Migration, Nomadism, and Range-Residency: How Landscape Dynamics Link Individual Movements to Population-Level Patterns

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- German Biodiversity and Research Center (BiK-F)
A moment for pedagogy:

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How Complex, Population-level Patterns Arise from Individual Movements

Key Elements:

- Population-level movement patterns
- Individual movement mechanisms
- Key role of dynamic resource landscapes

Relevance:

- Ungulates, but also birds

Approaches:

- Theoretical ecology + ecoinformatics
Population-level distributions
Population-level distributions
Population-level distributions
Conceptual framework for resources, population distributions and movement mechanisms

Movement Mechanisms
- Non-oriented
- Oriented
- Spatial memory

Individual Movement Paths & Population Distributions
- Range Residency
- Migration
- Nomadism I
- Nomadism II

Landscape Structure and Dynamics

Mueller and Fagan, Oikos 2008
Outline:

Overview

- Dynamics of resource landscapes
- Individual movement mechanisms

Real Animal Movements

- Mongolian gazelles
- Comparisons among ungulate species

Computational Modeling of Animal Movements

- Situation-dependent use of movement mechanisms
- Spatial memory as a navigation aid in dynamic landscapes

Looking Forward

- Learning and Experience (Migratory Whooping Cranes)
Conceptual framework for resources, population distributions and movement mechanisms
Resources...variability across 4 gradients:

a) Amount

many

few
Resources... variability across 4 gradients:

a) Amount
b) Spatial variability
Resources...variability across 4 gradients:

a) Amount
b) Spatial variability
c) Temporal variability

Dynamic Landscape

Static Landscape
Resources...variability across 4 gradients:

a) Amount
b) Spatial variability
c) Temporal variability
d) Predictability

Dynamic Landscape:
variable but predictable

Dynamic Landscape:
variable and unpredictable
Conceptual framework for resources, population distributions and movement mechanisms

Movement Mechanisms

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Individual Movement Paths & Population Distributions

Landscape Structure and Dynamics
Individual level movement mechanisms:

(1) **Non-oriented** (e.g., diffusion)

- sensory stimuli such as stomach fullness
- **stimuli coming from an animal’s current location**
- cause an alteration in an individual’s movement parameters (speed, turning angle)
- movement decision with *random direction*
Individual level movement mechanisms:

(2) **Oriented**, based on taxis and perceptual range

- e.g. visual detection of food good habitats
- stimuli *stem from a location beyond the animal’s current position*
- movement in a *predictable direction*.
Individual level movement mechanisms:

(3) **Spatial memory**, based on previous information derived from the recollection of
- an *individual’s own history*,
- communication with conspecifics,
- or as a *genetic inheritance* from its ancestors

- *path integration* (e.g., waggle dance in bees or magnetic compasses in birds)
- *cognitive maps* (e.g., geomagnetic coordinates and use of landmarks)
Resource landscapes:

1) Determine the effectiveness of alternative movement mechanisms
Resource landscapes:

1) Determine the effectiveness of alternative movement mechanisms
2) Lead to different emergent population-level distribution patterns

Mueller and Fagan, Oikos 2008
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NDVI timeseries of vegetation ‘greenness’
GIMMS dataset: 8 km resolution, but 30 years of biweekly data
Measuring resources for gazelles

Occupancy is greatest for mid-range NDVI values

Collecting data on movement & habitat use

Steps to Field Project
Collecting data on movement & habitat use

Steps to Field Project

0) Theoretical ecologist applies for animal care and use permit
Collecting data on movement & habitat use

Steps to Field Project

1) Put Satellite Collars on Gazelles
Collecting data on movement & habitat use

Steps to Field Project

1) Put Satellite Collars on Gazelles
2) Read Email from Gazelles
Collecting data on movement & habitat use

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1) Put Satellite Collars on Gazelles
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Characterizing Movement of Mongolian Gazelles

Serengeti - Mara Ecosystem

~400,000 wildebeest

Yellowstone NP

~60,000 elk

8,983 km²

25,000 km²
Characterizing Movement of Mongolian Gazelles

- Serengeti - Mara Ecosystem
  - ~400,000 wildebeest
  - 25,000 km²

- Mongolian gazelle yearly range
  - 1 animal
  - 27,958 km²

- Yellowstone NP
  - ~60,000 elk
  - 8,983 km²
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Dynamics of population distributions: Multispecies comparison

**Data: Four different ungulate species:**

- **Caribou of the Porcupine herd**  
  *(Craig Nicolson, UMASS & Porcupine Caribou Technical Committee)*

- **Mongolian gazelle**  
  *(UMASS, WCS, UMD, NZP)*

- **Patagonian guanaco**  
  *(Andres Novaro, Argentine Research Council)*

- **Moose in Massachusetts**  
  *(David Wattles, Stephen DeStefano, UMASS)*

Mueller et al. in press. Global Ecology and Biogeography
Dynamics of population distributions: Multispecies comparison

Notice scales!
Dynamics of population distributions: Multispecies comparison

Realized mobility
Dynamics of population distributions: Multispecies comparison

Realized mobility

Movement coordination

![Graph showing realized mobility and movement coordination across different species.](image)
Dynamics of population distributions: Multispecies comparison

Mueller et al. in press. Global Ecology and Biogeography
Relating Dynamics of Population Distributions to Dynamics of Landscapes
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Individual-based Neural Net Genetic Algorithm (ING) Model

A consumer seeking resources by moving through a heterogeneous landscape ...

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Input Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>non-oriented</td>
<td>bias, currentResourceUptake, uptakePrevious8Steps, searchEffortPrevious8Steps</td>
</tr>
<tr>
<td>oriented</td>
<td>seeAnything?, currentX, currentY, stepCounter</td>
</tr>
<tr>
<td>spatial memory</td>
<td></td>
</tr>
</tbody>
</table>

→ Designed so that individual movement mechanisms may be “turned off”
Individual-based Neural Net Genetic Algorithm (ING) Model

Two key landscape features:

1) Patch Size

2) Resource Predictability

Probability Patch Does Not Move Between Generations

Foci:

1) Frequency
2) Time of use
3) “Relevance” of different movement mechanisms

\[
\text{Relevance} = 1 - \left[ \frac{\text{efficiency}_{\text{reduced neural network}}}{\text{efficiency}_{\text{full neural network}}} \right]
\]
Efficiency is greatest in predictable landscapes with large patch sizes.

Contours are efficiency of movement (Avg. resources per movement step)

Consumers evolved to use different mechanisms in different situations.

Predictable Resources

Unpredictable Resources

Consumers evolved to use different mechanisms in different situations.

Close to zero throughout.
Consumers evolved to use different mechanisms in different situations

Most unexpected result:

Memory used extensively at intermediate patch sizes to systematically search the entire domain

Memory may contribute to ‘superdiffusion’ observed in many empirical systems

\[ MS \left( D t^\alpha \right), \quad \alpha > 1 \]
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• Learning and Experience (Migratory Whooping Cranes)
Navigating through a dynamic, disordered landscape

-- Habitat patches, which can be transient

-- Reference memory (shortest path across)

-- Working memory (most recent $n$ patches)

-- Rule 1: If on migration route, go to next patch in reference memory, provided it exists

-- Rule 2: Go to the nearest patch not in the working memory

Berbert et al. in review.
Fraction of times walker successfully migrates

Critical working memory is inflection point
Critical working memory ($\mu_w$)

Landscape Persistence

Walker gets trapped in small areas. → Sedentarism

Walker is free to explore all space.
Walker efficiency
(\# patches / \# steps for successful migrations)

Working memory ($\mu_w$)
Critical working memory ($\mu_w$) vs. Landscape Persistence

High efficiency
→ Migration

Low efficiency
→ Nomadism
Collaborators:

- Volker Grimm (UFZ, Germany)
- Kirk Olson (Wildlife Conservation Society)
- Peter Leimgruber (Smithsonian)
- Todd Fuller (Univ. Mass.)
- Craig Nicolson (Univ. Mass.)
- Andres Novaro (Argentine Research Council)
- Maria Bolgeri (Argentine Scientific Agency)
- Gunnar Dressler (UFZ, Germany)
- Justin Calabrese (Smithsonian)
- David Wattles (Univ. Mass. / USGS)
- Steven DeStefano (Univ. Mass. / USGS)
- Devatuyla Kavathekar (Univ. Maryland)
- Juliana Berbert (Univ. Estadual Paulista, Brazil)
- Roberto Kraenkel (Univ. Estadual Paulista, Brazil)
- Jim Tucker (NASA)

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- US National Science Foundation
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  -- Advances in Bioinformatics Panel
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Whooping Crane (*Grus americana*)

- tallest bird in North America
- one of only 2 crane species in North America
- long lived >20 years in the wild
- ~70 mating pairs in Wood Buffalo NP
Whooping Crane (Grus americana)

“Experimental” eastern flock migrates from Wisconsin to Florida
Eastern Flock of Whooping Cranes

-- Not yet reproducing in wild
-- Population augmented from captive breeding
-- Captive birds don’t instinctively know how to migrate, so they must be taught …
Eastern Flock of Whooping Cranes

-- Unique opportunities for studying long distance movements

-- Individuals trained in controlled ways, and tracked over many years:

  → Information on learning (age, group composition)

-- Human – controlled breeding:

  → Known pedigrees

→ Tease apart genetics from environmental influences (work in progress / not today)
Quantifying migratory movements

-- First southbound flight: trained by ultralight aircraft
-- Subsequent flights (N and S): birds only, individually or in groups
-- Intense monitoring (and GPS) give spatiotemporal details of each bird’s migration
-- Measure:
  • Departure/arrival dates
  • Trip duration
  • Deviation from straight line
-- How do cranes’ migratory journeys change across years?
Experience brings efficiency: older birds fly direct.
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Experience brings efficiency: older birds fly direct
Older birds travel more slowly

<table>
<thead>
<tr>
<th>Individual Age</th>
<th>Days en route between winter and summer grounds</th>
<th>Average Age of Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
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<td>9</td>
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</table>
So older cranes:

1) Fly more directly with much less deviation (85% reduction in 9 years)
2) Take longer to travel the migration route
3) Depart and arrive earlier on both N- and S-bound legs (not shown)
So older cranes:

1) Fly more directly with much less deviation (85% reduction in 9 years)

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Do not anthropomorphize this .....
A Google Earth Plug-in to Aid Visualization of Animal Movements

Java World Wind transitioning to a Google API

Kavathekar et al. in prep.
Gazelles encounter border fences → Real world reflecting boundaries
Effects of imposing a barrier to movement

Animal distributions and movement behaviors in relation to resource dynamics

Part 1: (conceptual)
Framework of resource distributions and animal movements

Part 2: (empirical)
> Resource distributions and movements of Mongolian gazelle

Part 3: (empirical)
> Comparison of movements between species
Part 1: Conceptual framework for resources, population distributions and movement mechanisms

Movement Mechanisms
- Non-oriented
- Oriented
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Landscape Structure
i.e., amount, versatiliy, predictability, and heterogeneity of resources

Individual Movement Paths & Population Distributions

Mueller and Fagan, Oikos 2008
Visualization of Gazelle Movements

Sep 4, 2007
Discussion

*Conservation Strategies Nomadism versus Migration:*
- protection of seasonal ranges (e.g. calving grounds)
- protection of migration routes
- integrative landscape approaches vs. protected areas
- Minimum Dynamic area

*Coping with changes in patterns of primary productivity as a consequence of climate change:*

What population level pattern and which individual level movement behaviors are more threatened or more flexible?