Q1: How do landuse and climatic change affect species’ niche throughout their ranges?

Q2: How does climatic influence vary across a species’ global range after accounting for biotic interactions?

Q3: How does the spatial scale of population synchrony vary with climate change?
Q1: How do landuse and climatic change affect species’ niche throughout their ranges?

Q2: How does climatic influence vary across a species’ global range?

Q3: How does the spatial scale of population synchrony vary with climate change?
Dynamic complexity and stability of herbivore populations at the species distribution scale

Stabilizing by density dependence

Destabilizing by variation in environmental conditions

**Goal**: Investigate the extent to which variation in abiotic and biotic environmental covariates is associated with the variation in the stability of populations across a species distribution.
elk / red deer
*Cervus elephas*

- short growing season in summer
  + temperature and precipitation in winter
  ↓
  reproductive and survival rates
  ↓
  stability of population dynamics

1) Northerly distribution
2) Wide longitudinal distribution
3) Data of multiple globally distributed populations available.

Ahrestani *et al.*
Stable population dynamics
NASA – 8 May 2014
22 globally distributed elk & red deer populations

Ahrestani et al.
Stable population dynamics
NASA – 8 May 2014
Bayesian state-space
second-order autoregressive population model

\[ X_{i,t} = \beta_{i,0} + (1 + \beta_{i,1})X_{i,t-1} + \beta_{i,2}X_{i,t-2} + \varepsilon_{i,t} \]  

(1)

\[ Y_{i,t} \sim N(X_{i,t}, \tau_{i,t}) \]  

(2)

\( X_{i,t} \): time-series of loge true abundances
\( \beta_{i,0} \): rate of intrinsic population growth
\( \beta_{i,1} \): strength of direct density dependence
\( \beta_{i,2} \): strength of delayed density dependence
\( \varepsilon_{i,t} \): process stochasticity
\( Y_{i,t} \): observations
\( \tau_{i,t} \): observation error

Ahrestani \textit{et al.}.
Stable population dynamics
NASA – 8 May 2014
Bayesian state-space second-order autoregressive population model with a covariate

\[ X_{i,t} = \beta_{i,0} + (1 + \beta_{i,1})X_{i,t-1} + \beta_{i,2}X_{i,t-2} + \beta_{i,3}NDVI_{i,t-1} + \epsilon_{i,t} \quad (1) \]

\[ Y_{i,t} \sim N(X_{i,t}, \tau_{i,t}) \quad (2) \]

\( X_{i,t} \): time-series of \( \log_e \) true abundances  
\( \beta_{i,0} \): rate of intrinsic population growth  
\( \beta_{i,1} \): strength of direct density dependence  
\( \beta_{i,2} \): strength of delayed density dependence  
\( \beta_{i,3} \): strength of covariate  
\( \epsilon_{i,t} \): process stochasticity  
\( Y_{i,t} \): observations  
\( \tau_{i,t} \): observation error
Time series of the elk & red deer populations

Ahrestani et al.

Stable population dynamics

NASA – 8 May 2014
<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Resolution/Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td><strong>Coefficient of variation</strong> of annual growing season Normalized Difference Vegetation Index (NDVI)</td>
<td>8-km² - bimonthly (AVHRR &amp; MODIS)</td>
</tr>
<tr>
<td>Model 2</td>
<td><strong>Maximum</strong> annual growing season Normalized Difference Vegetation Index (NDVI)</td>
<td></td>
</tr>
<tr>
<td>Model 3</td>
<td>Start of the growing season</td>
<td>1° - monthly Global Precipitation Climatology Centre</td>
</tr>
<tr>
<td>Model 4</td>
<td>Length of the growing season</td>
<td>1° - daily National Centre for Environmental Prediction Reanalysis II</td>
</tr>
<tr>
<td>Model 5</td>
<td>End of the growing season</td>
<td></td>
</tr>
<tr>
<td>Model 6</td>
<td>Coefficient of variation of annual wintertime temperature</td>
<td></td>
</tr>
<tr>
<td>Model 7</td>
<td>Coefficient of variation of annual wintertime precipitation</td>
<td></td>
</tr>
<tr>
<td>Model 8</td>
<td>Northern Hemisphere Land Temperature Anomaly (NHLTA)</td>
<td></td>
</tr>
</tbody>
</table>

*7 & 8 interpolated to 8-km² using Geospatial Data Abstraction Library*

Ahrestani et al. Stable population dynamics NASA – 8 May 2014
Sensitivity analysis – spatial extent

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Stable population dynamics

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Calculating growing season parameters

Johnson & Eklundh (2004) TIMESAT

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Density dependence parameter plane

\[ X_{i,t} = \beta_{i,0} + (1 + \beta_{i,1})X_{i,t-1} + \beta_{i,2}X_{i,t-2} + \varepsilon_{i,t} \]

Royama 1992
Model estimates of density dependence parameter pairs
Distribution of parameter pairs

Regions of the \((1+\beta_1, \beta_2)\) parameter plane
Influence of environmental variables on density dependence

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Influence of environmental variables & population trends

Model 1 - NDVI

Model 8 - NHLTA
Conclusions

The most stable dynamics were observed in populations experiencing:
• negative trends in the variation in vegetation productivity
• positive departures from long-term mean annual temperature

The application of stability theory in a Bayesian state-space framework provides important insights into variation in the complexity of population dynamics and their environmental drivers at the species-distribution scale.