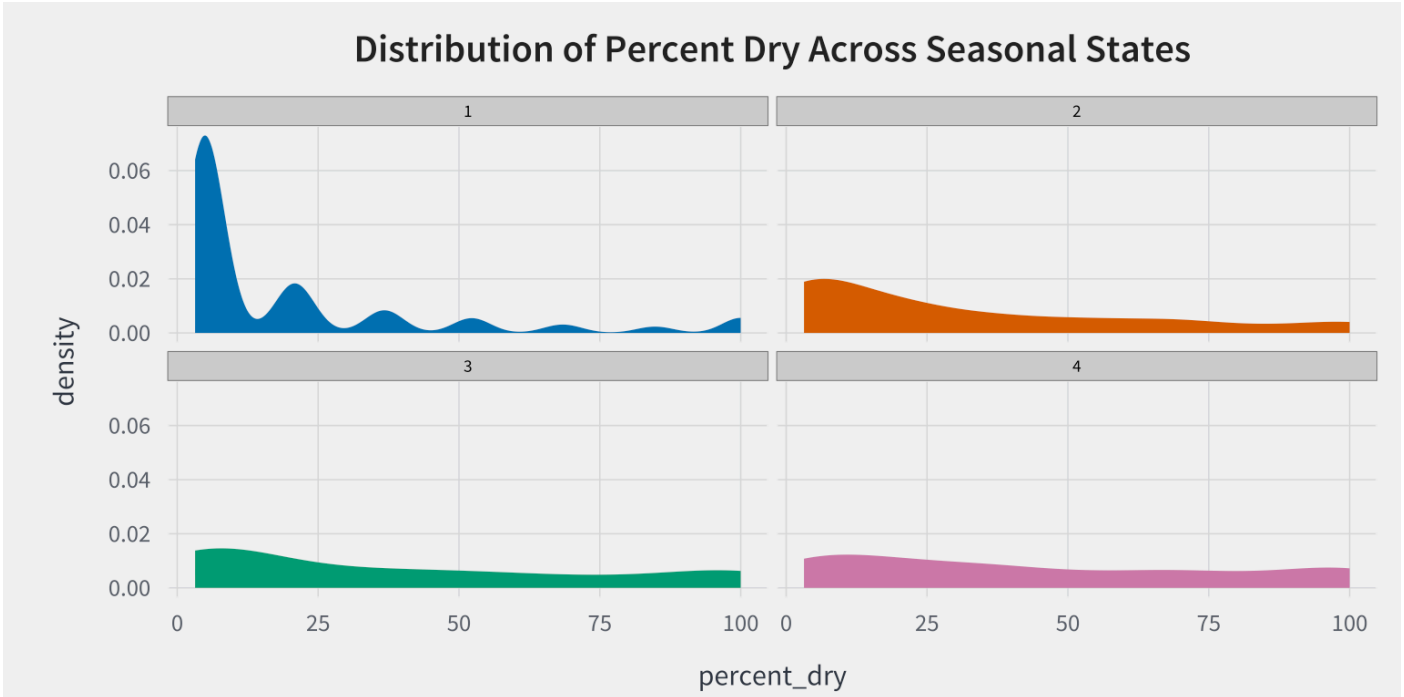

Seasonal State Assignments - Bearded Seals
EB2009_3000_06A1346
EB2009_3001_06A1332
EB2009_3002_06A1357
EB2011_3000_10A0219
EB2011_3001_10A0552
EB2011_3002_10A0200
EB2012_3003_09A0888
01 July
15 Oct
01 Feb
time since 01 April

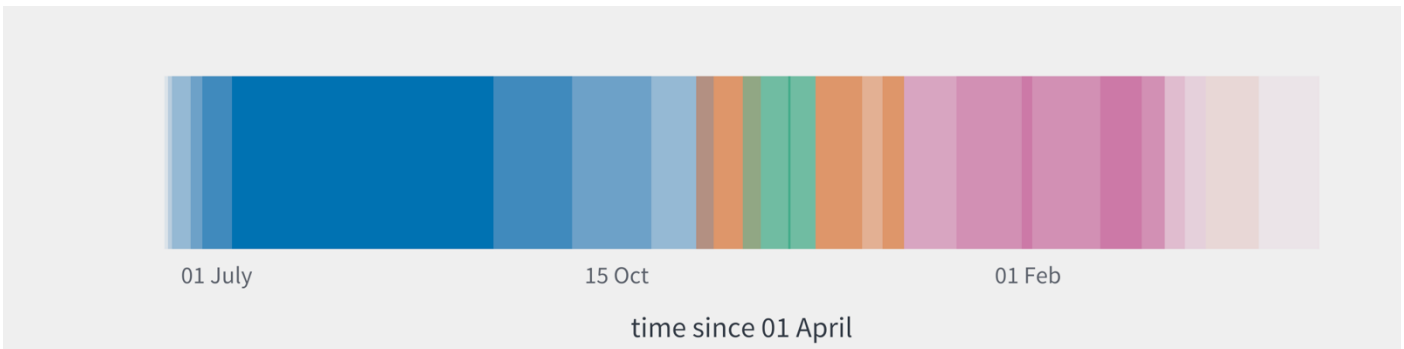
## Majority Seasonal State Assignments - Bearded Seals

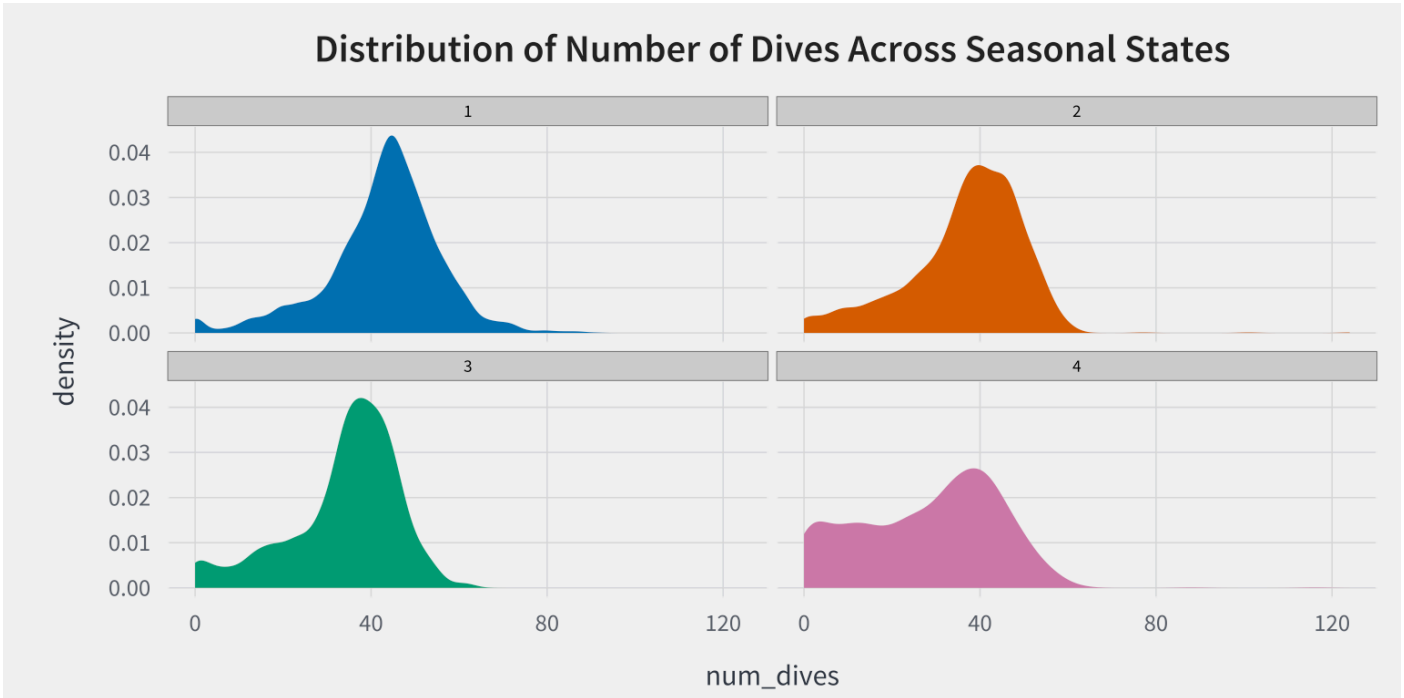


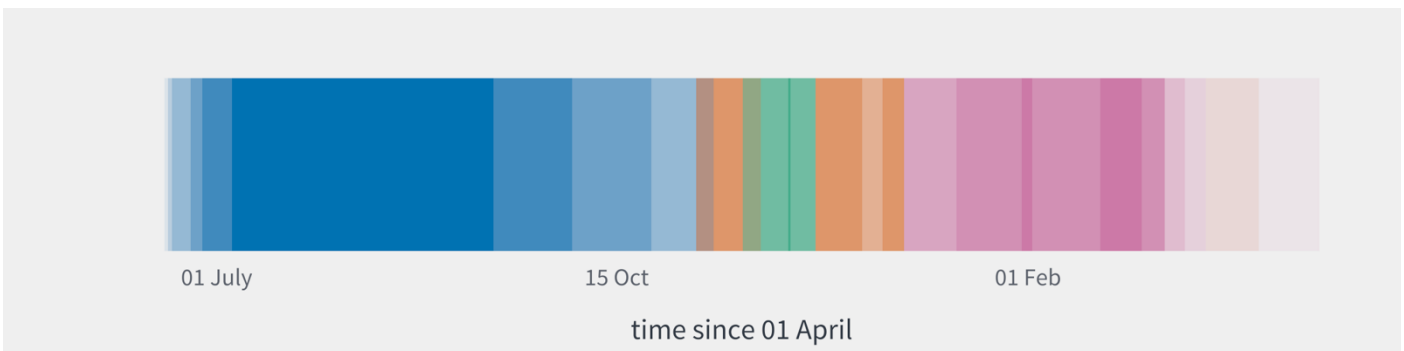
## Majority Seasonal State Assignments - Bearded Seals

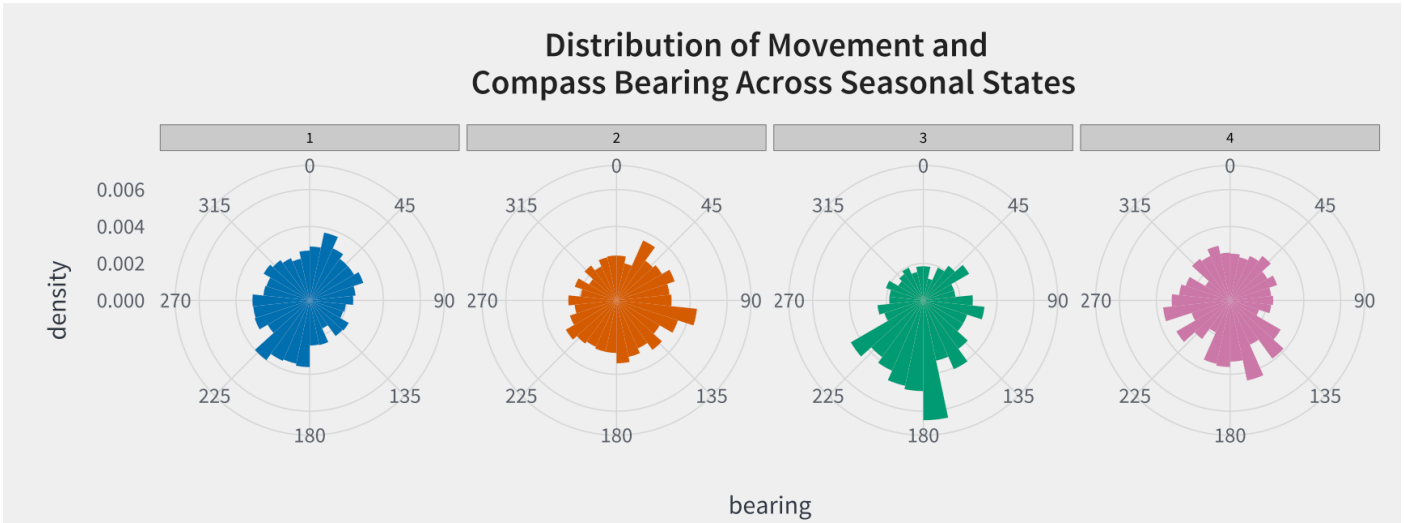


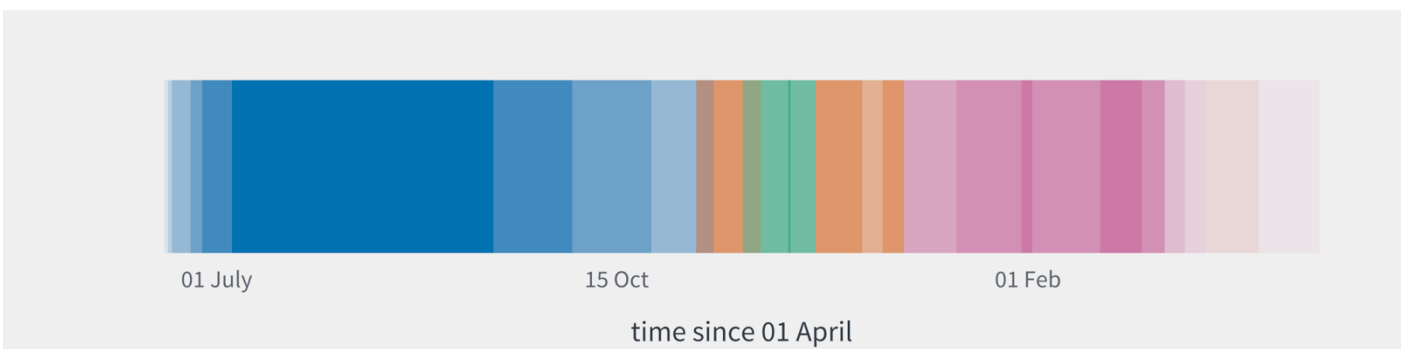

Distribution of Percent Dry Across Seasonal States
1
2
3
4
density
0.06
0.04
0.02
0.00
0
25
50
75
100
percent_dry

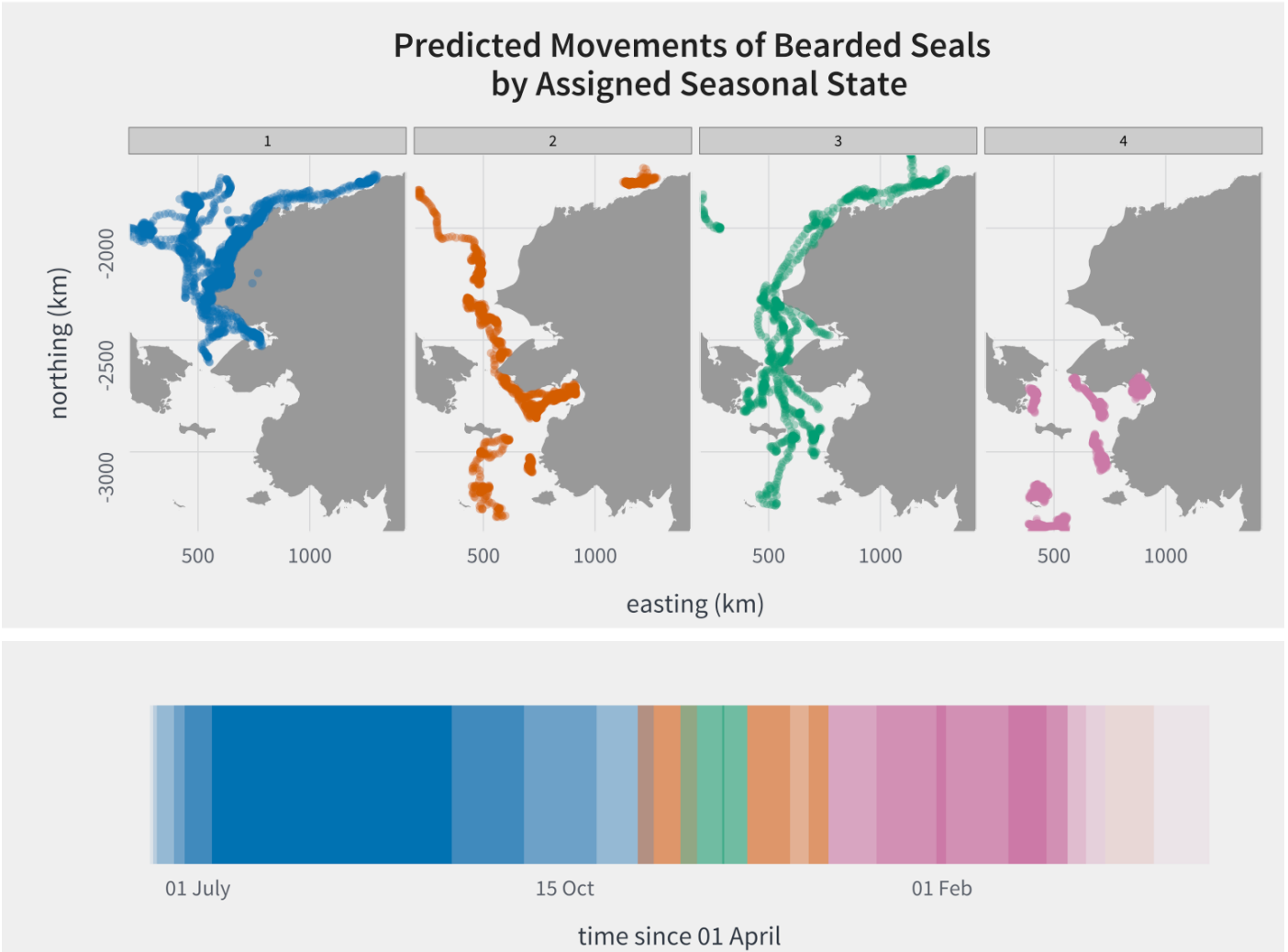

01 July
15 Oct
01 Feb
time since 01 April


Distribution of Number of Dives Across Seasonal States
1
2
3
4
density
0.04
0.03
0.02
0.01
0.00
0
40
80
120
num_dives

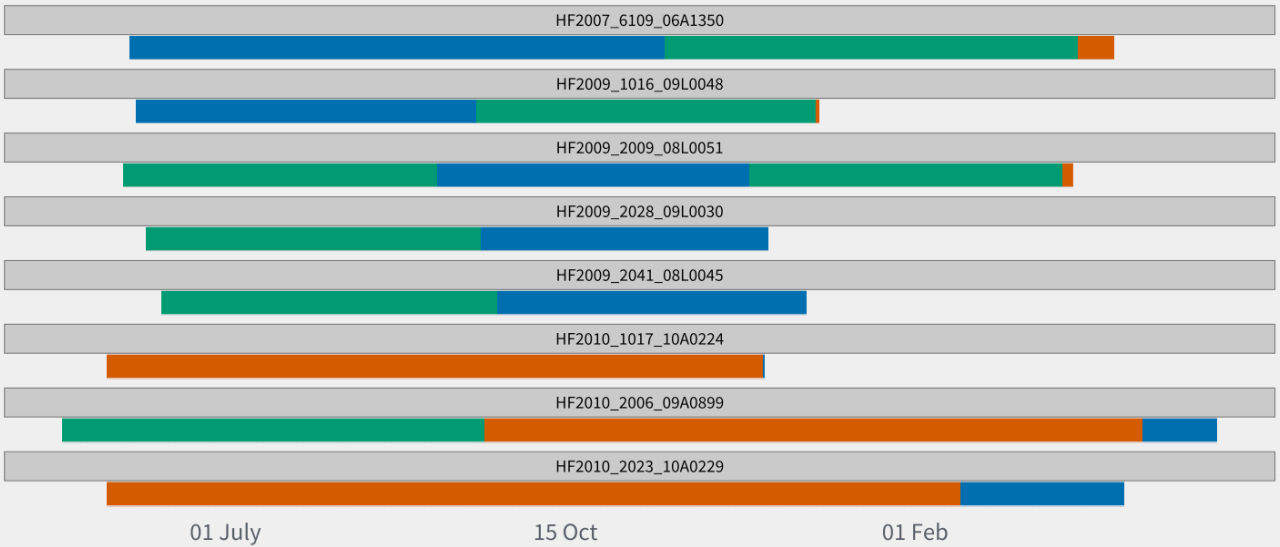

01 July
15 Oct
01 Feb
time since 01 April


Distribution of Movement and
Compass Bearing Across Seasonal States
1
2
3
4
density
0.006
0.004
0.002
0.000
0
45
90
135
180
225
270
315
bearing

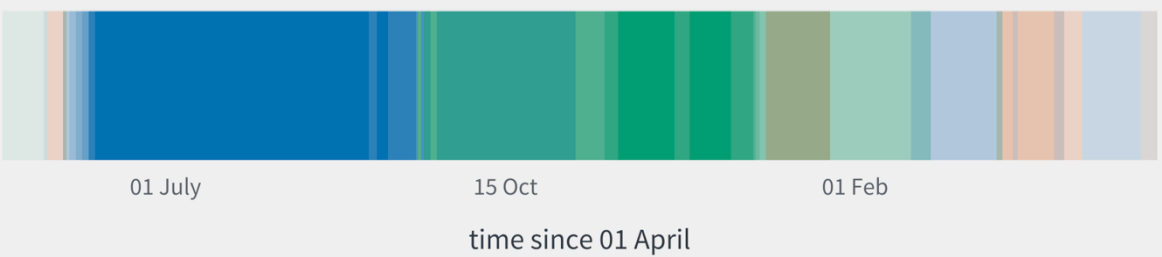

01 July
15 Oct
01 Feb
time since 01 April


Predicted Movements of Bearded Seals
by Assigned Seasonal State
1
2
3
4
northing (km)
-2000
-2500
-3000
500
1000
easting (km)
01 July
15 Oct
01 Feb
time since 01 April

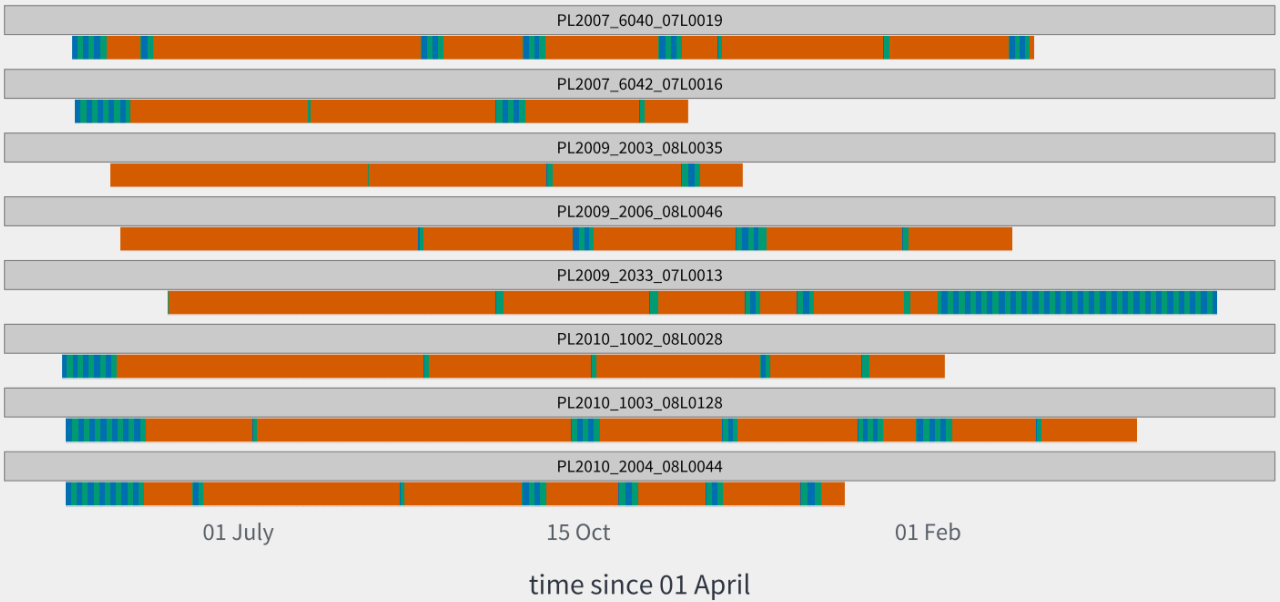
## Seasonal State Assignments - Ribbon Seals (sample)



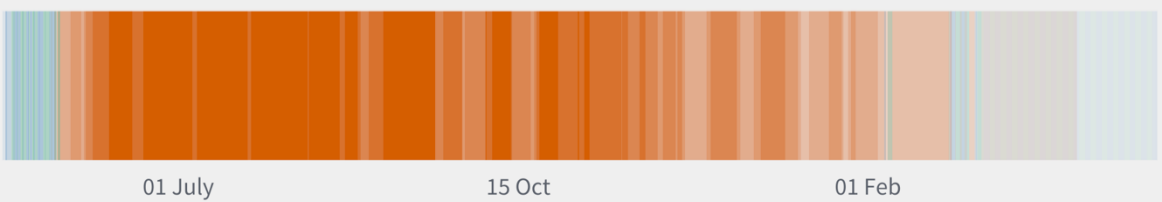

## Majority Seasonal State Assignments - Ribbon Seals



## Seasonal State Assignments - Young Spotted Seals (sample)




## Majority Seasonal State Assignments - Young Spotted Seals



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

*Ribbon and spotted seals remind us we still have more work to do*

# Future Considerations

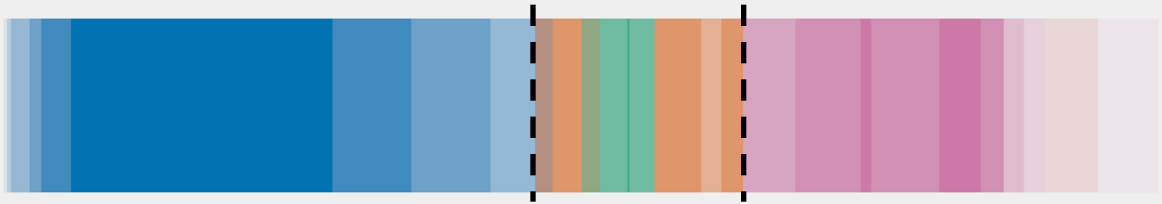
- Still just a ‘proof of concept’

- Fix transition probabilities so they are one-way
- Separate out individual heterogeneity
- 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*



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