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

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- University of Maryland
- Smithsonian Conservation Biology Institute
- 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 <u>dynamic</u> resource landscapes

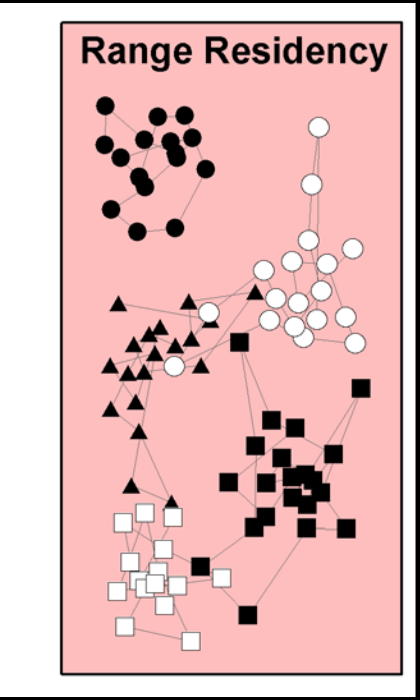
Relevance:

- Ungulates, but also birds

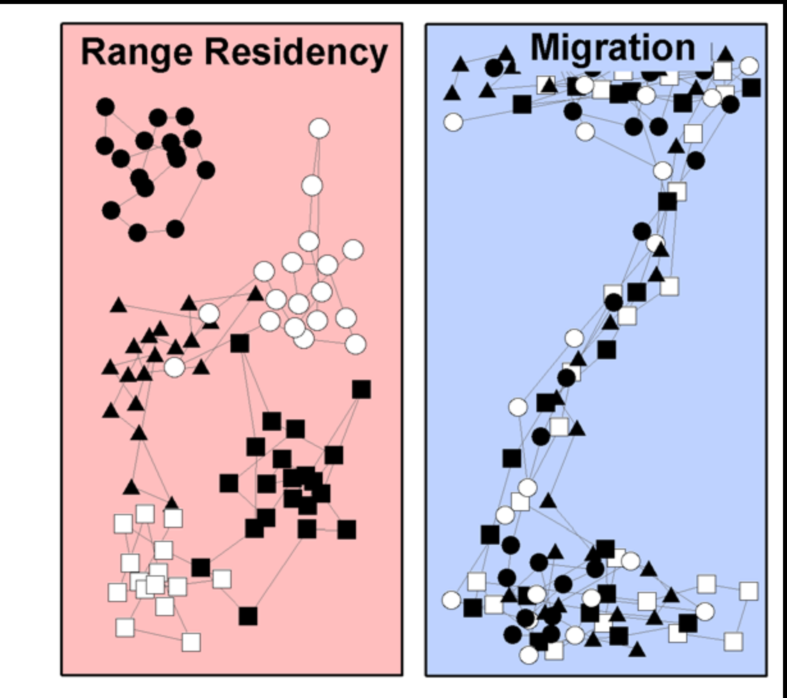
Approaches:

- Theoretical ecology + ecoinformatics

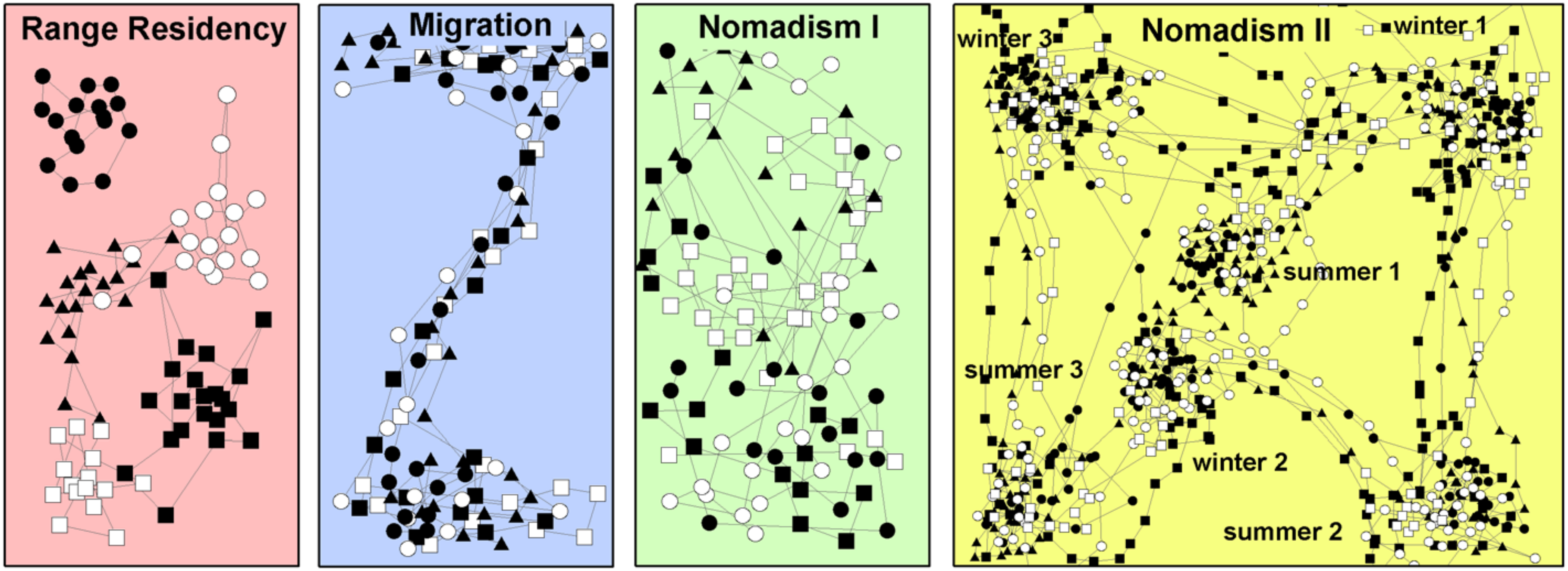
Population-level distributions



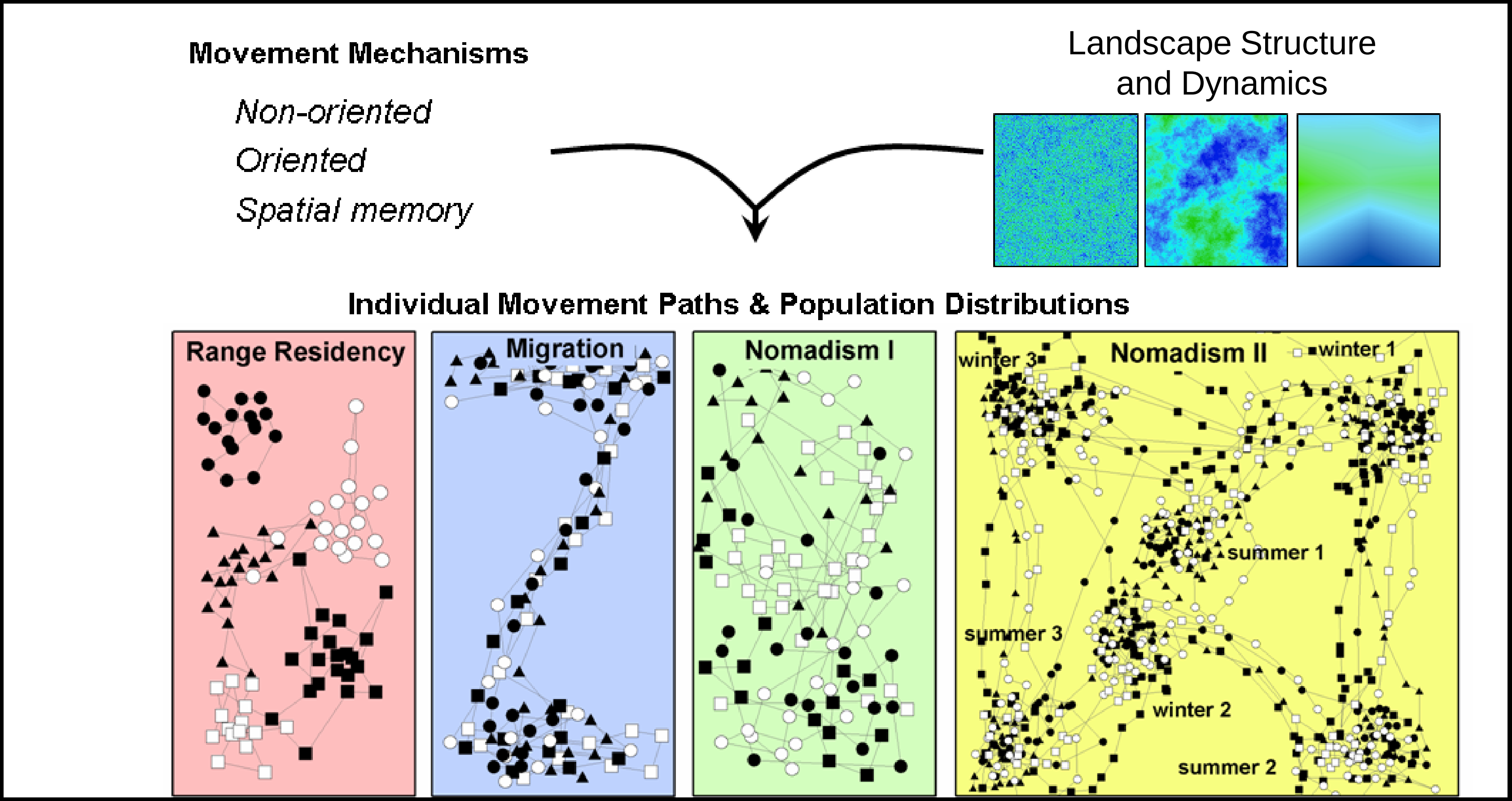
Population-level distributions



Population-level distributions



Conceptual framework for resources, population distributions and movement mechanisms



Mueller and Fagan, Oikos 2008

Outline :

Overview

- Dynamics of resource landscapes
- Individual movement mechanisms

Real Animal Movements

- Mongolian gazelles
- Comparisons among ungulate species

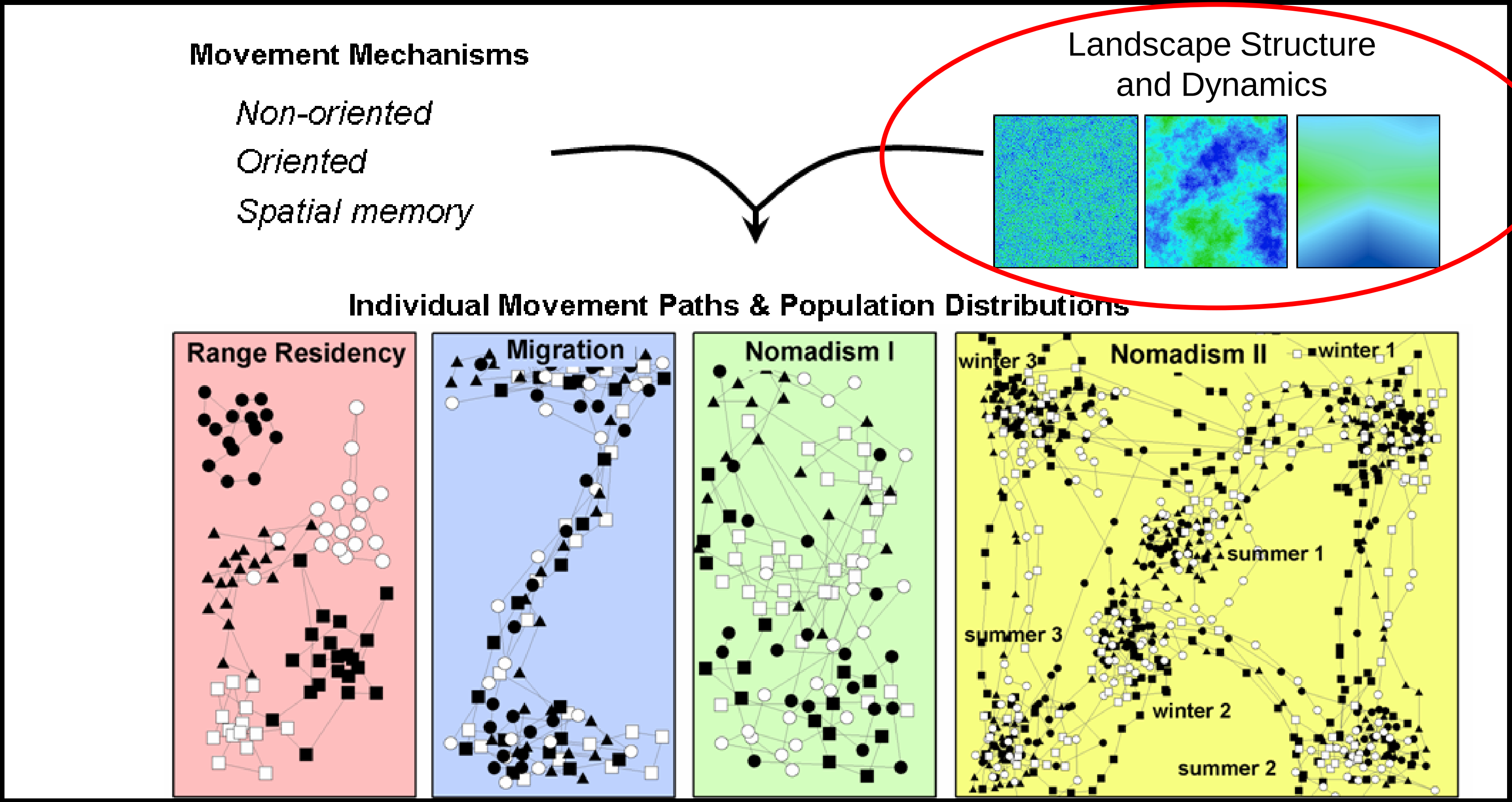
Computational Modeling of Animal Movements

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

Looking Forward

- Learning and Experience (Migratory Whooping Cranes)

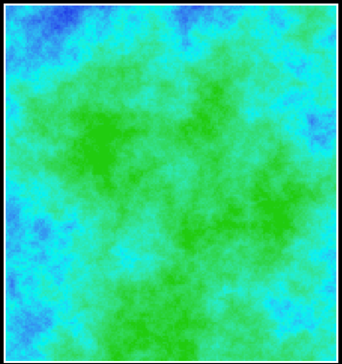
Conceptual framework for resources, population distributions and movement mechanisms



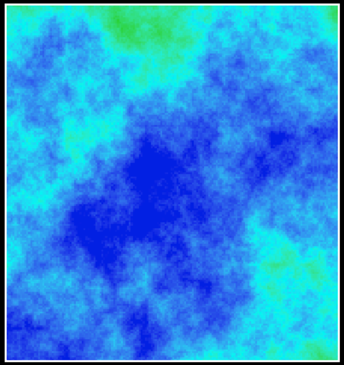
Resources…variability across **4 gradients:**

a) Amount

many



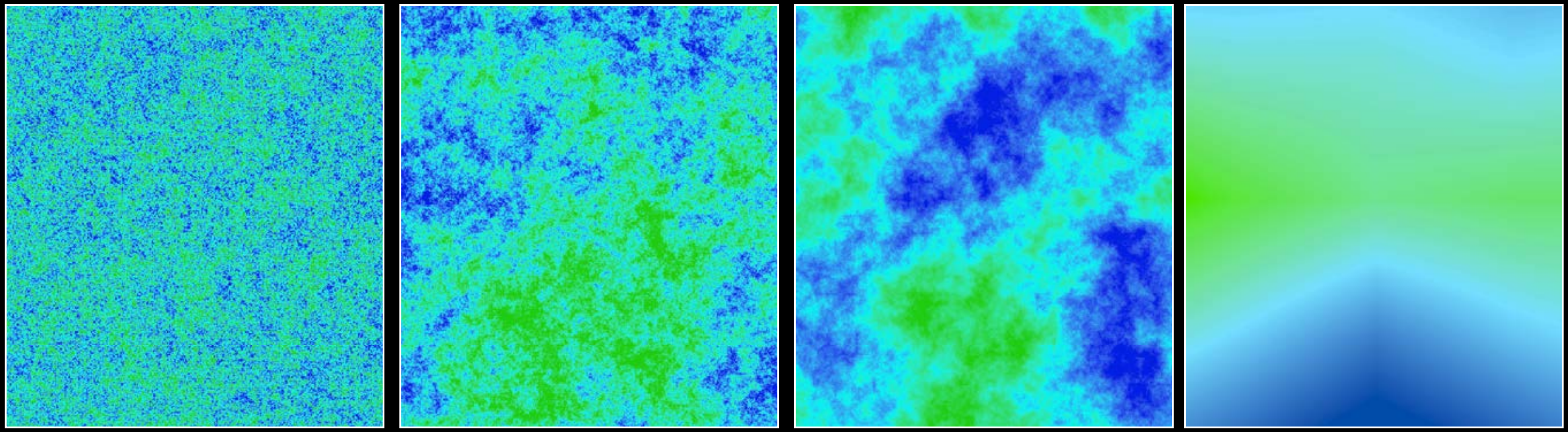
few



Resources…variability across **4 gradients:**

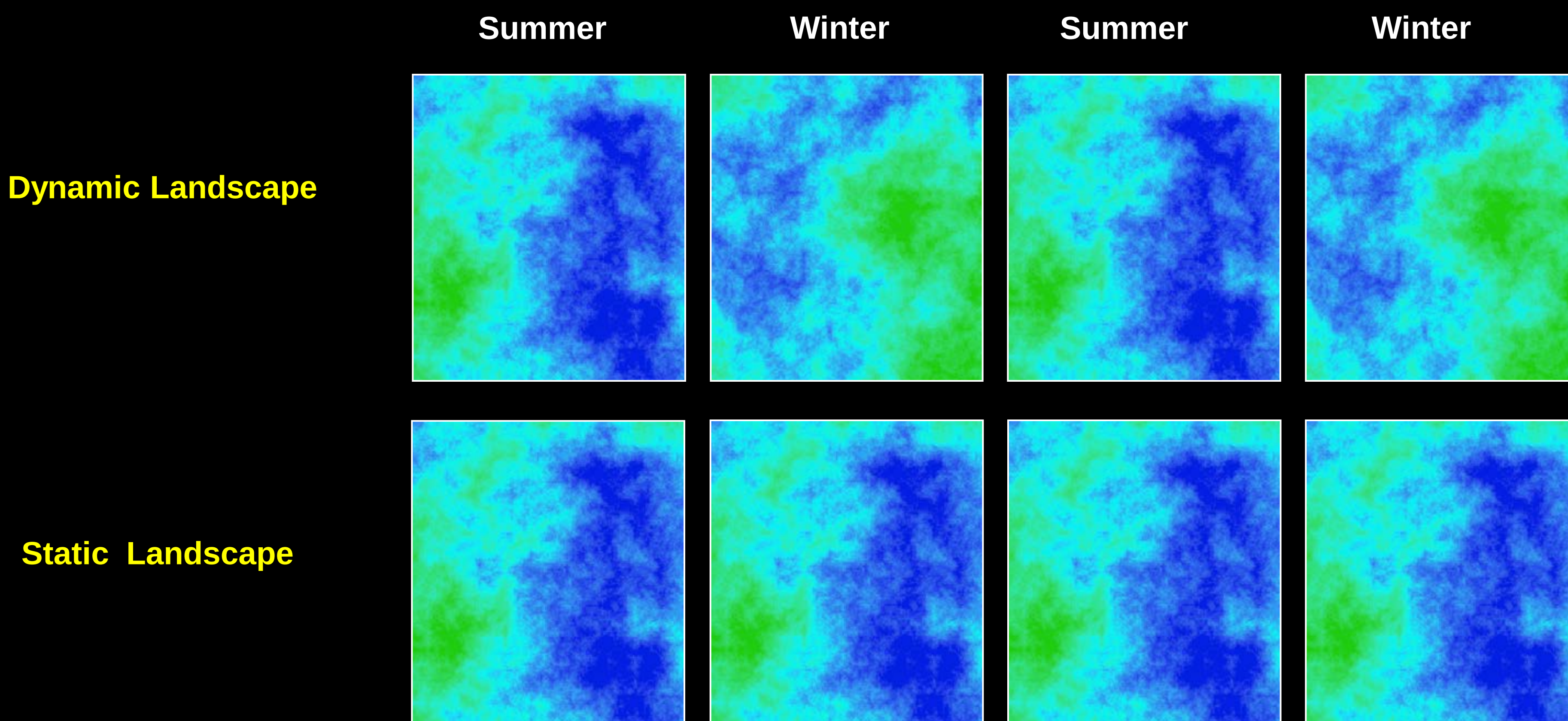
a) Amount
b) Spatial variability

Fine → coarse



Resources…variability across **4 gradients:**

a) Amount
b) Spatial variability
c) Temporal variability



Resources…variability across **4 gradients:**

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

Summer **Winter** **Summer** **Winter**

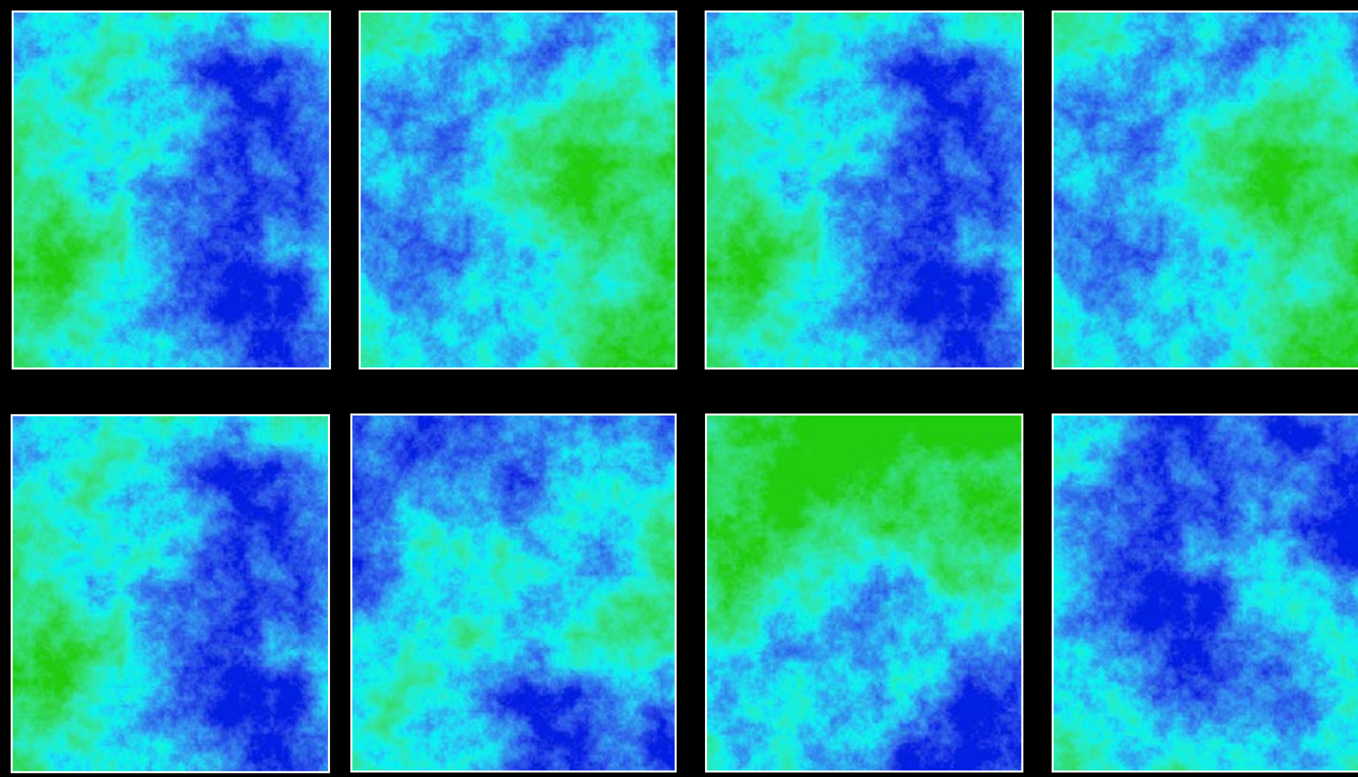
Dynamic Landscape:

variable but predictable

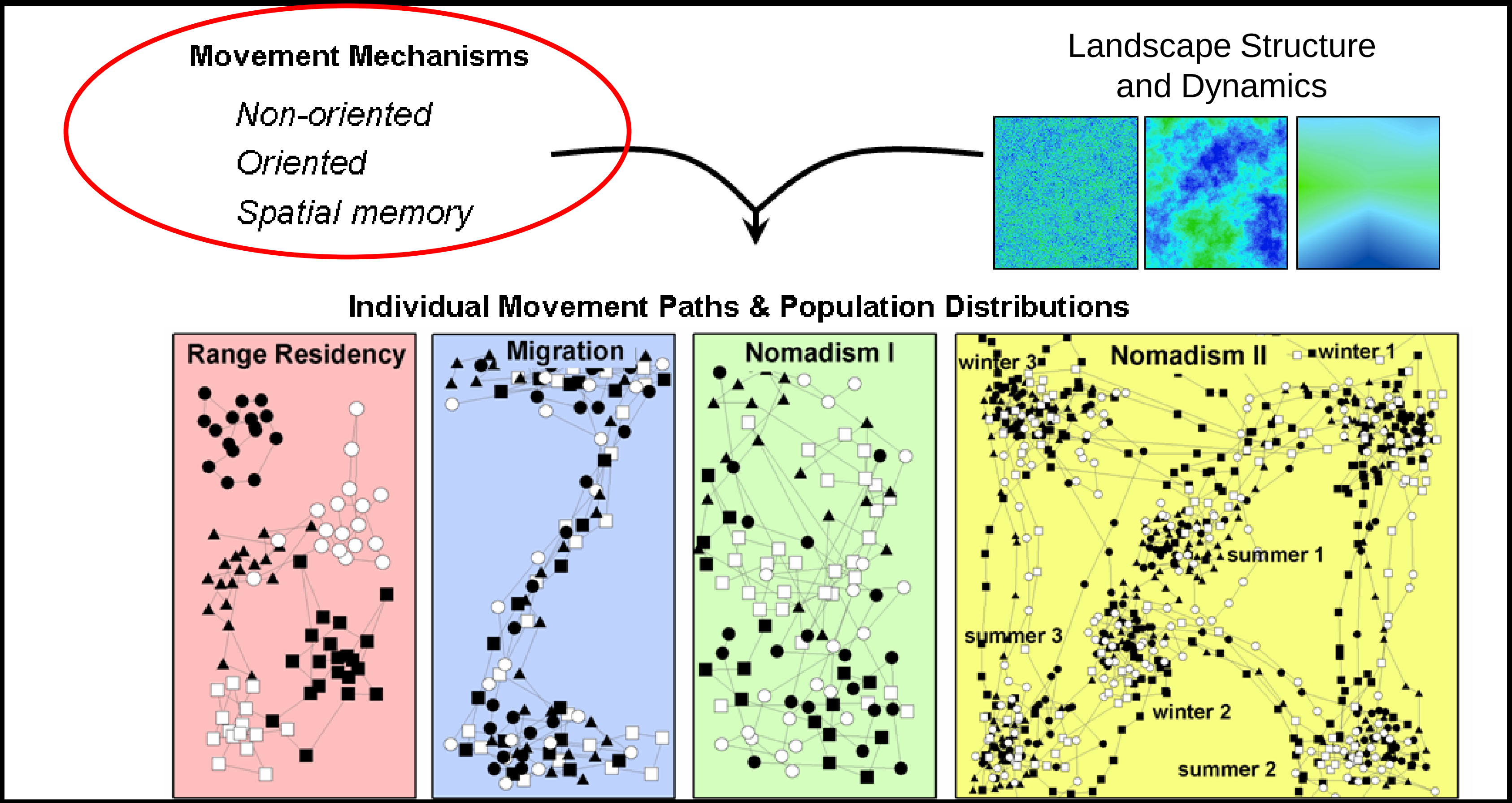
Dynamic Landscape:

variable and

unpredictable



Conceptual framework for resources, population distributions and movement mechanisms



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*.

<u>Individual level movement mechanisms:</u>

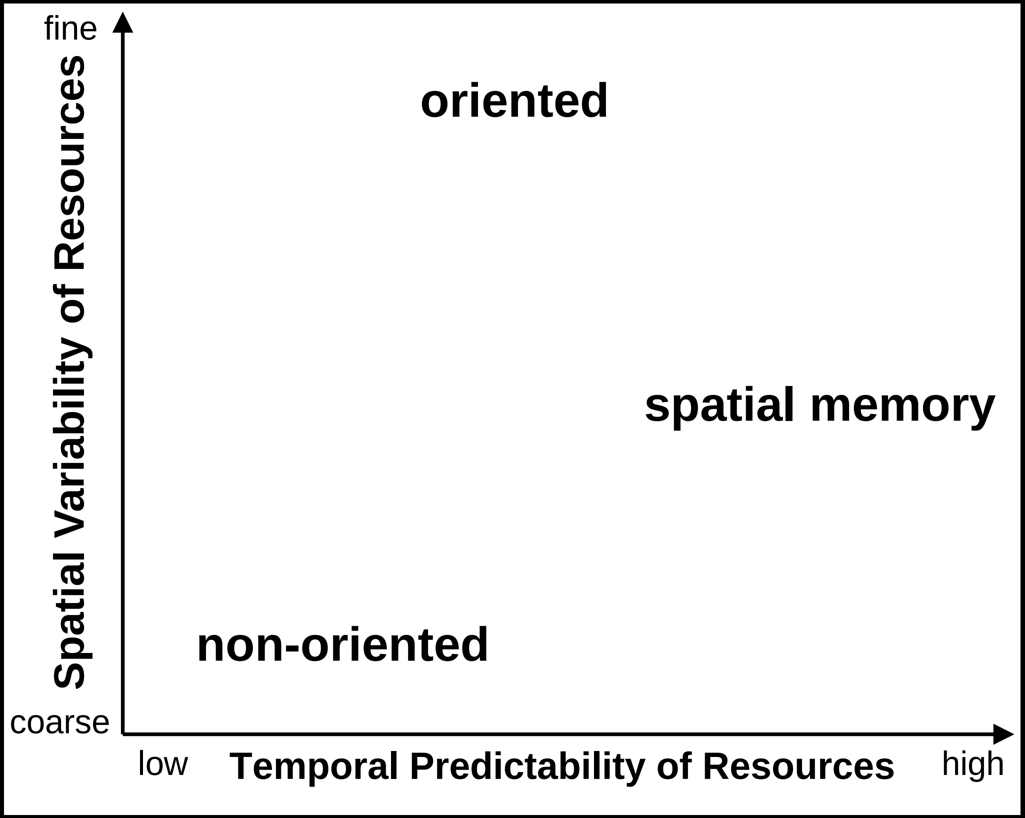
(3) ***Spatial memory,*** based on previous information derived from the recollection of

- an *<u>individual's own history</u>*,
- *<u>communication with conspecifics</u>*,
- or as a *<u>genetic inheritance</u>* 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:

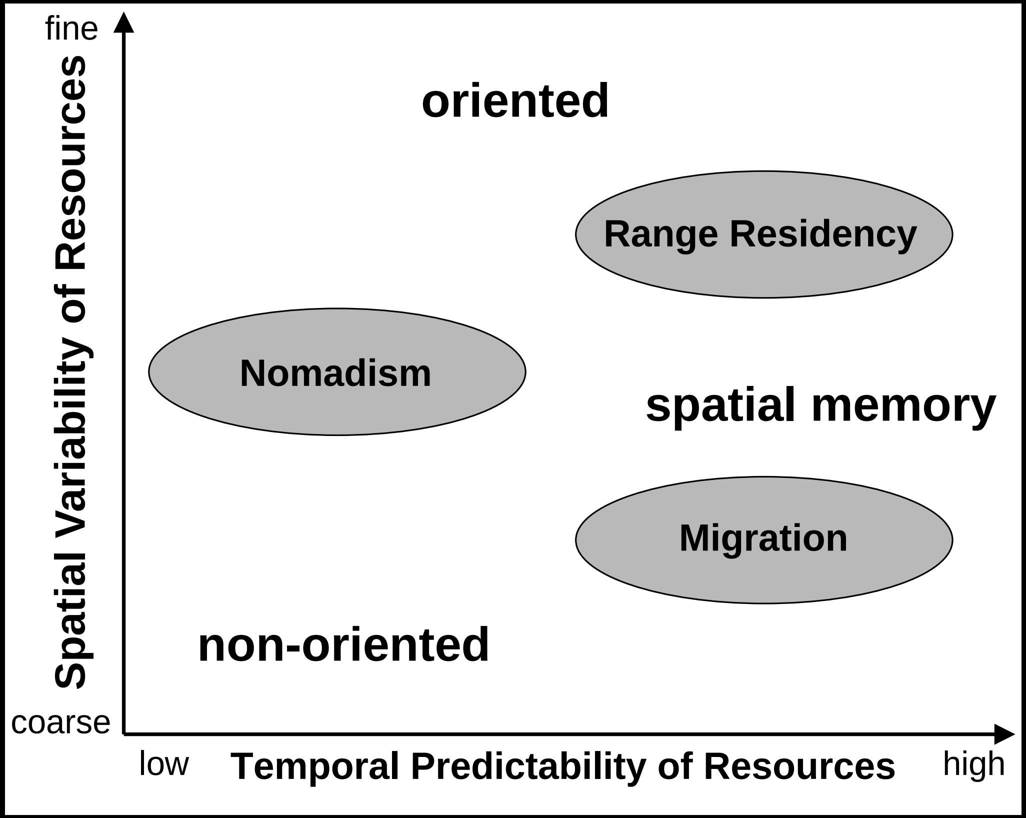
1) Determine the effectiveness of alternative movement mechanisms



Mueller and Fagan, Oikos 2008

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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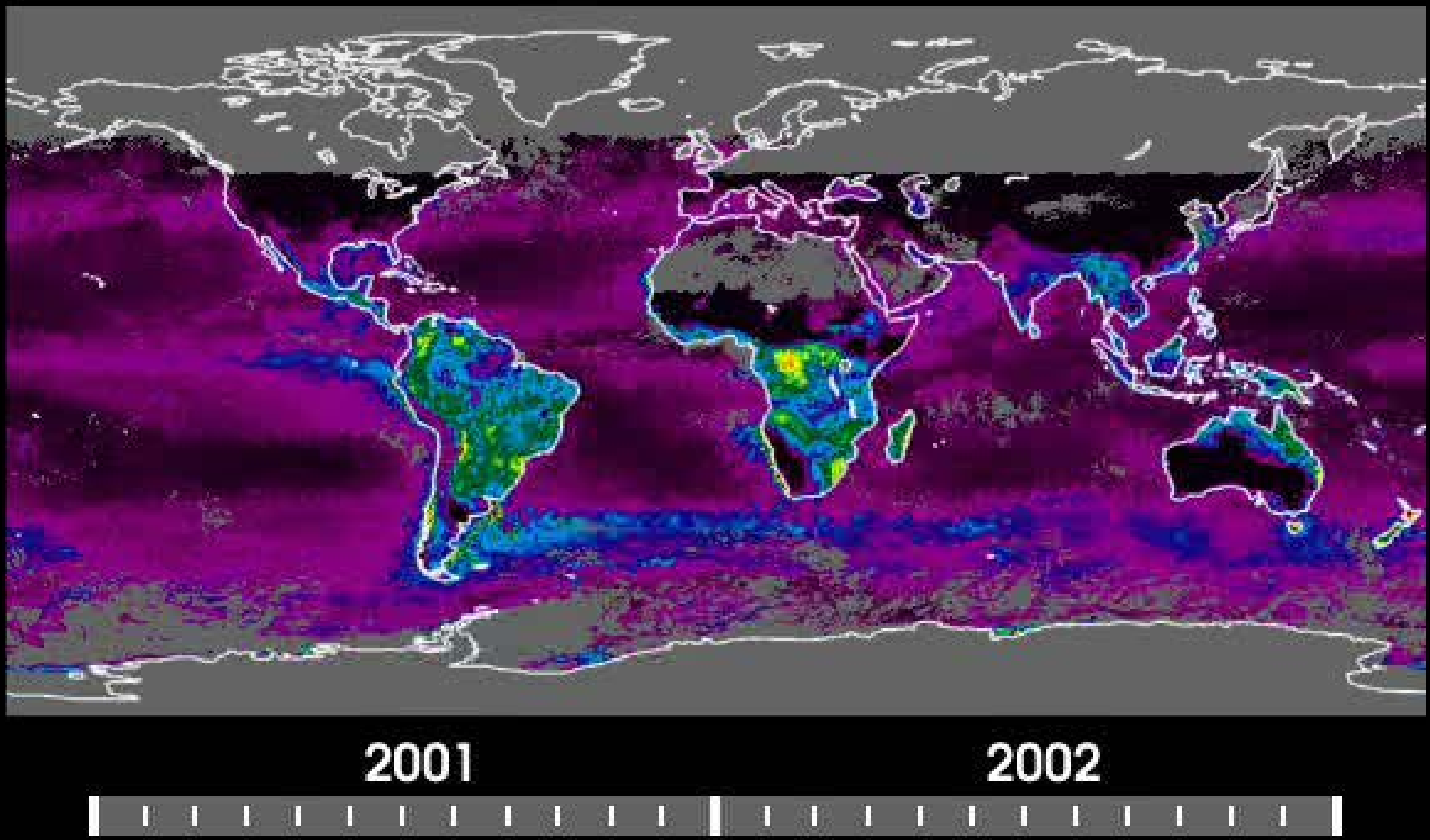
Looking Forward

- Learning and Experience   (Migratory Whooping Cranes)

Russia
Lake Baikal
Mongolia
Taiga
Mongolia
Ulaan Baatar
Grasslands
Eastern Steppes
Gobi Desert
China
0
150
300 Kilometers

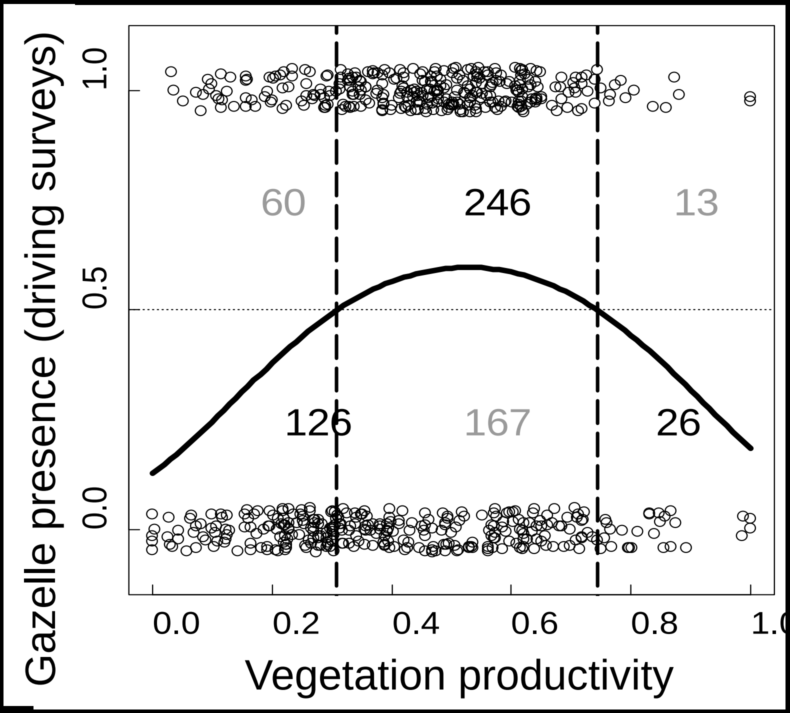


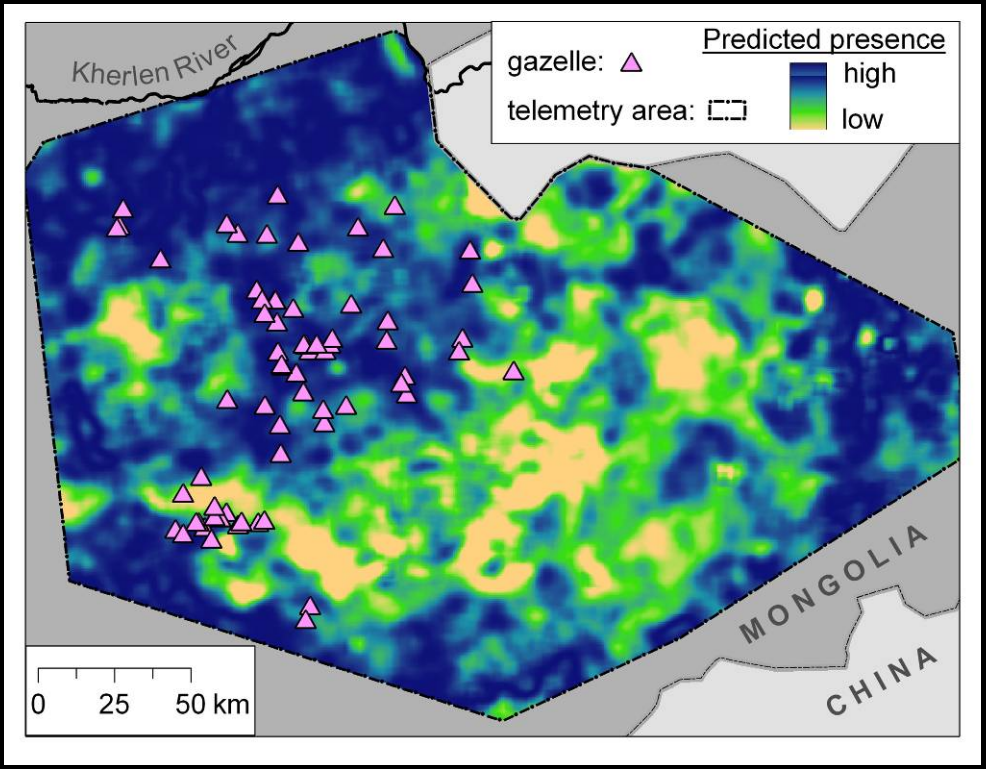
NDVI timeseries of vegetation 'greenness'
GIMMS dataset: 8 km resolution, but 30 years of biweekly data



Measuring resources for gazelles

Occupancy is greatest for mid-range NDVI values





Mueller et al., J. Appl. Ecol. 2008

Collecting data on movement & habitat use

Steps to Field Project

Collecting data on movement & habitat use

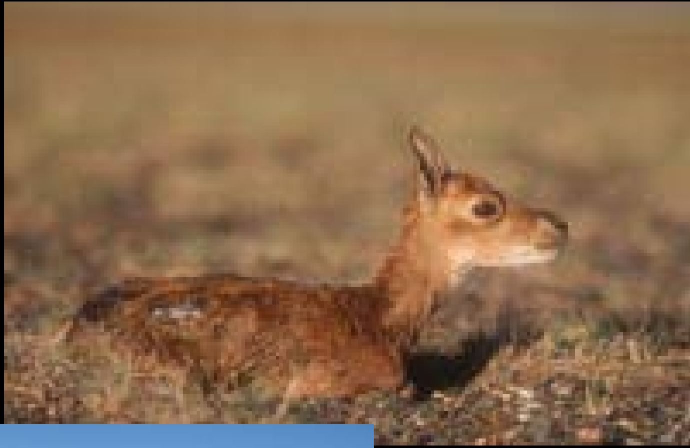
Steps to Field Project

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

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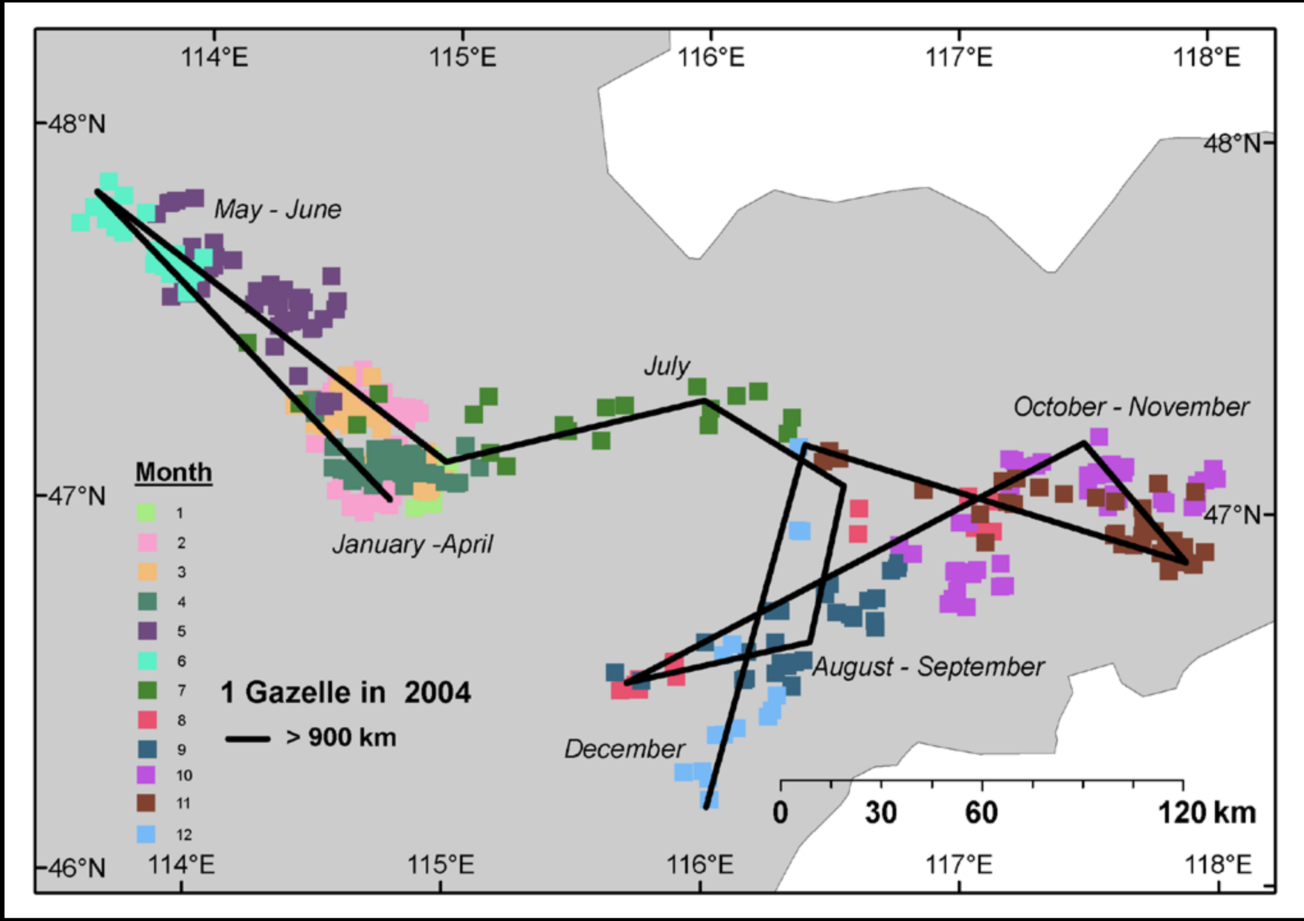
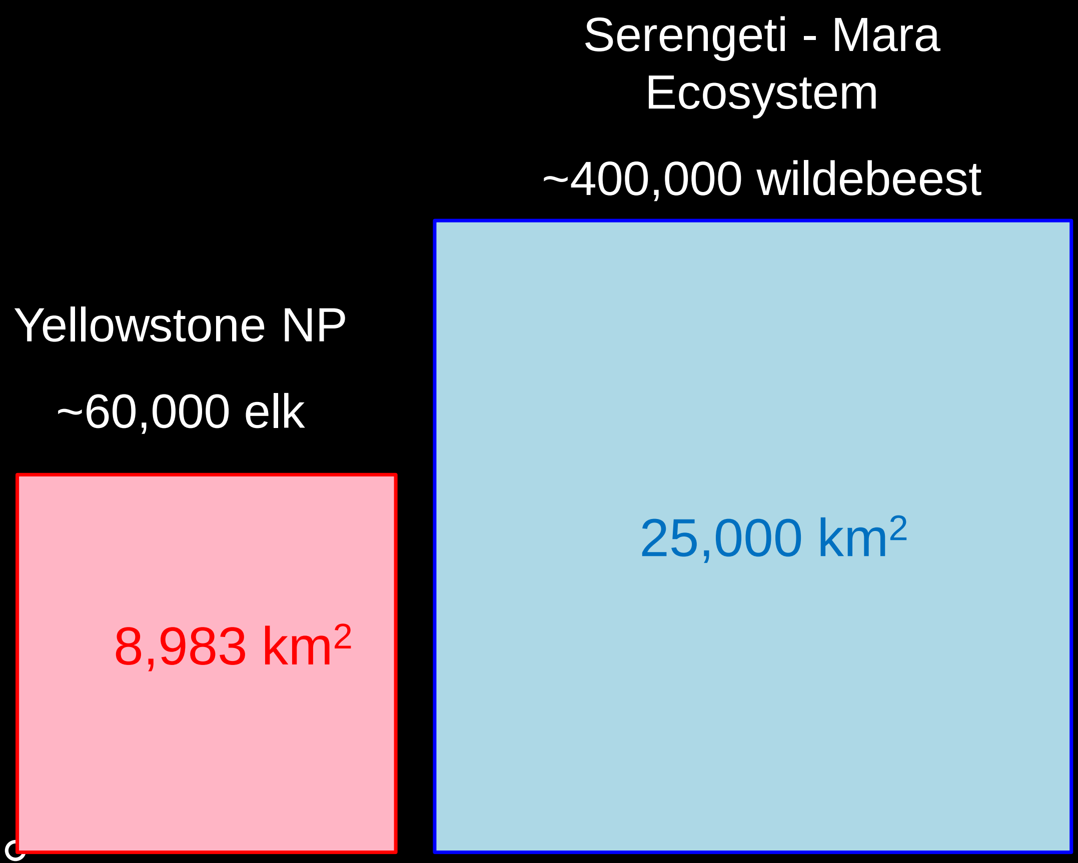


Characterizing Movement of Mongolian Gazelles



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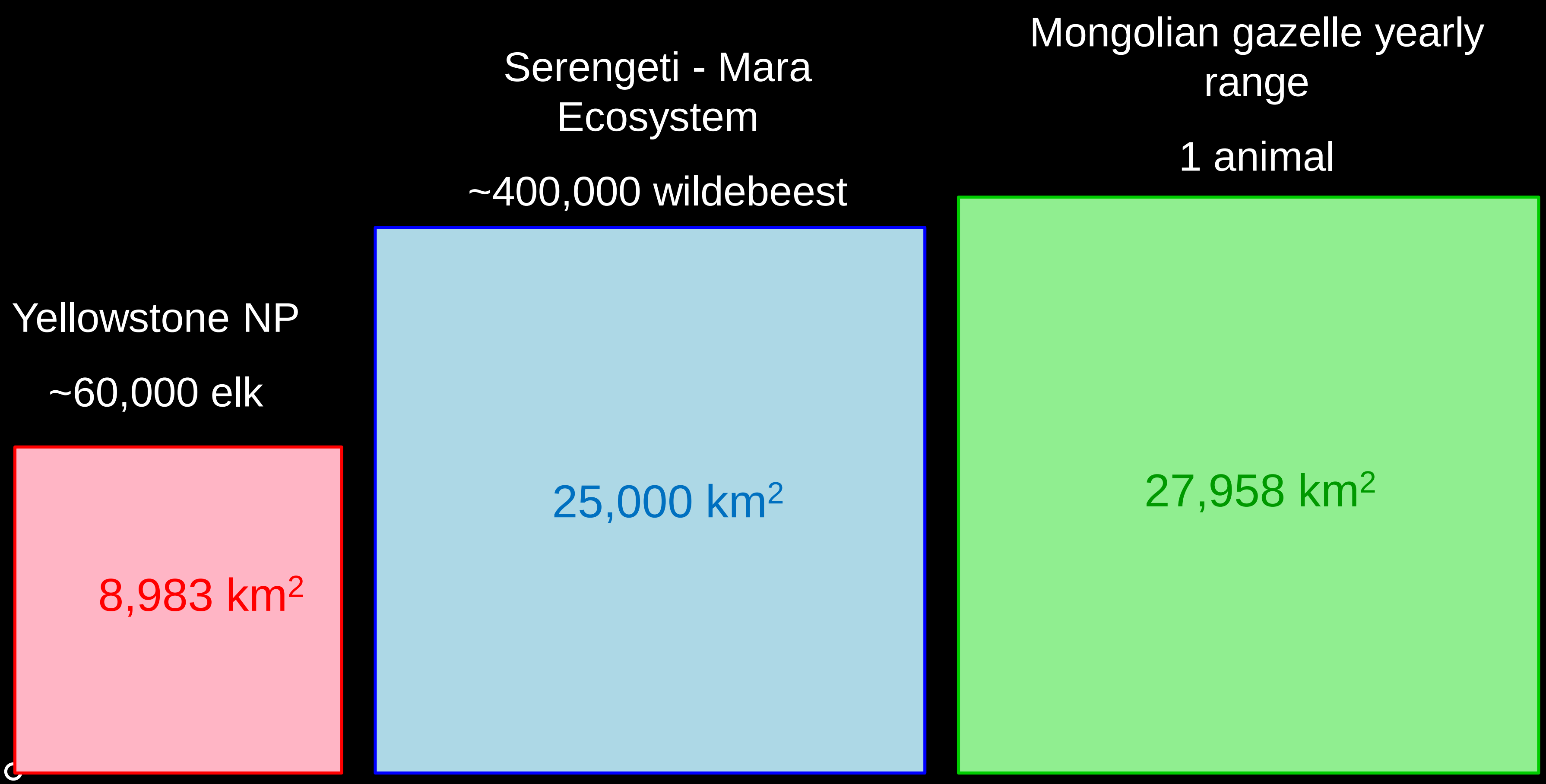

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Dynamics of population distributions: Multispecies comparison

Data: Four different ungulate species:

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

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

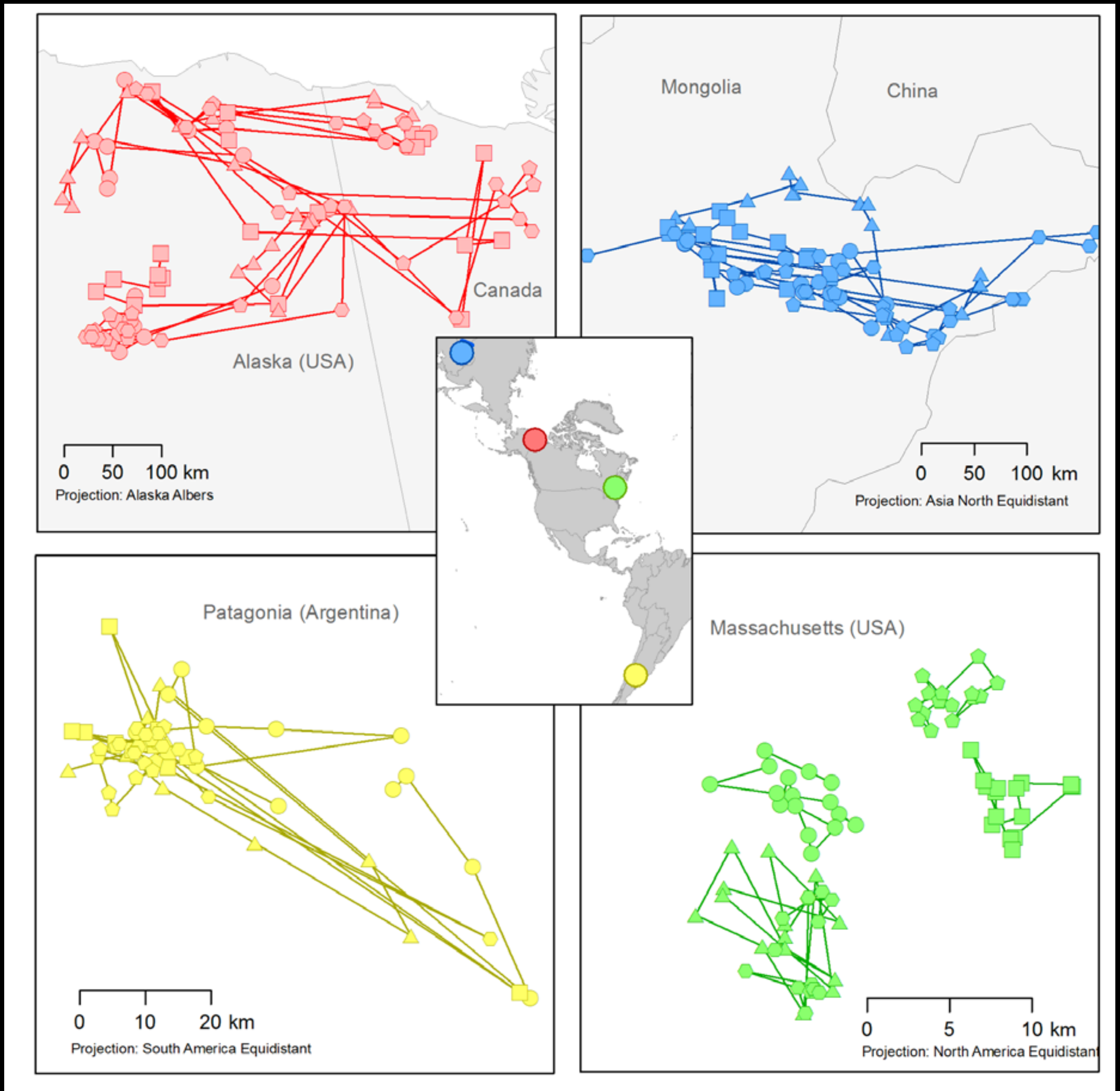
- **Patagonian guanaco**
  (*Andres Novaro, Argentine Research Council*)

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

Mueller et al. in press. Global Ecology and Biogeography

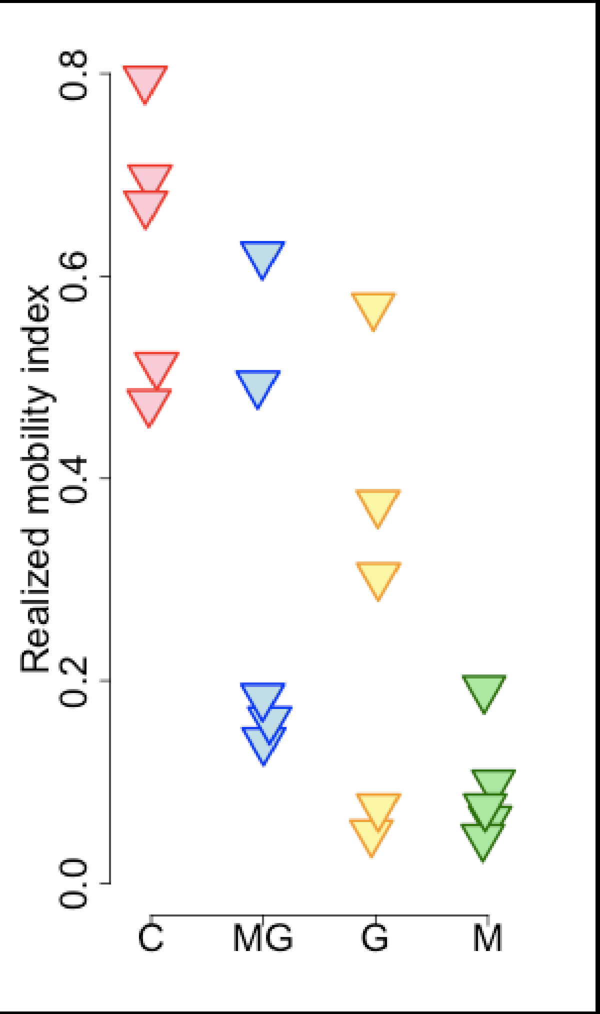
Dynamics of population distributions: Multispecies comparison

Notice scales !



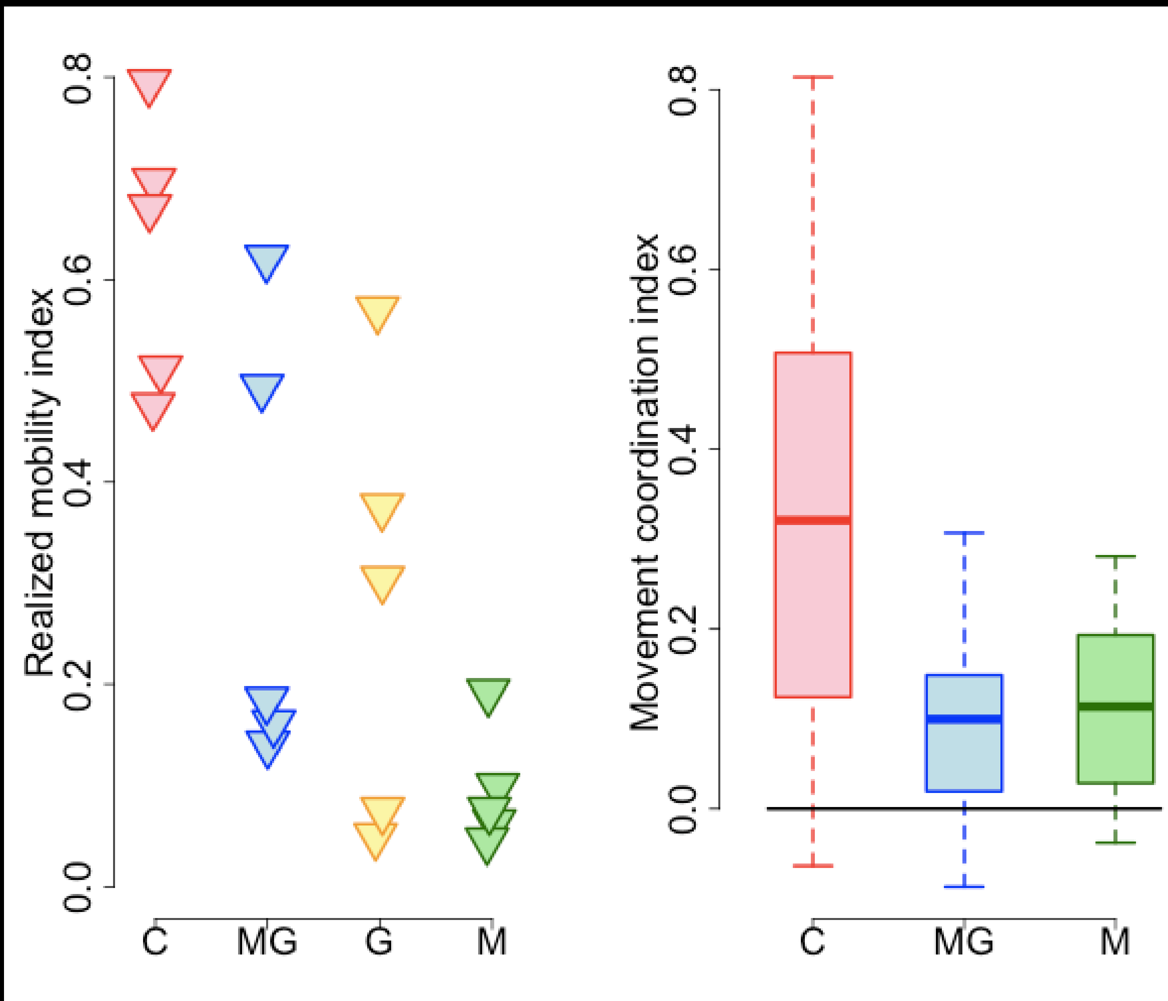
Dynamics of population distributions: Multispecies comparison

Realized mobility



Dynamics of population distributions: Multispecies comparison

Realized mobility Movement coordination



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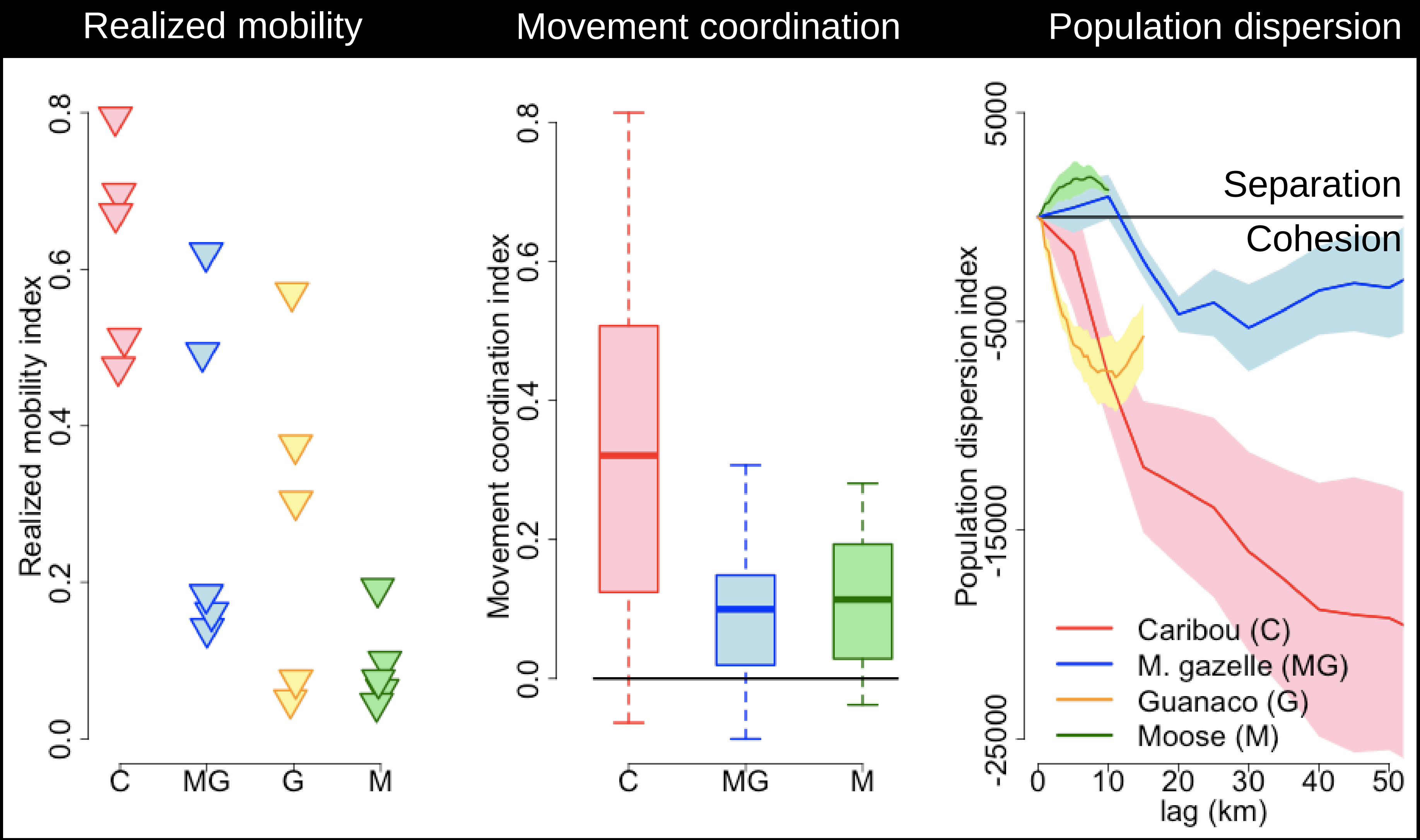
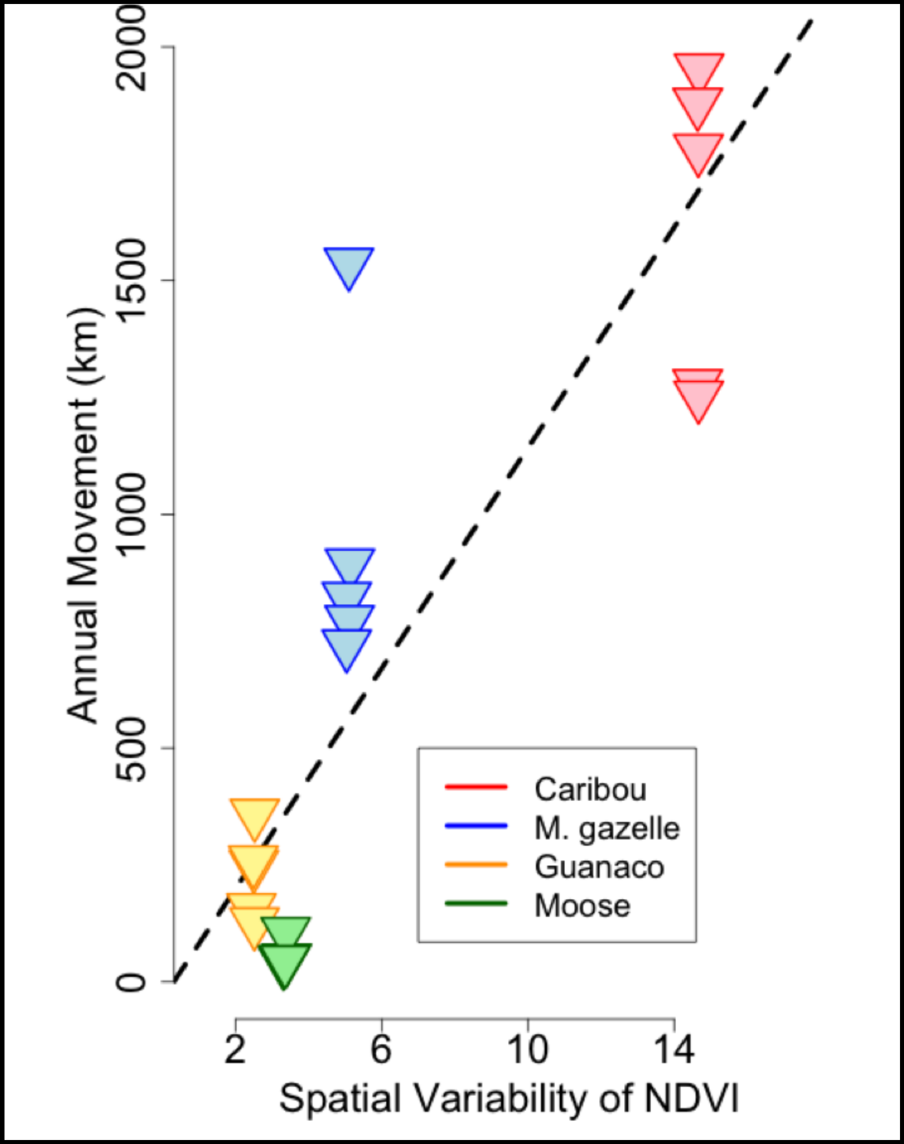
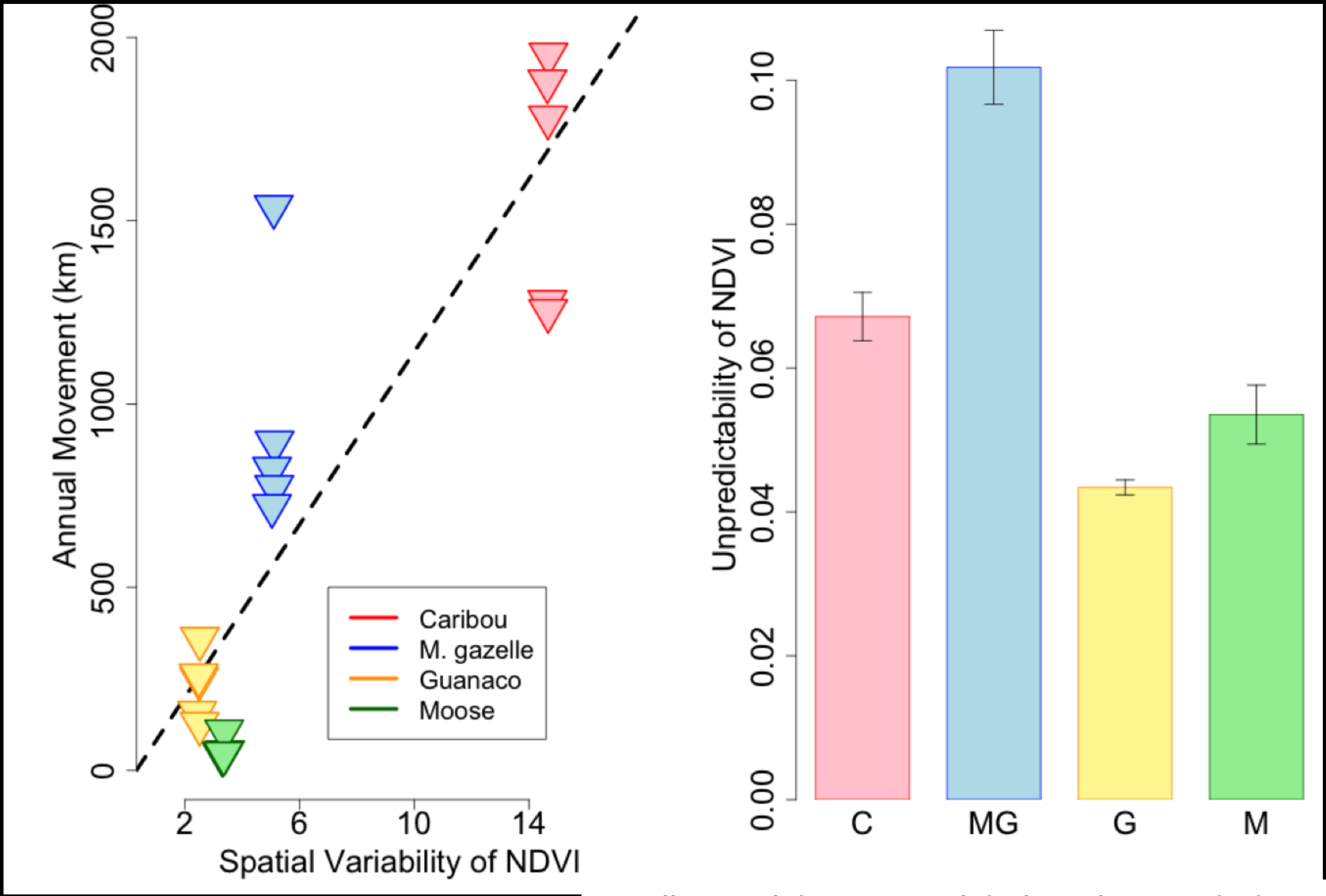


Mueller et al. in press. Global Ecology and Biogeography

Relating Dynamics of Population Distributions to Dynamics of Landscapes



Relating Dynamics of Population Distributions to Dynamics of Landscapes



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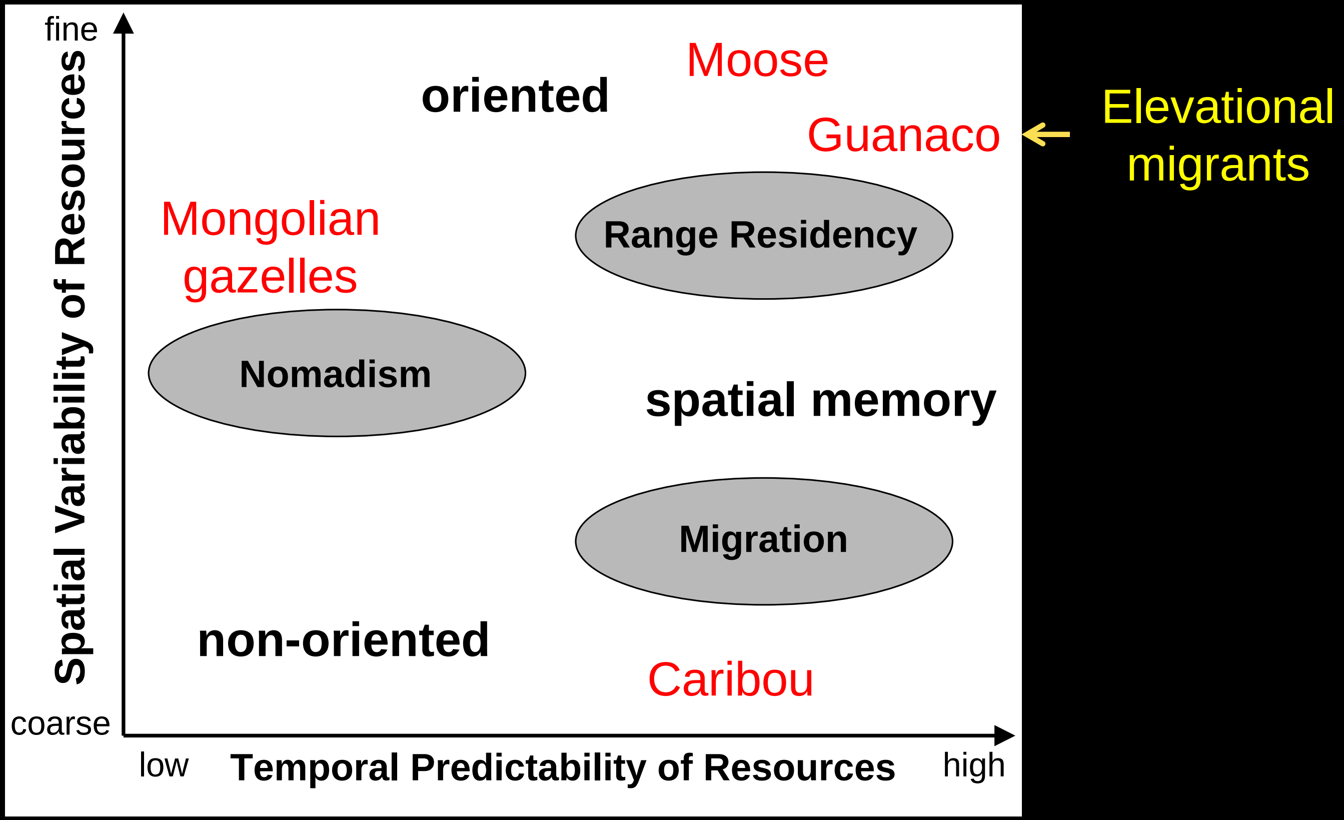

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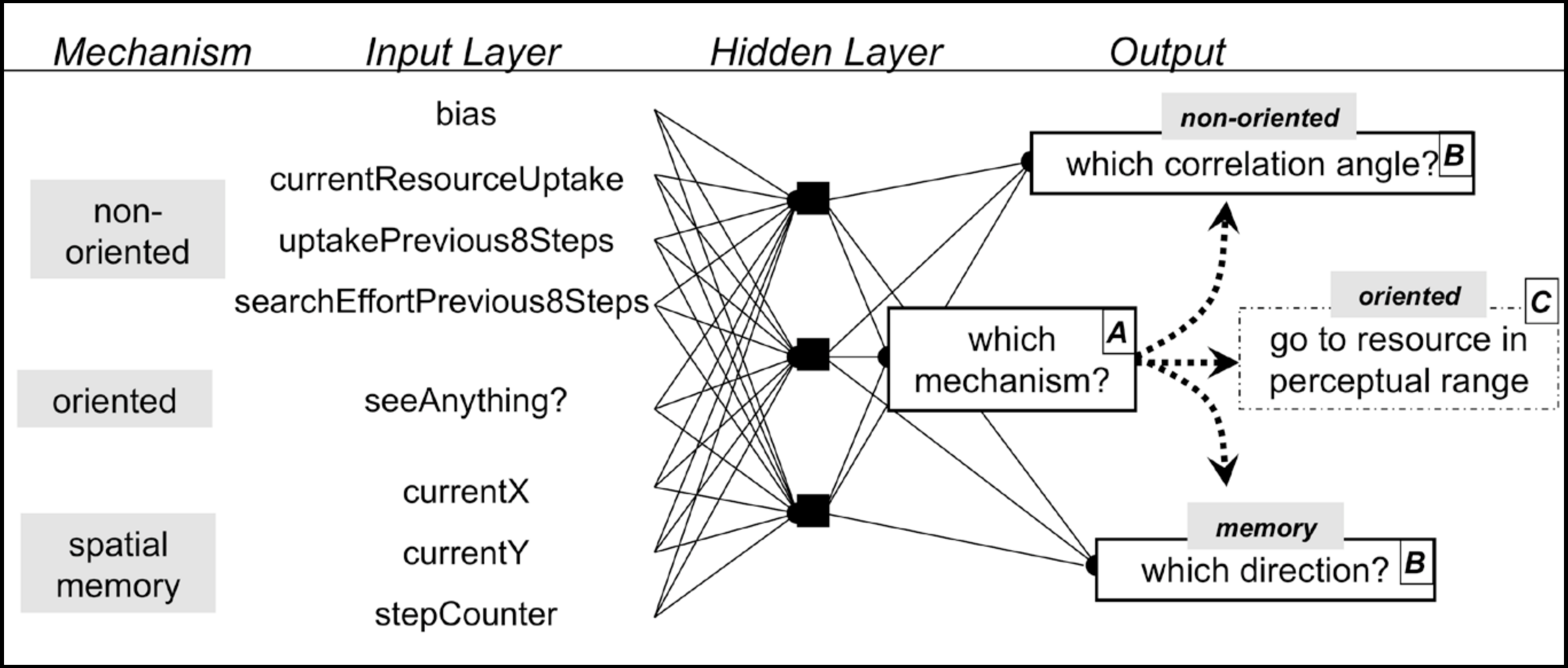
Individual-based Neural Net Genetic Algorithm (ING) Model

A consumer seeking resources by moving through a heterogeneous landscape …



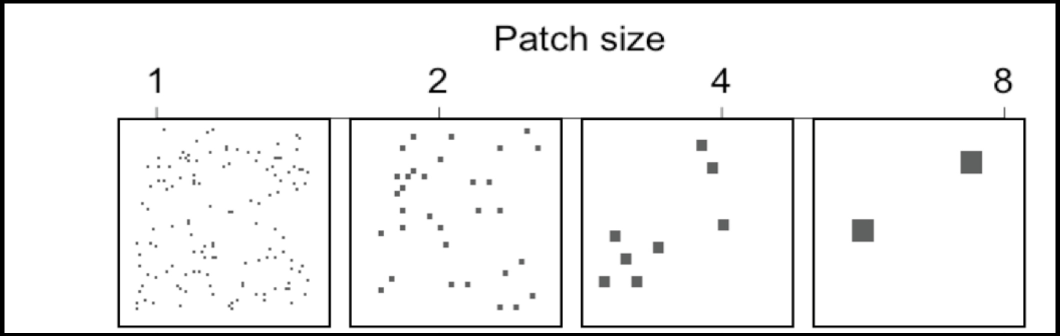
→ Designed so that individual movement mechanisms may be " turned off "

Mueller, Fagan, & Grimm. Theoretical Ecology. In press.

Individual-based Neural Net Genetic Algorithm (ING) Model

Two key landscape features:

1) Patch Size



2) Resource Predictability

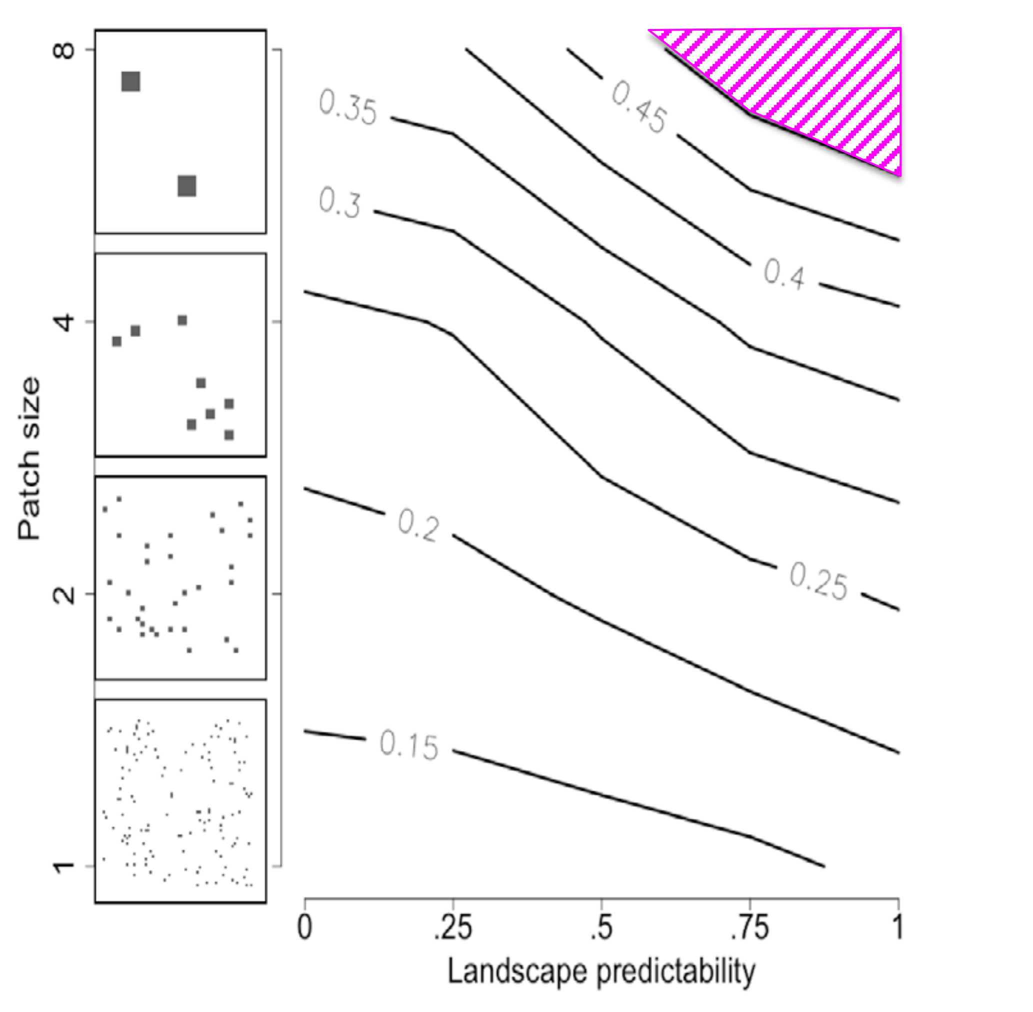
Probability Patch Does Not Move Between Generations

Foci:

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

$$\text{Relevance} = 1 - \left[\frac{efficiency_{\text{reduced neural network}}}{efficiency_{\text{full neural network}}} \right]$$

Efficiency is greatest in predictable landscapes with large patch sizes

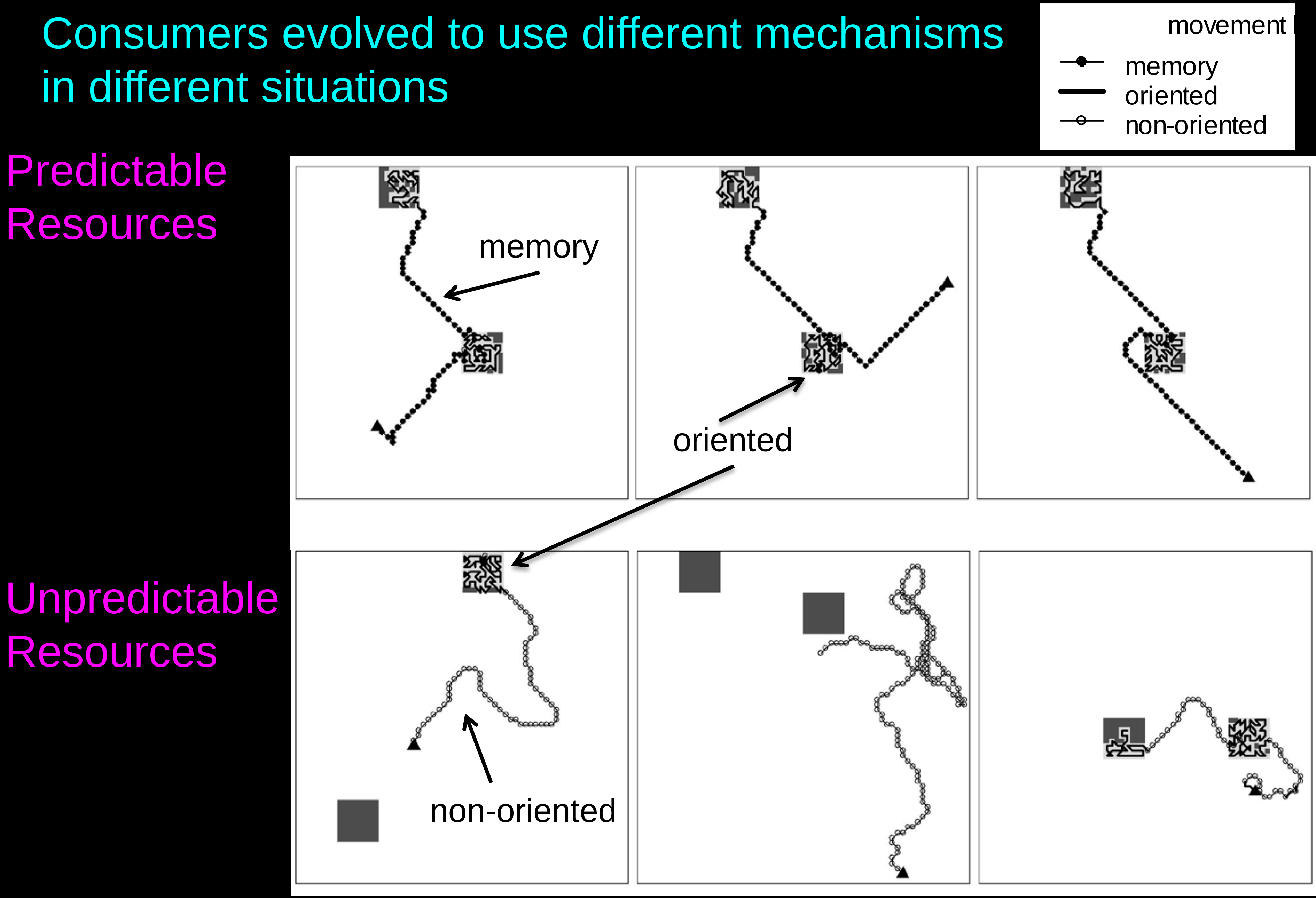


Contours are efficiency of movement

(Avg. resources per movement step)

Mueller, Fagan, & Grimm. Theoretical Ecology. In press.

Consumers evolved to use different mechanisms in different situations



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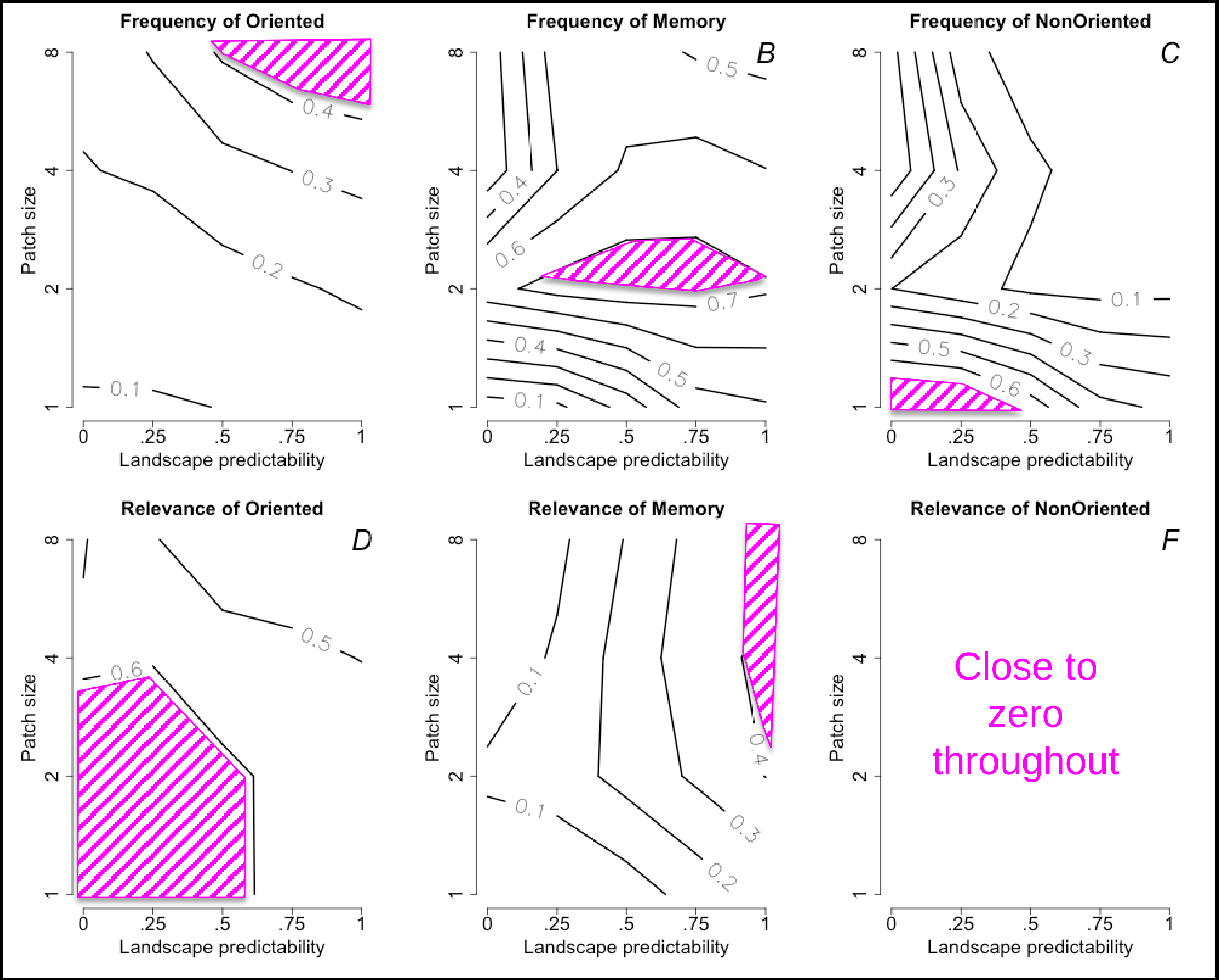

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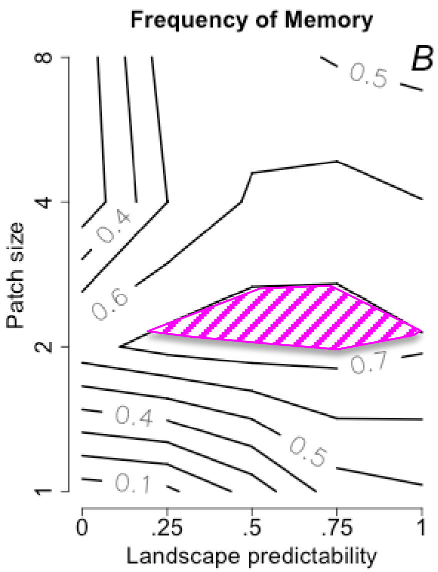

Most unexpected result:

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

Memory may contribute to 'superdiffusion' observed in many empirical systems

$$MSD = Dt^{\alpha}, \qquad \alpha > 1$$

Mueller, Fagan, & Grimm. Theoretical Ecology. In press.

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Navigating through a dynamic, disordered landscape

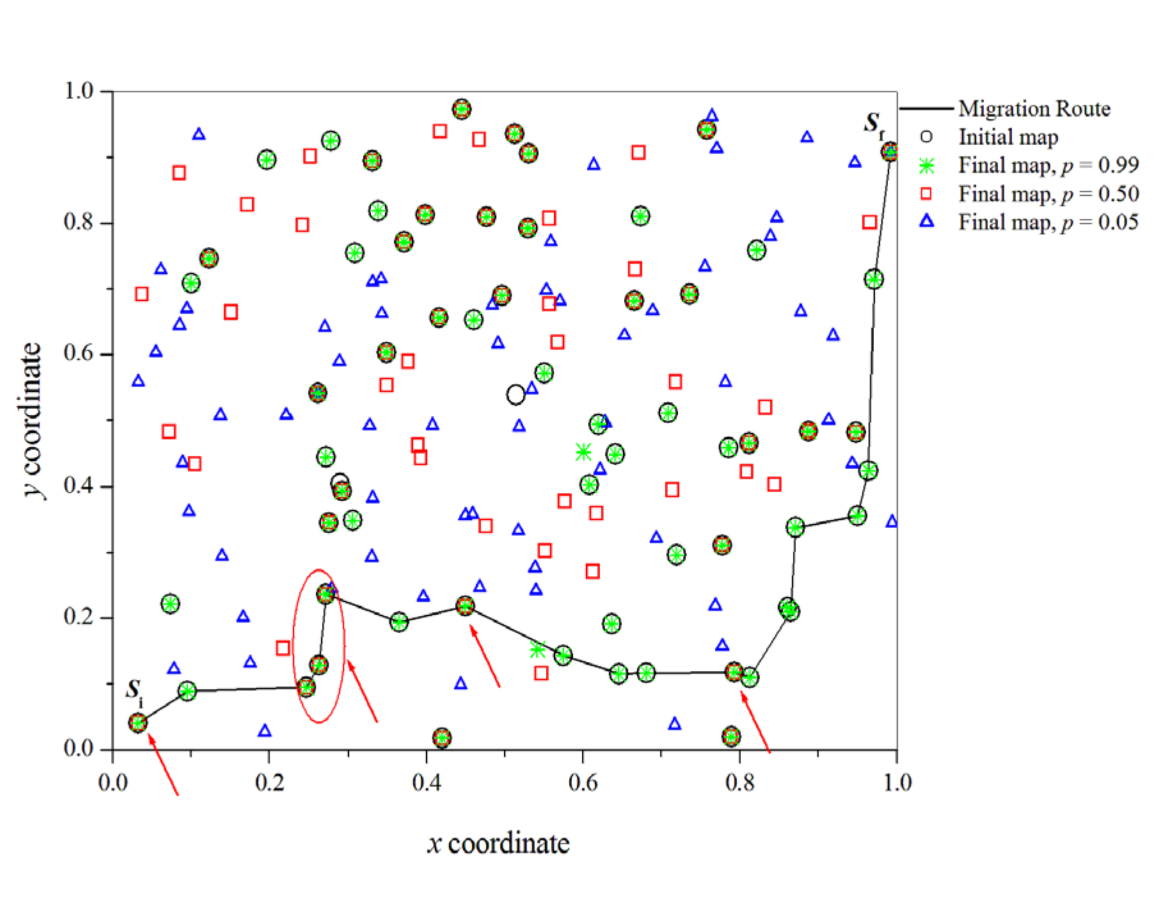
-- Habitat patches, which can be transient

-- Reference memory (shortest path across)

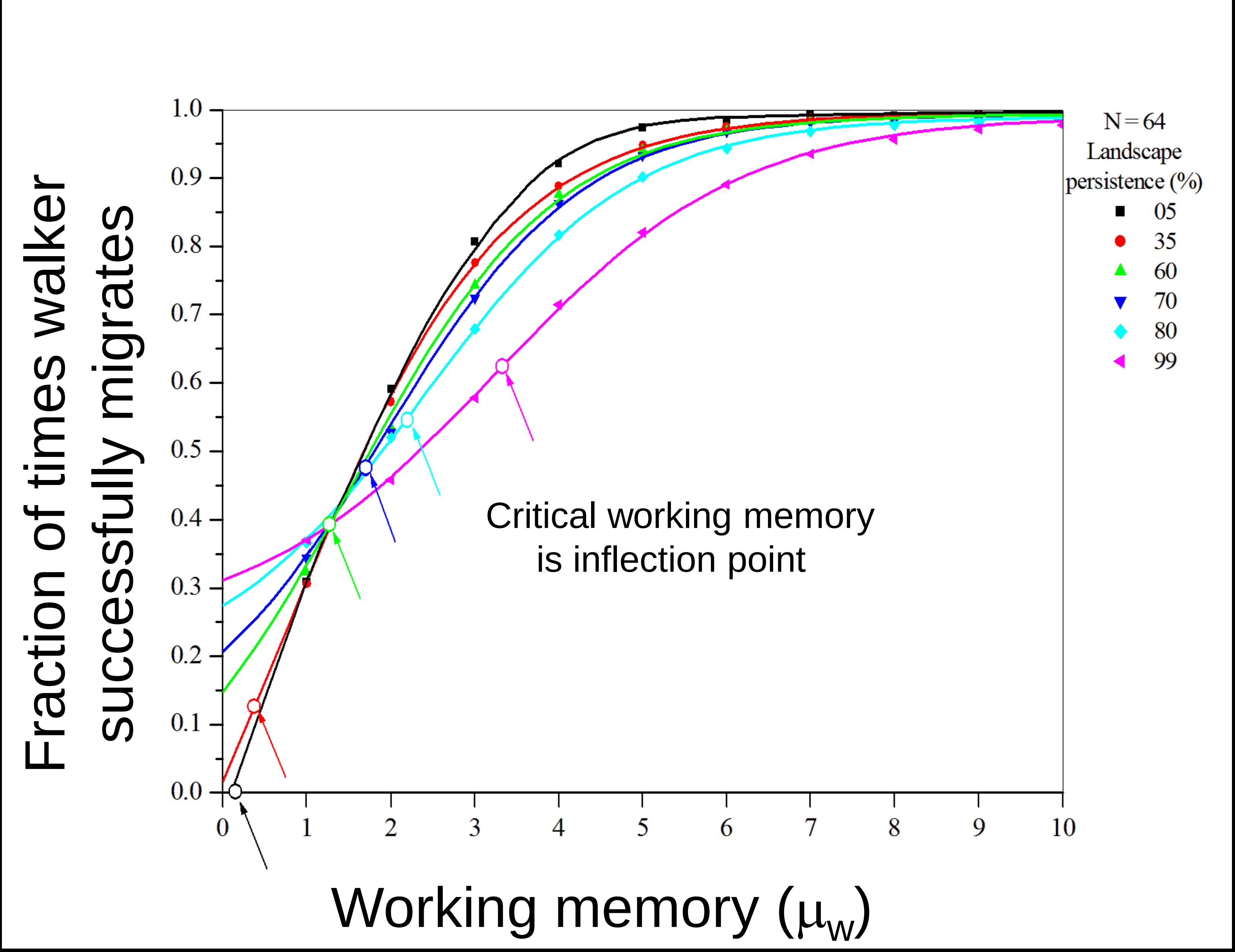
-- Working memory (most recent *n* patches)

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

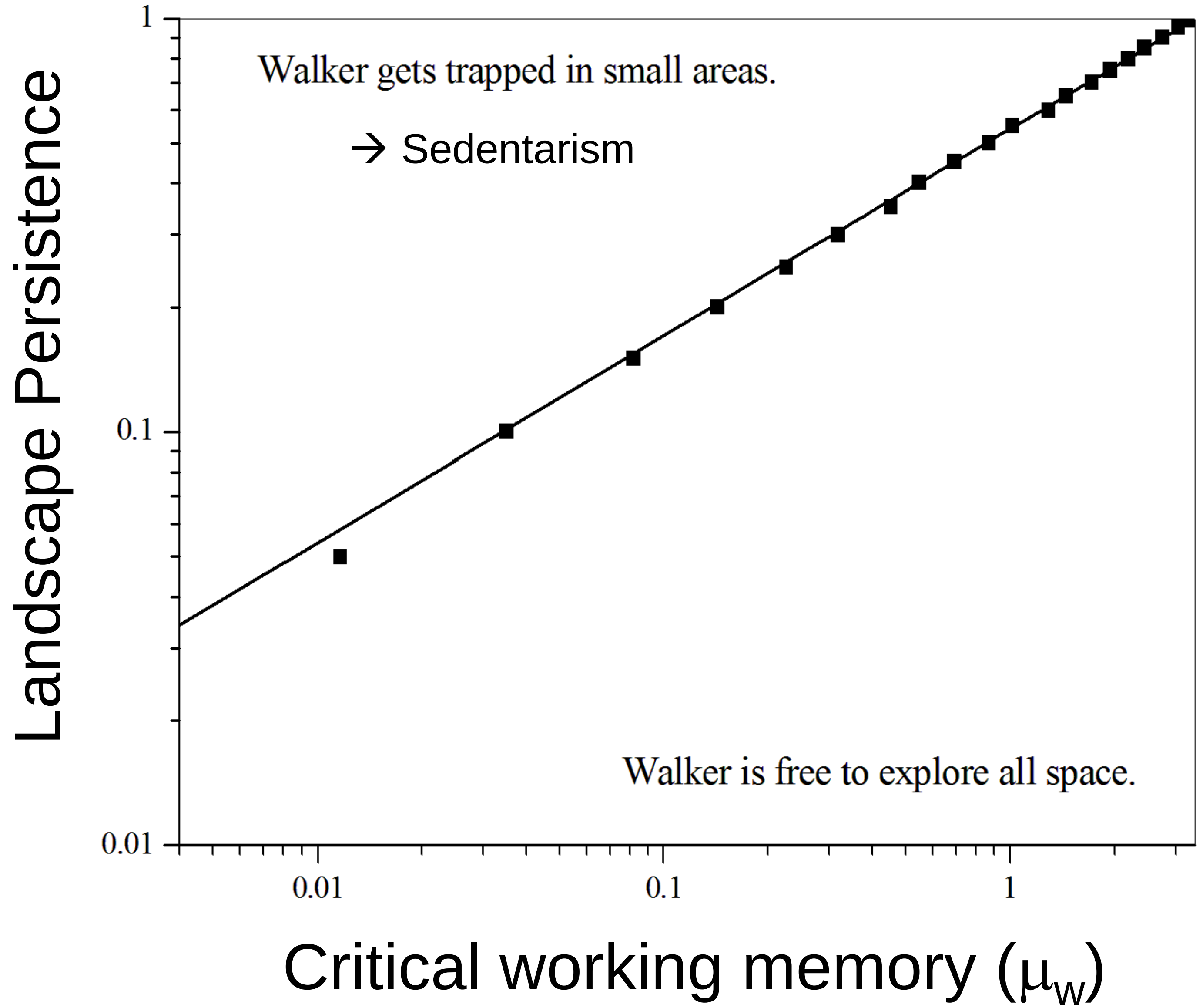
-- Rule 2: Go to the nearest patch not in the working memory



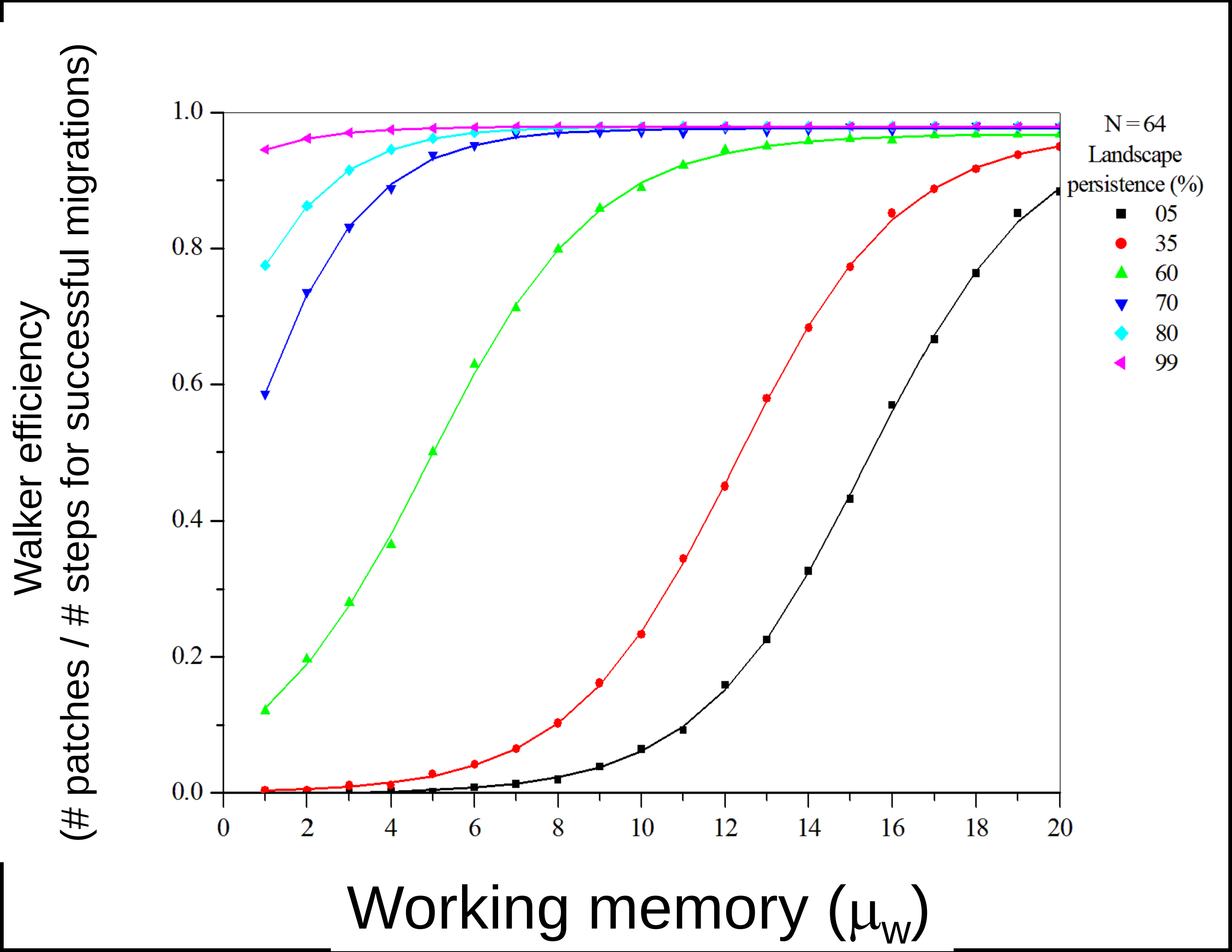
Berbert et al. in review.



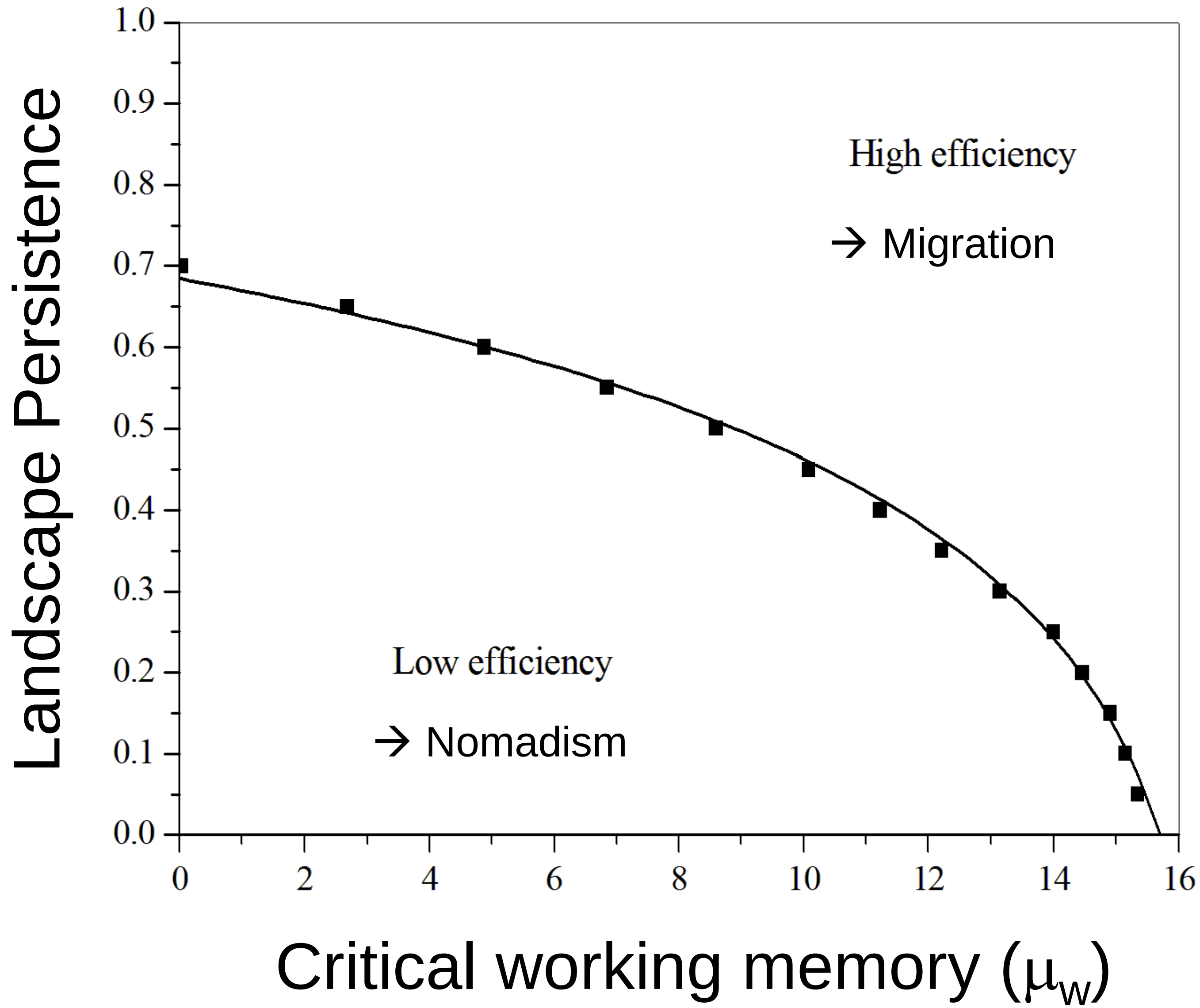
Fraction of times walker successfully migrates
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
10
N = 64
Landscape persistence (%)
05
35
60
70
80
99
Critical working memory
is inflection point
Working memory (μ_w)



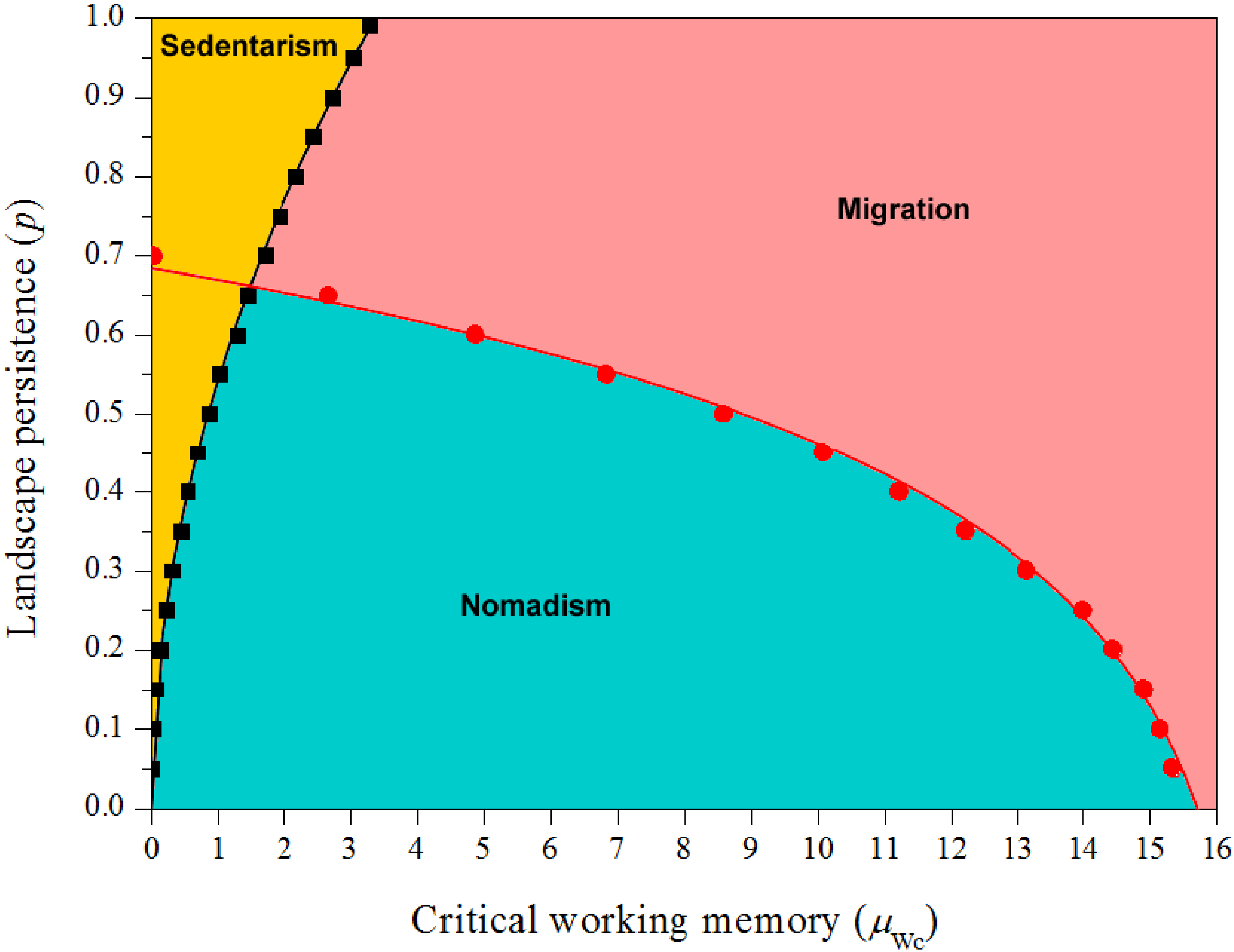
Walker gets trapped in small areas.
→ Sedentarism
Walker is free to explore all space.
1
0.1
0.01
0.01
0.1
1
Landscape Persistence
Critical working memory (μ_w)



Walker efficiency
(# patches / # steps for successful migrations)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
18
20
N = 64
Landscape
persistence (%)
05
35
60
70
80
99
Working memory (μw)



Landscape Persistence
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
High efficiency
→ Migration
Low efficiency
→ Nomadism
Critical working memory (μ_w)



Sedentarism
Migration
Nomadism
Landscape persistence (p)
Critical working memory (μ_{Wc})
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

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)

Funding:

- US National Science Foundation

  -- Ecology Panel
  -- 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*)

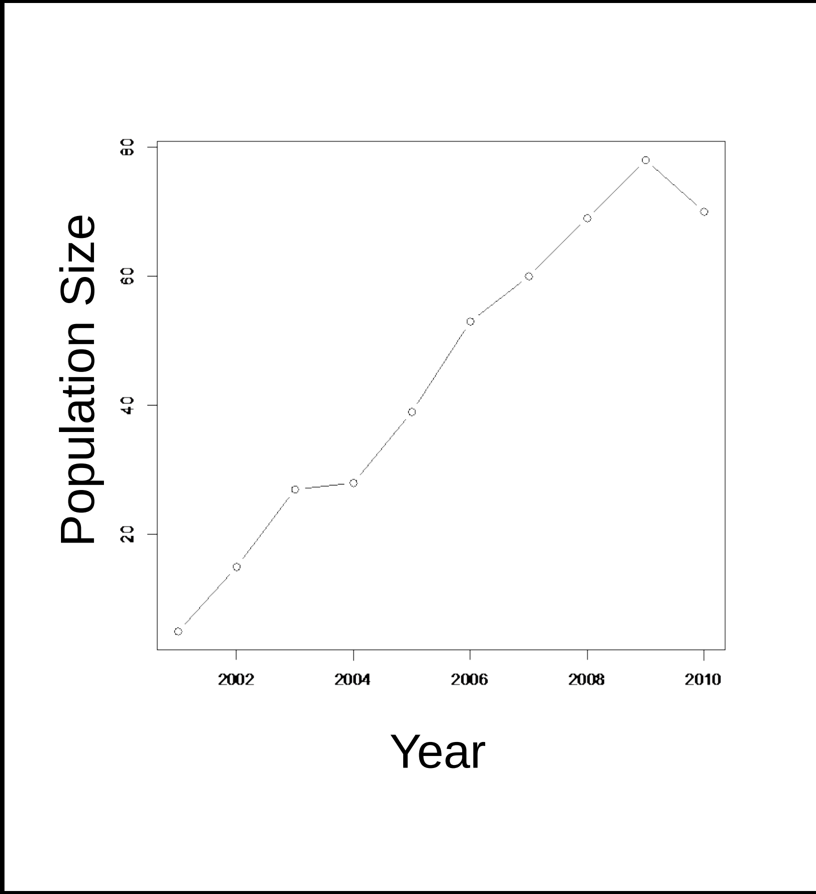
"Experimental" eastern flock migrates from Wisconsin to Florida

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

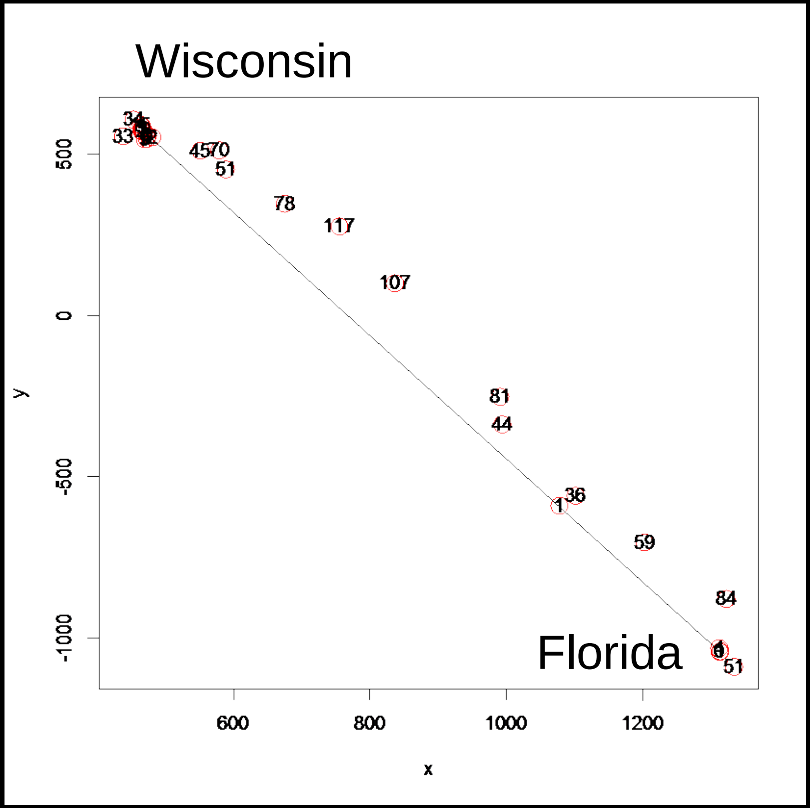
of each bird's migration

-- Measure:

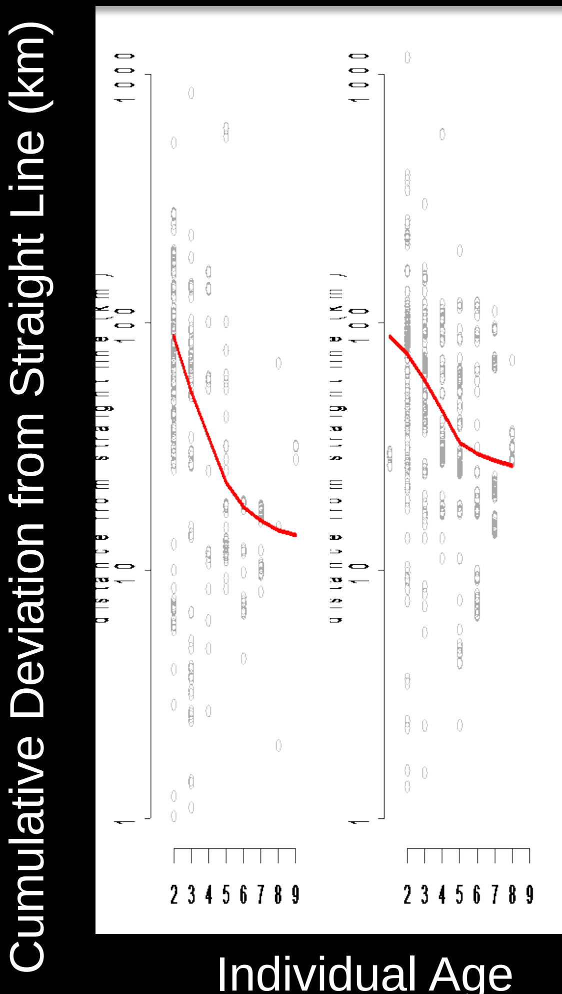
- Departure/ arrival dates
- Trip duration
- Deviation from straight line

-- How do cranes' migratory

journeys change across years ?

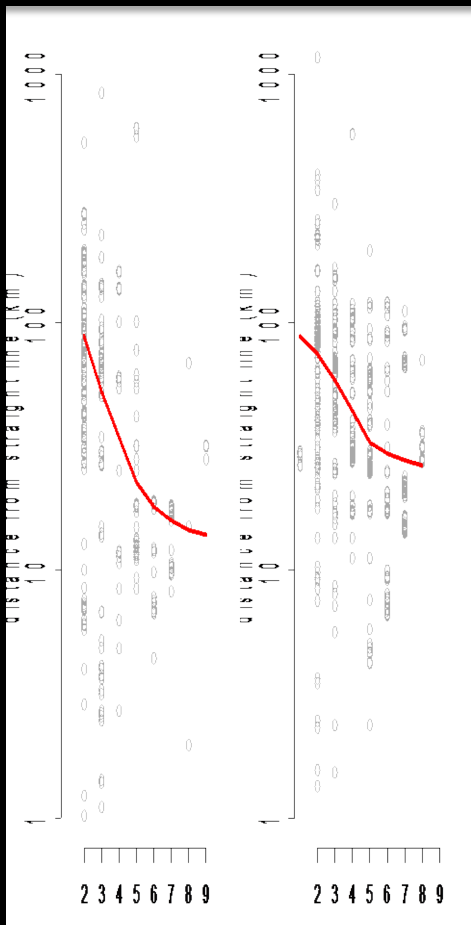


Experience brings efficiency: older birds fly direct

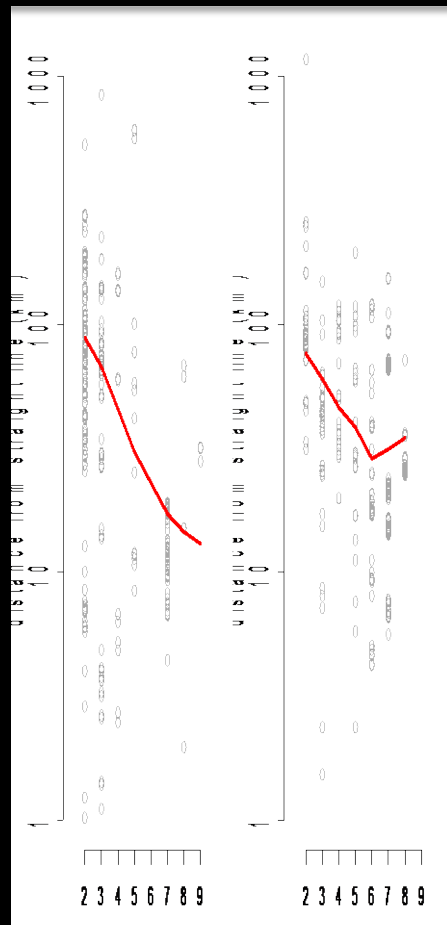


Experience brings efficiency: older birds fly direct

Cumulative Deviation from Straight Line (km)



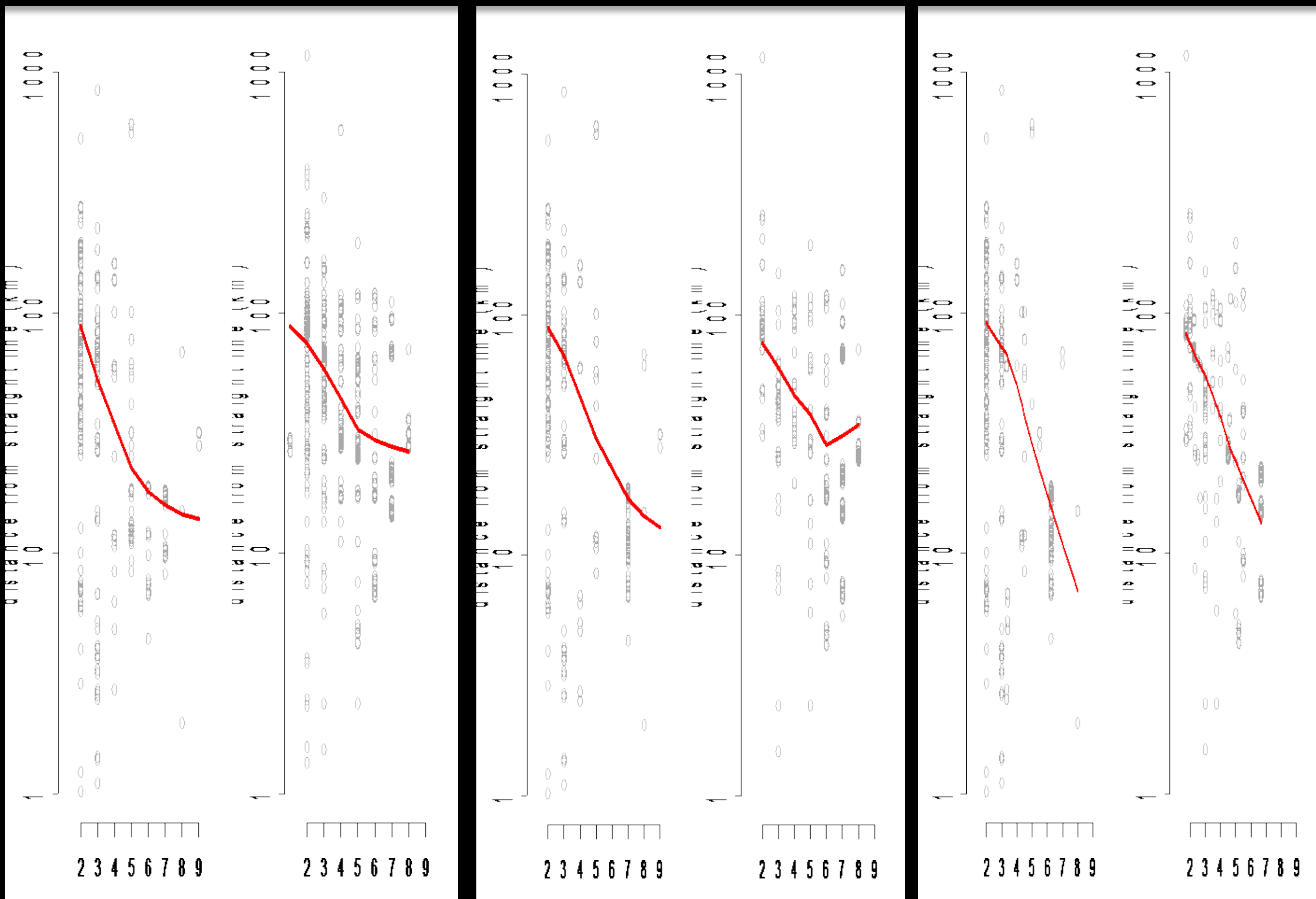
Individual Age



Oldest Individual
in group

Experience brings efficiency: older birds fly direct

Cumulative Deviation from Straight Line (km)

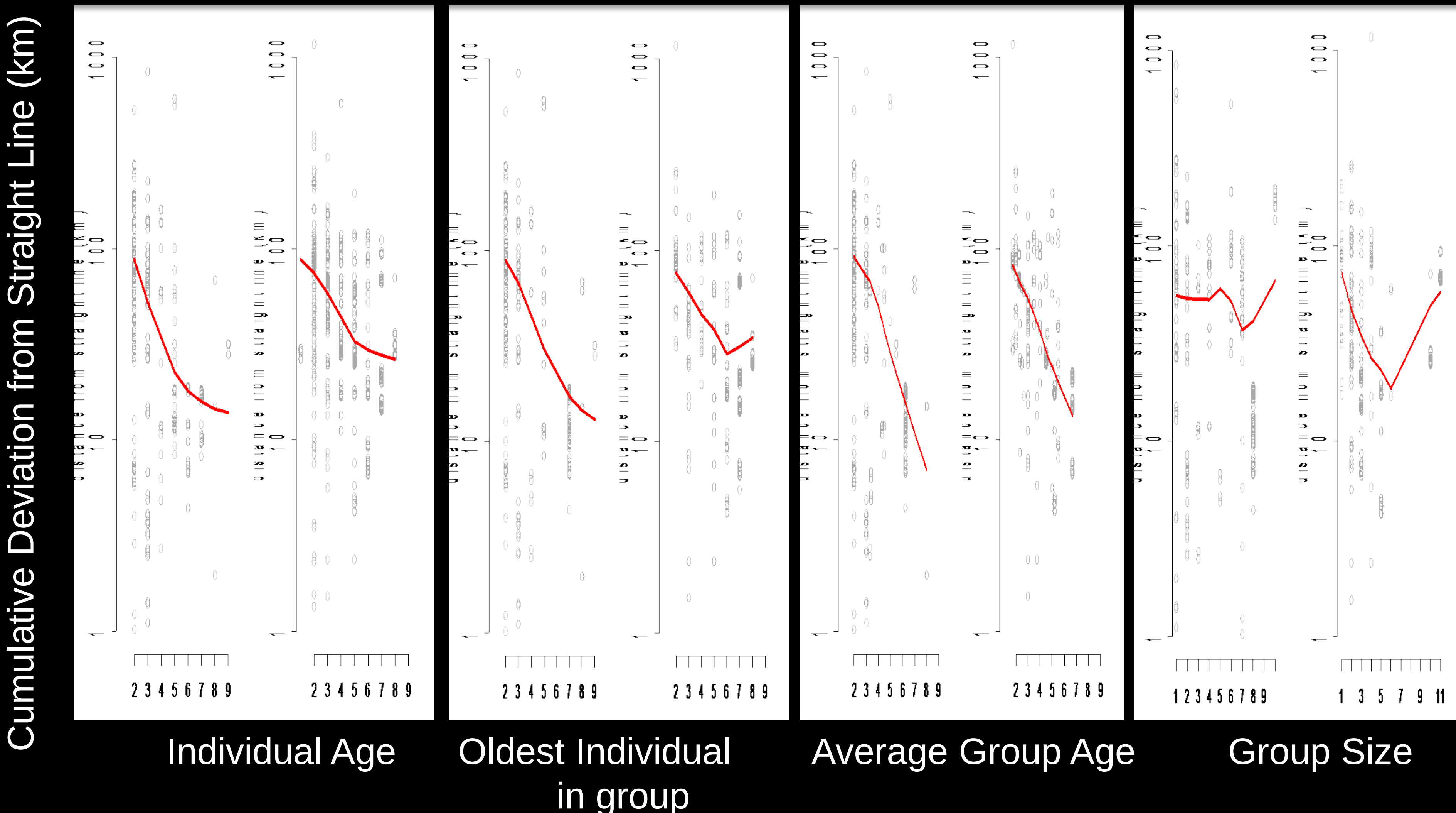


Individual Age

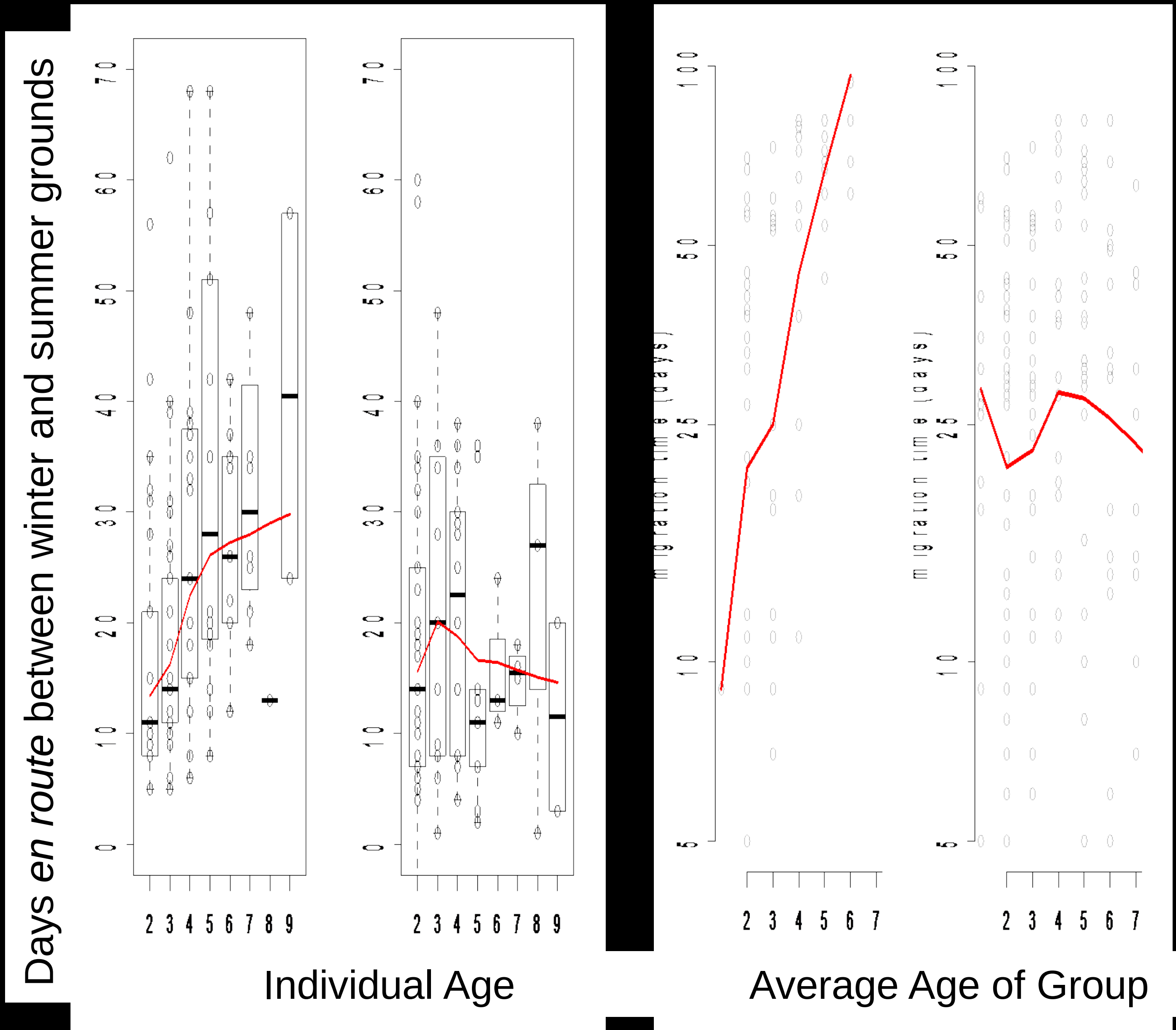
Oldest Individual in group

Average Group Age

Experience brings efficiency: older birds fly direct



Older birds travel more slowly



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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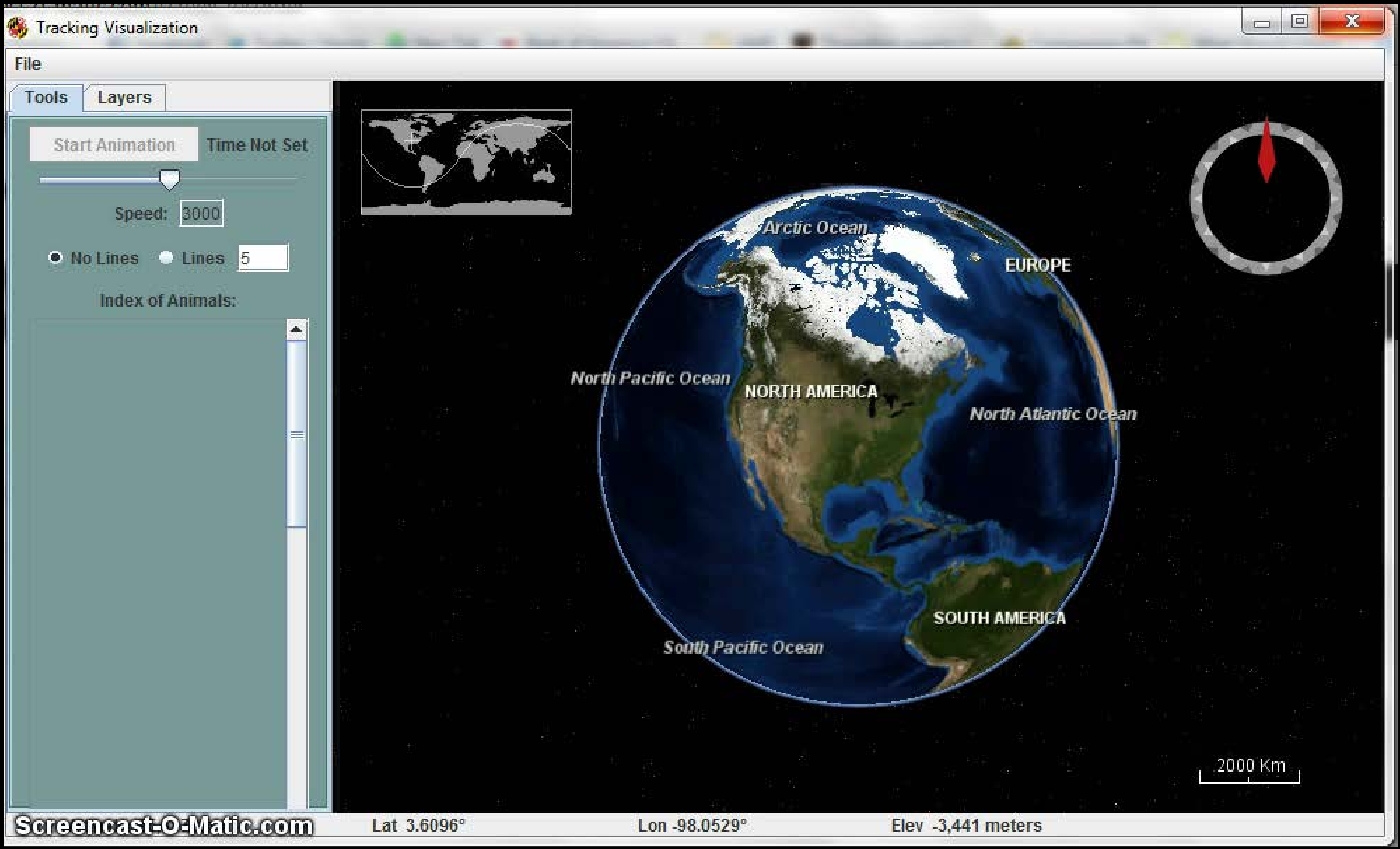
Do not anthropomorphize this …..

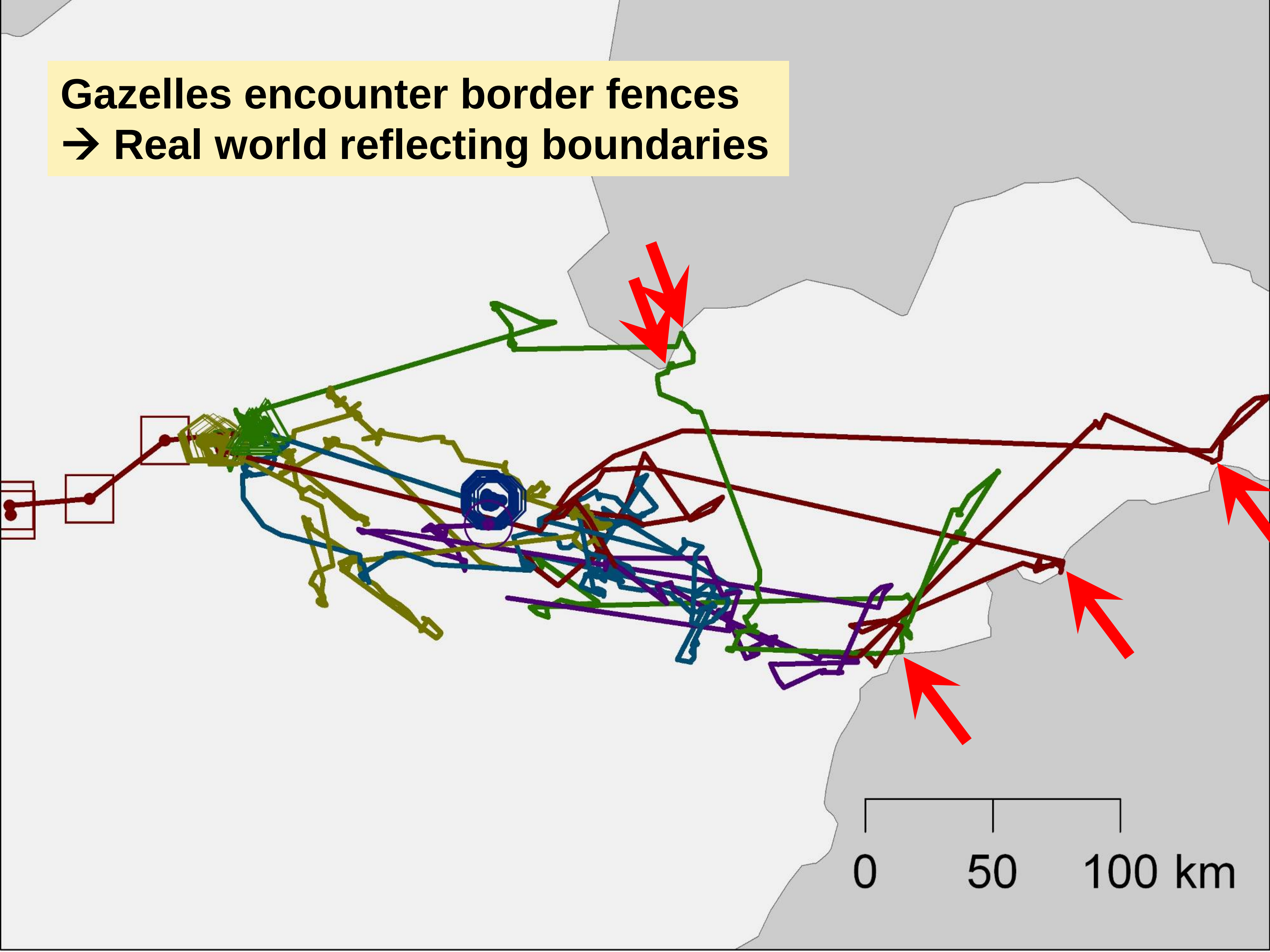
A Google Earth Plug-in to Aid Visualization of Animal Movements



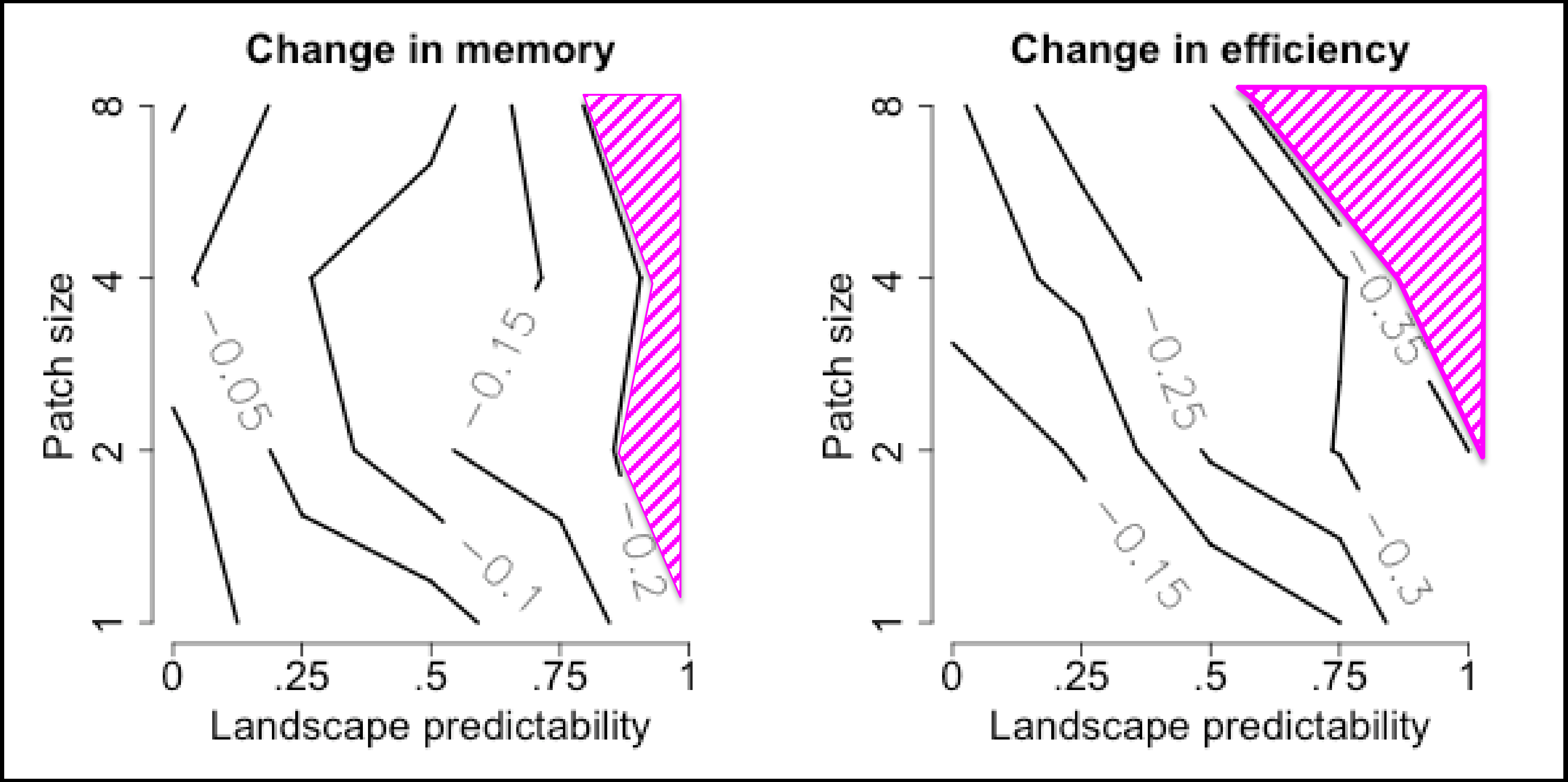
Java World Wind transitioning to a Google API

Kavathekar et al. in prep.

Gazelles encounter border fences
→ Real world reflecting boundaries



Effects of imposing a barrier to movement



Mueller, Fagan, & Grimm. Theoretical Ecology. In press.

Animal distributions and movement behaviors in relation to resource dynamics

Framework of resource distributions and

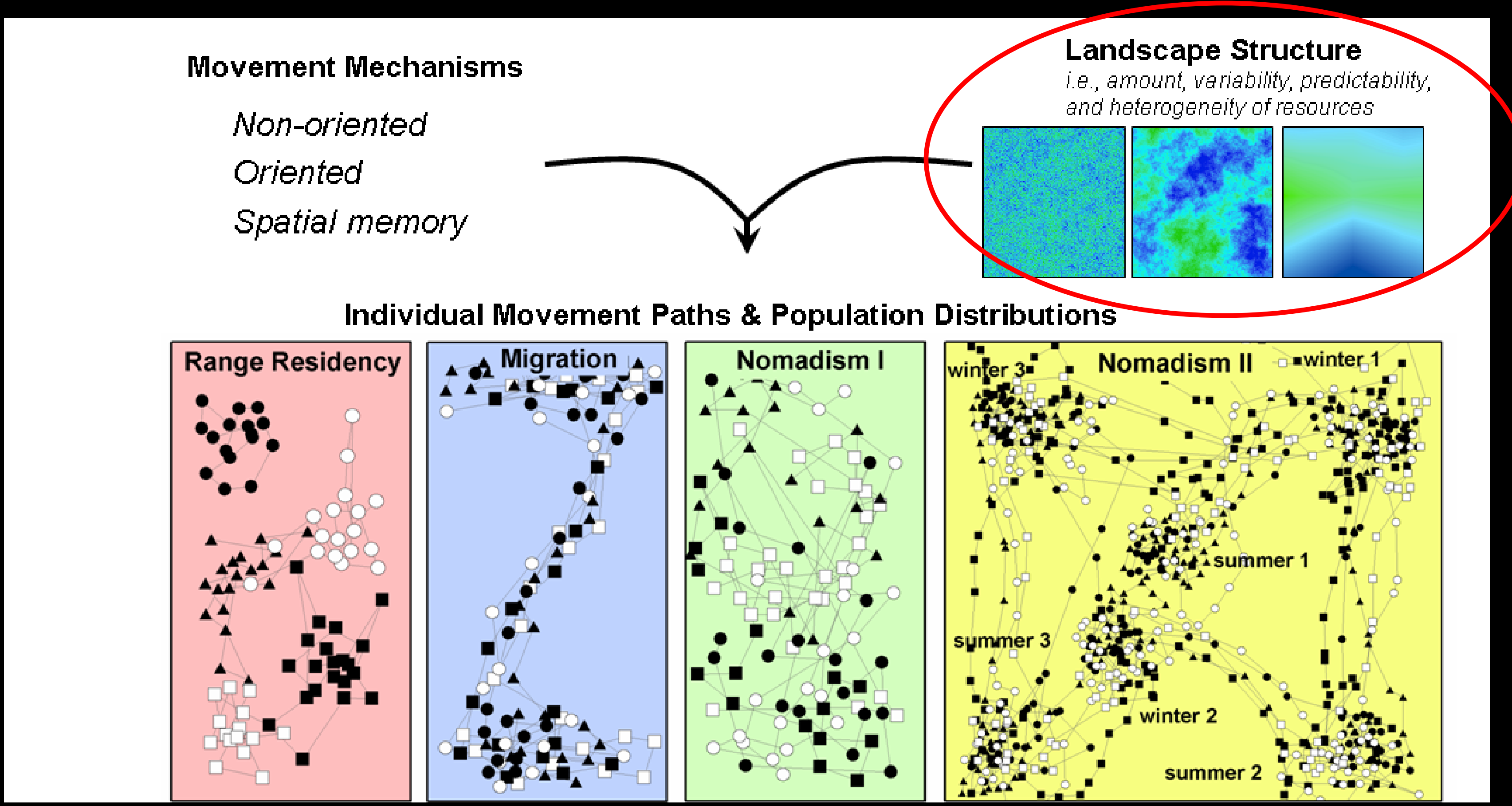
Part 2 : (empirical)

> Resource distributions and movements of Mongolian gazelle

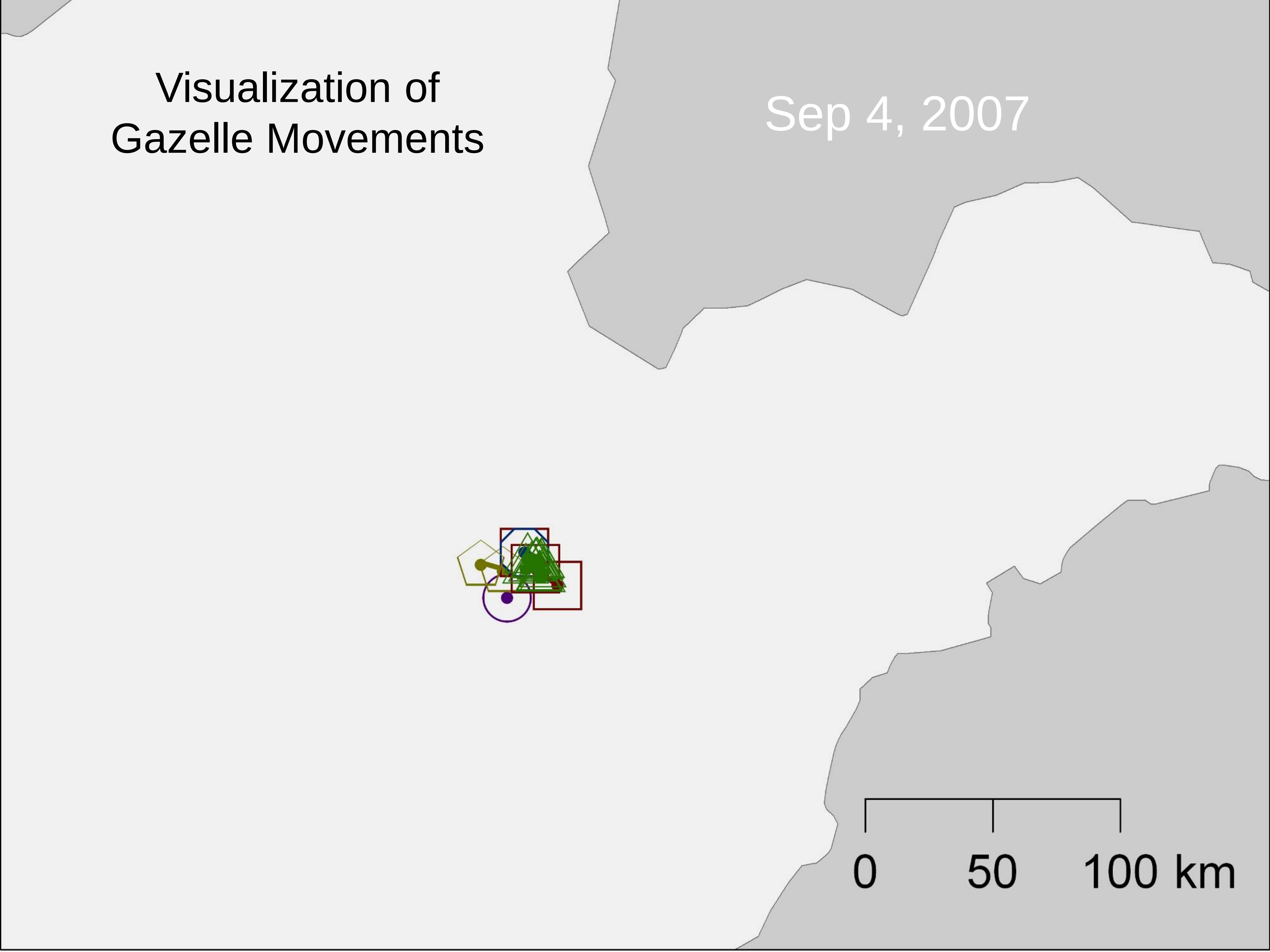
Part 3 : (empirical)

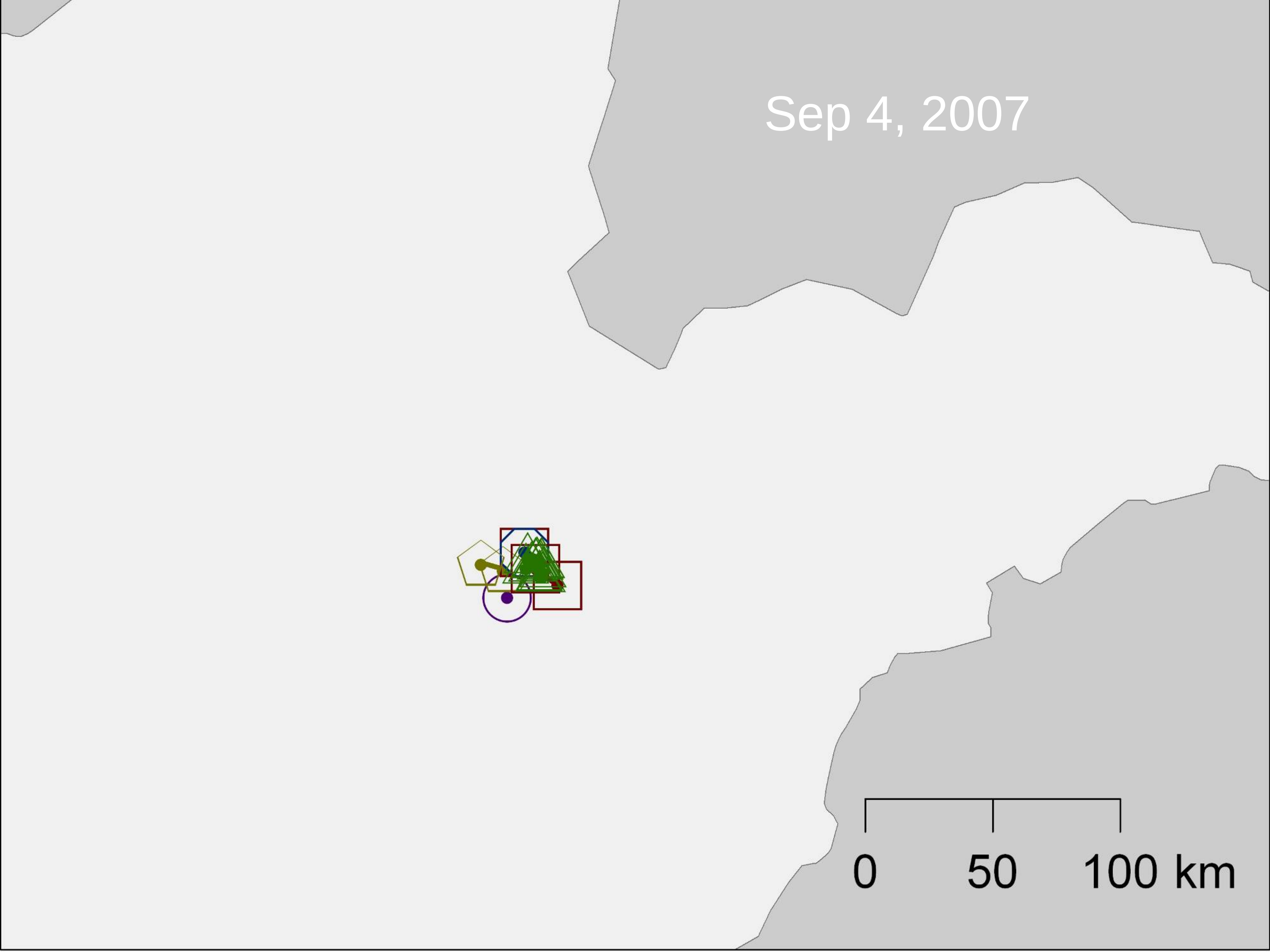
> Comparison of movements between species

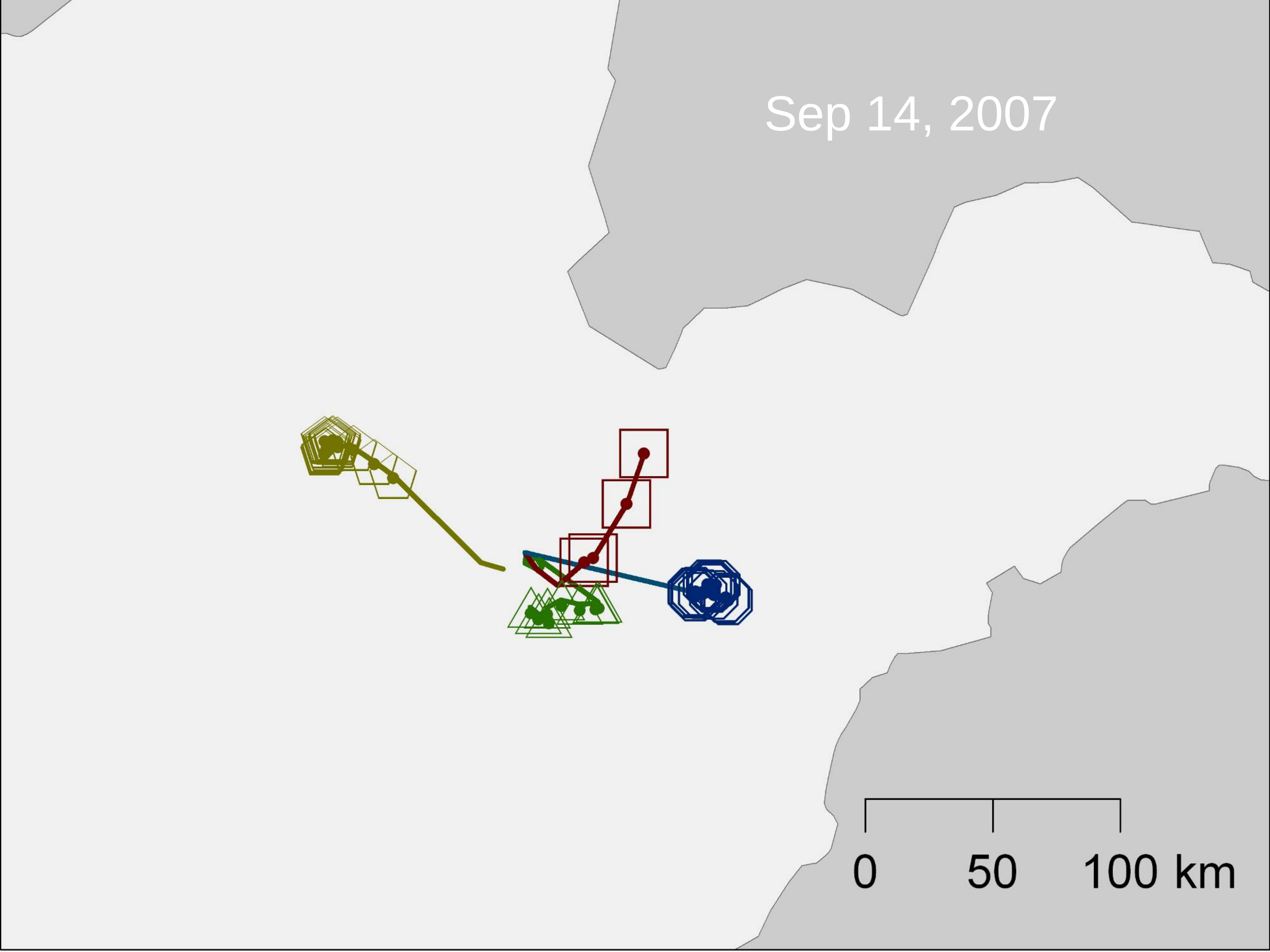
Part 1: Conceptual framework for resources, population distributions and movement mechanisms

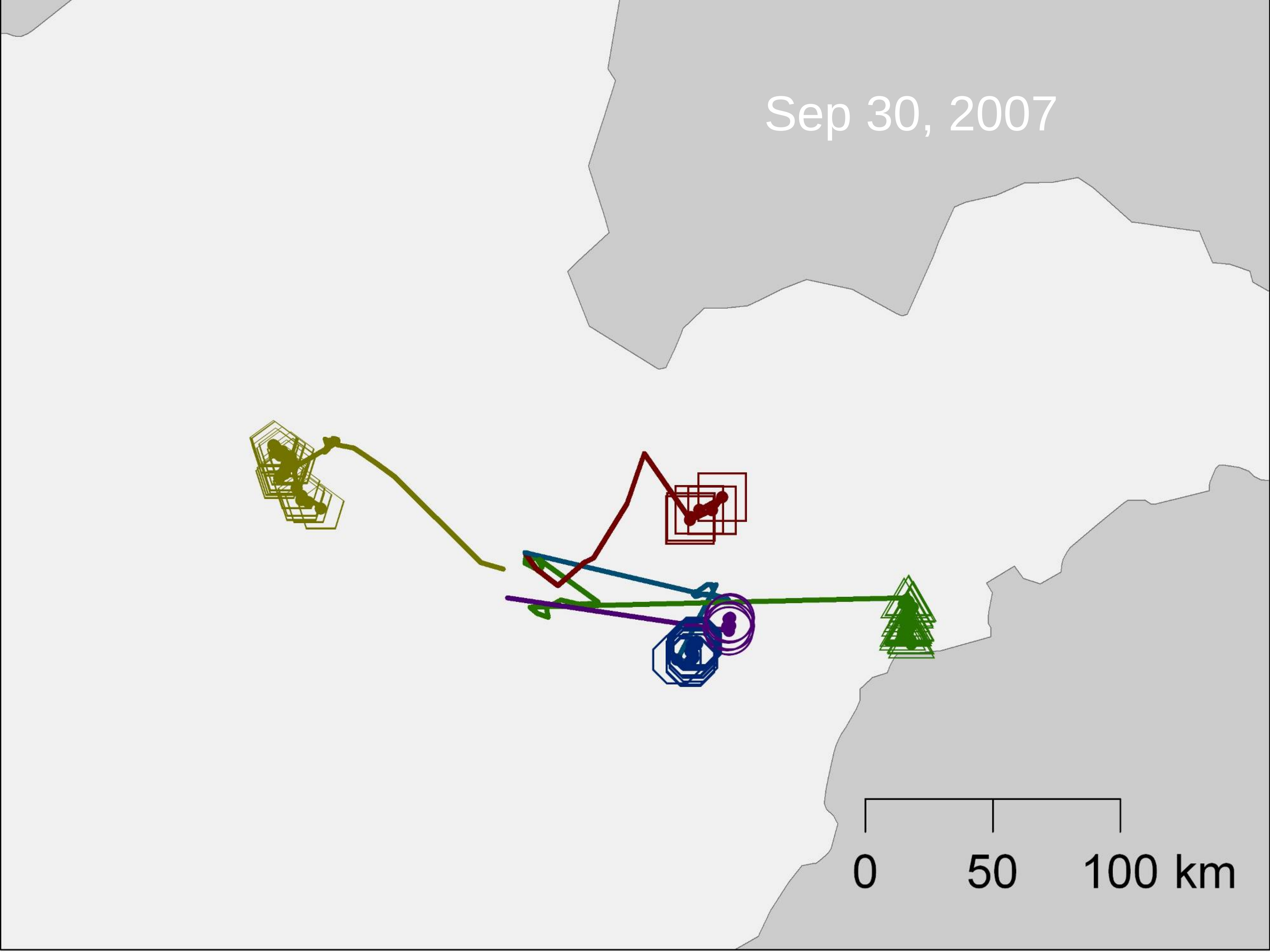


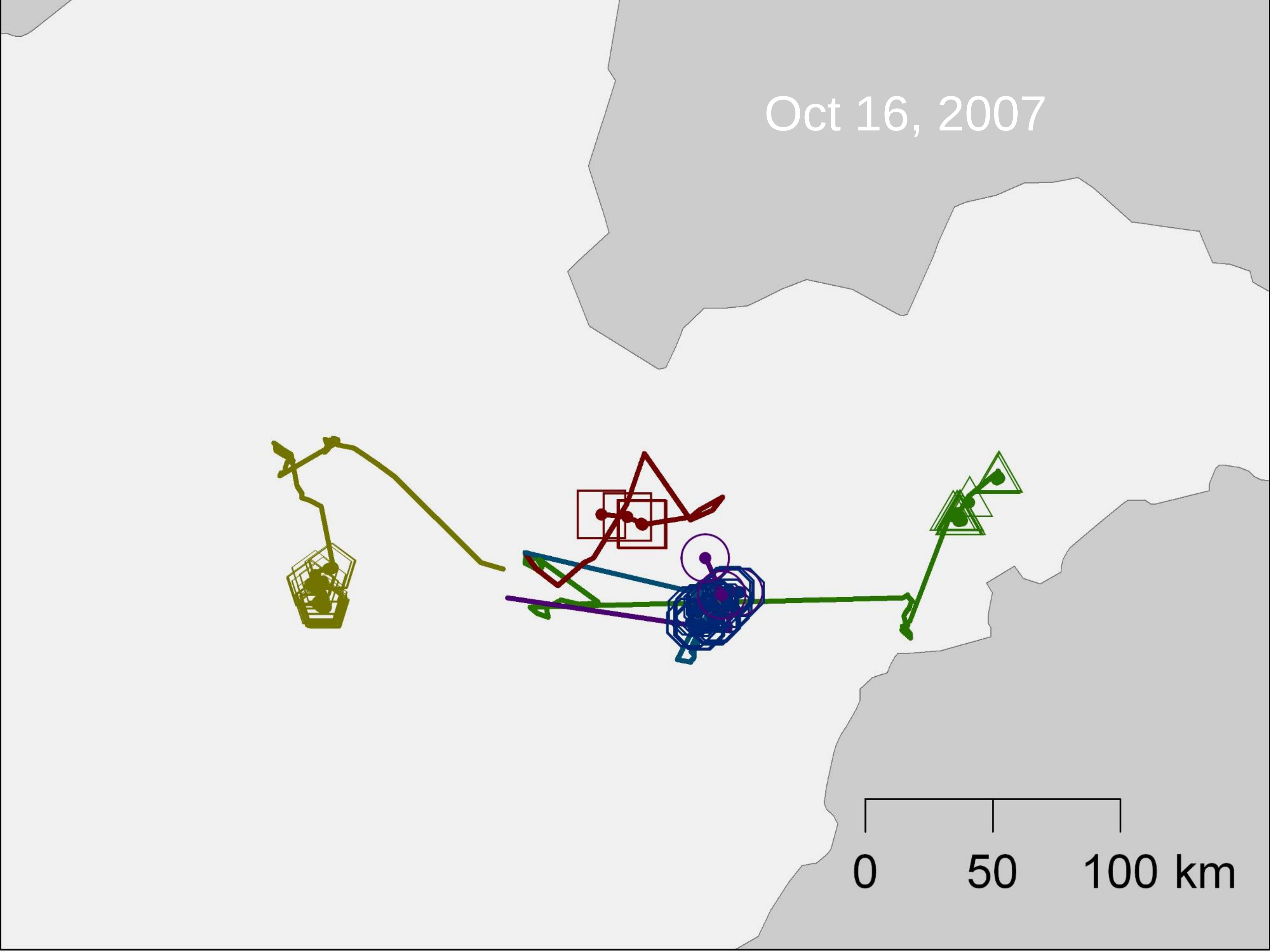
Mueller and Fagan, Oikos 2008


Visualization of
Gazelle Movements
Sep 4, 2007
0
50
100 km

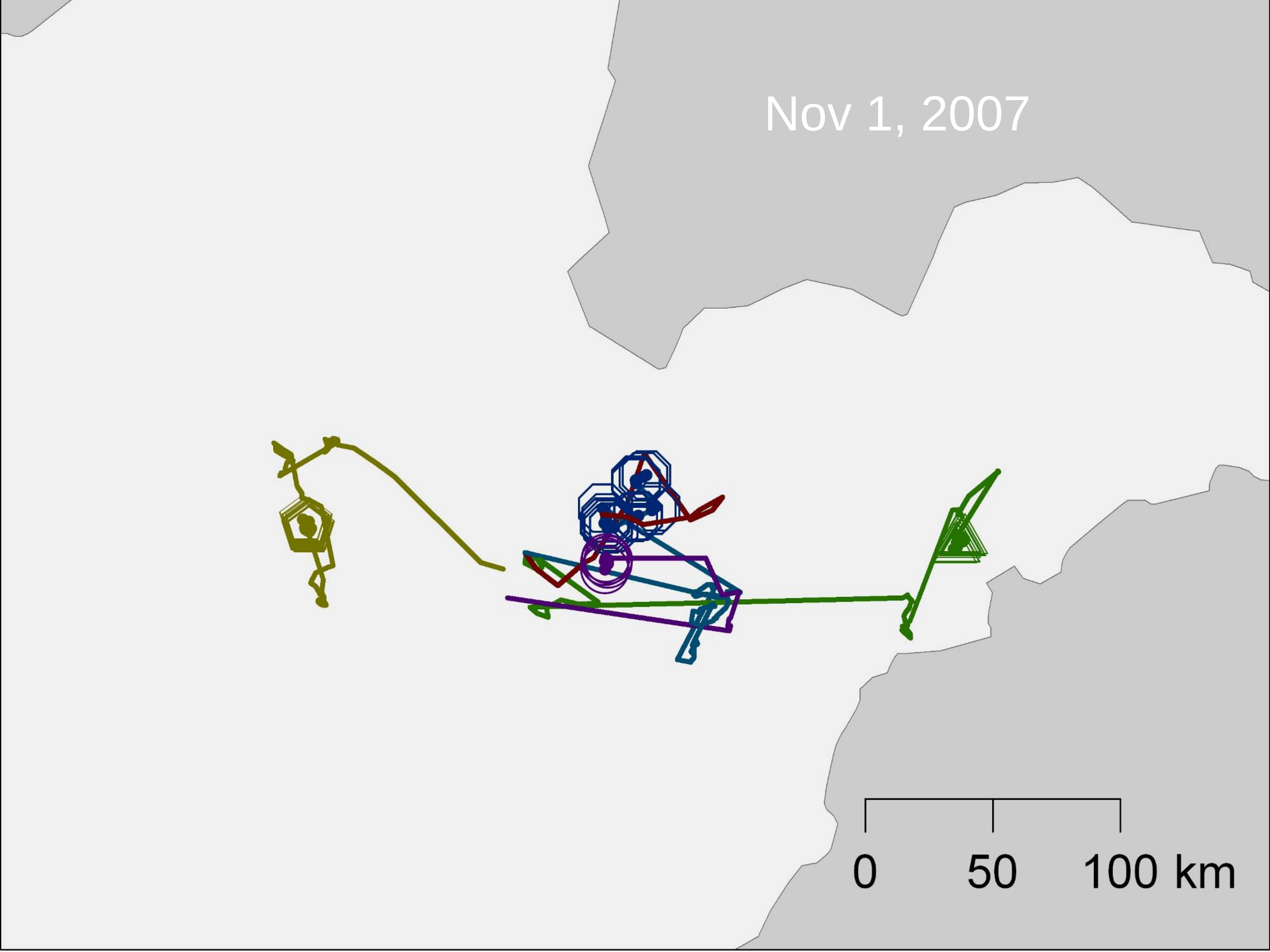

Sep 4, 2007
0
50
100 km


Sep 14, 2007
0
50
100 km

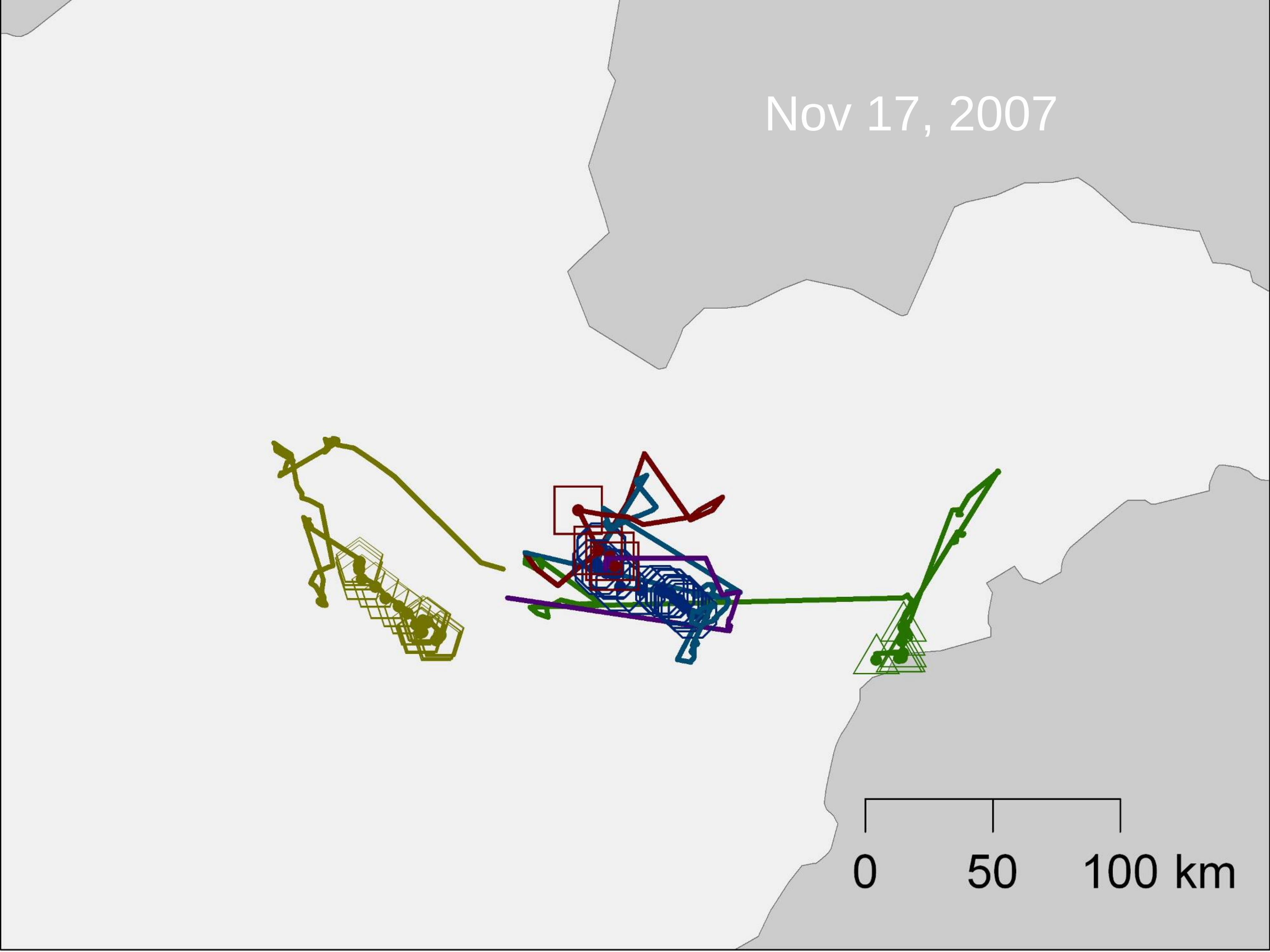

Sep 30, 2007
0
50
100 km

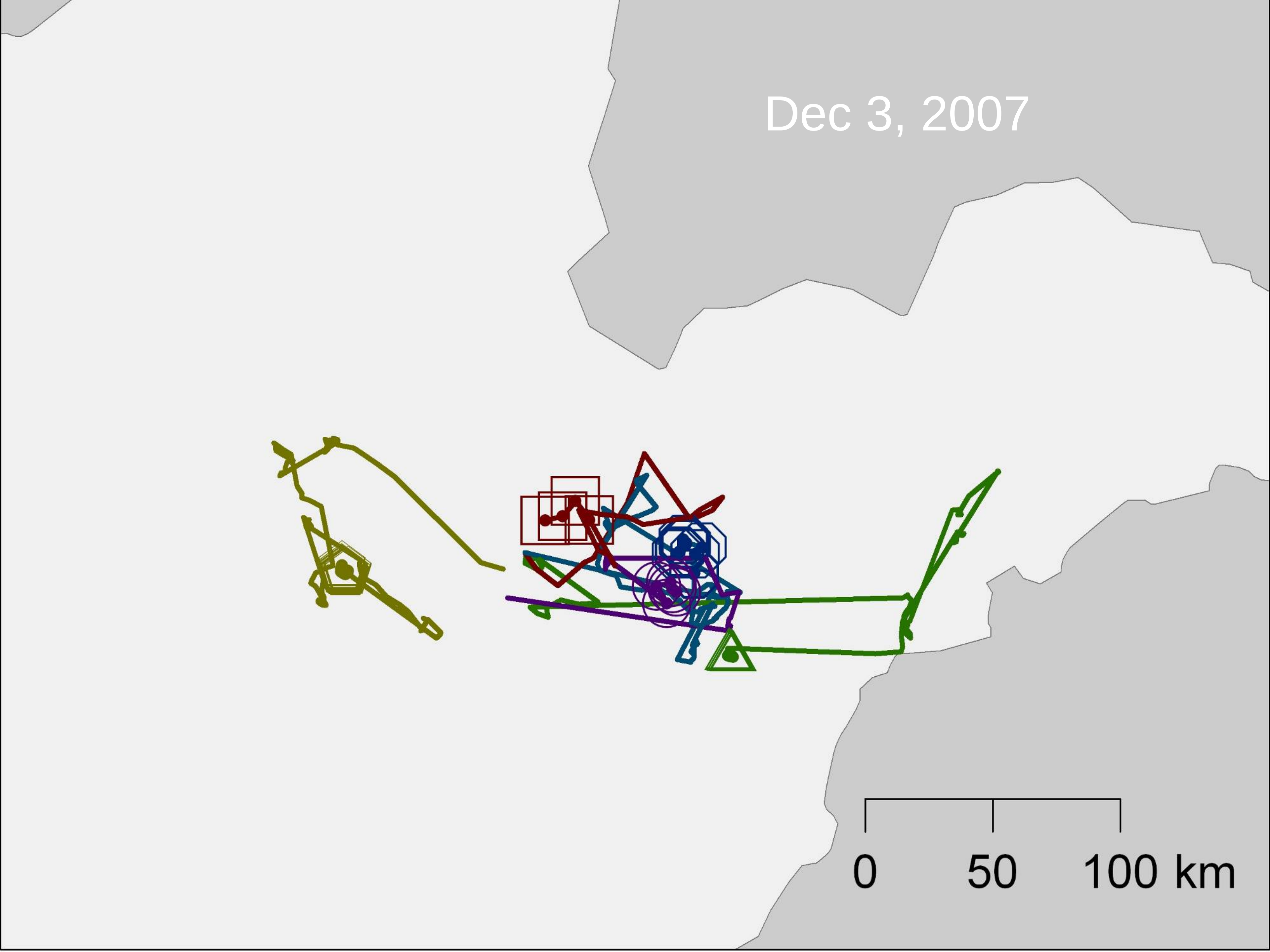


Oct 16, 2007
0
50
100 km

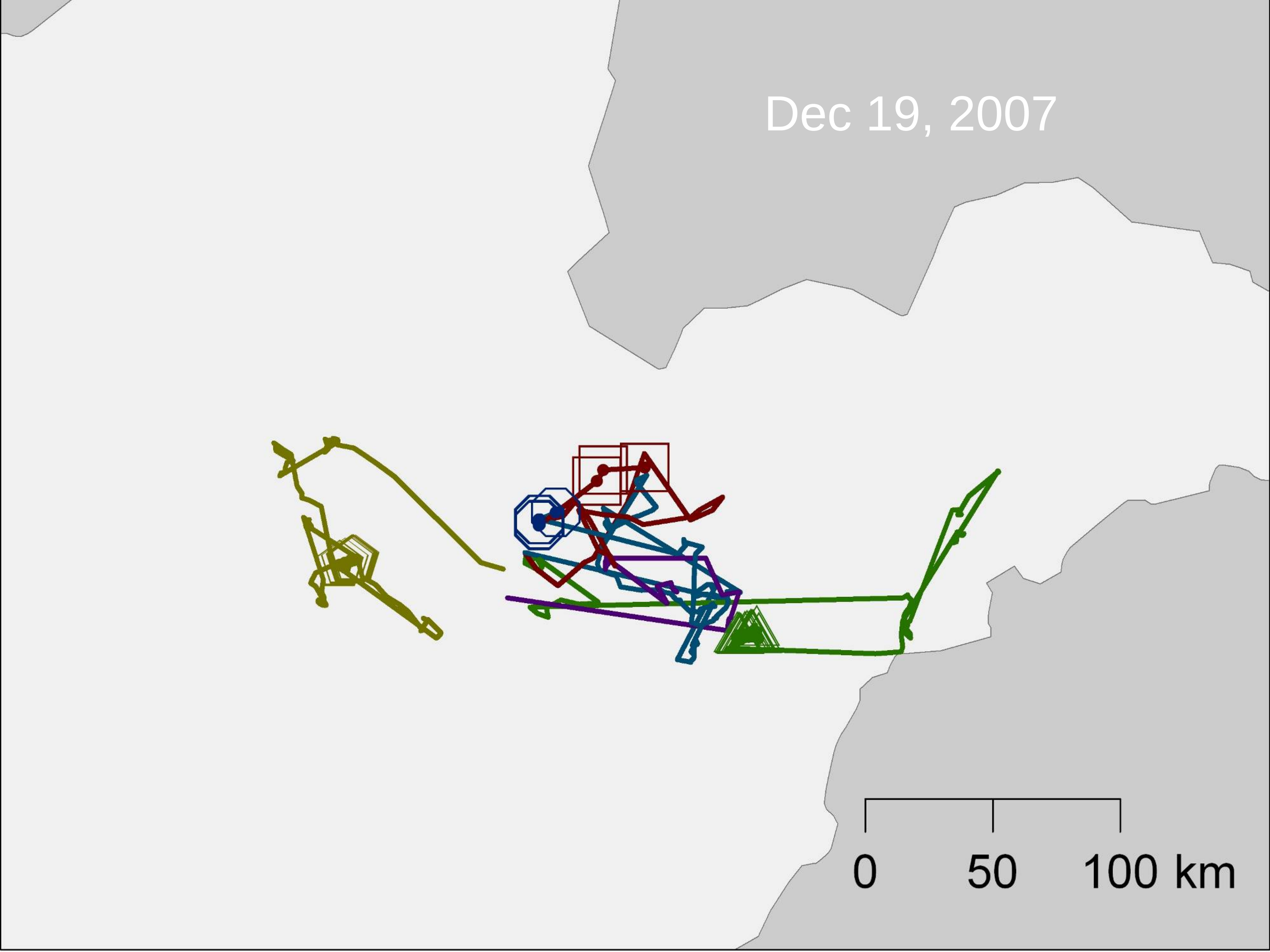


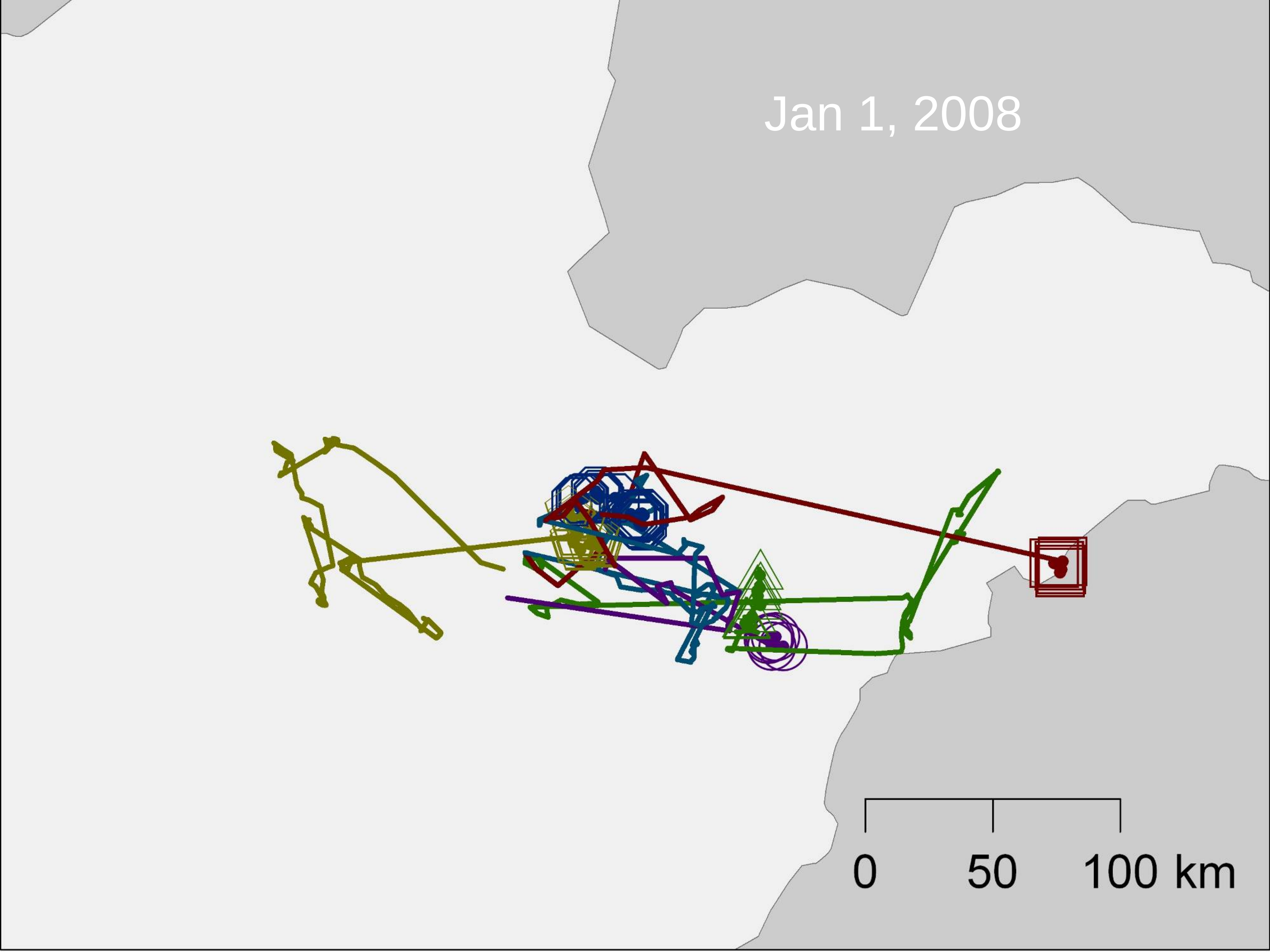
Nov 1, 2007
0
50
100 km

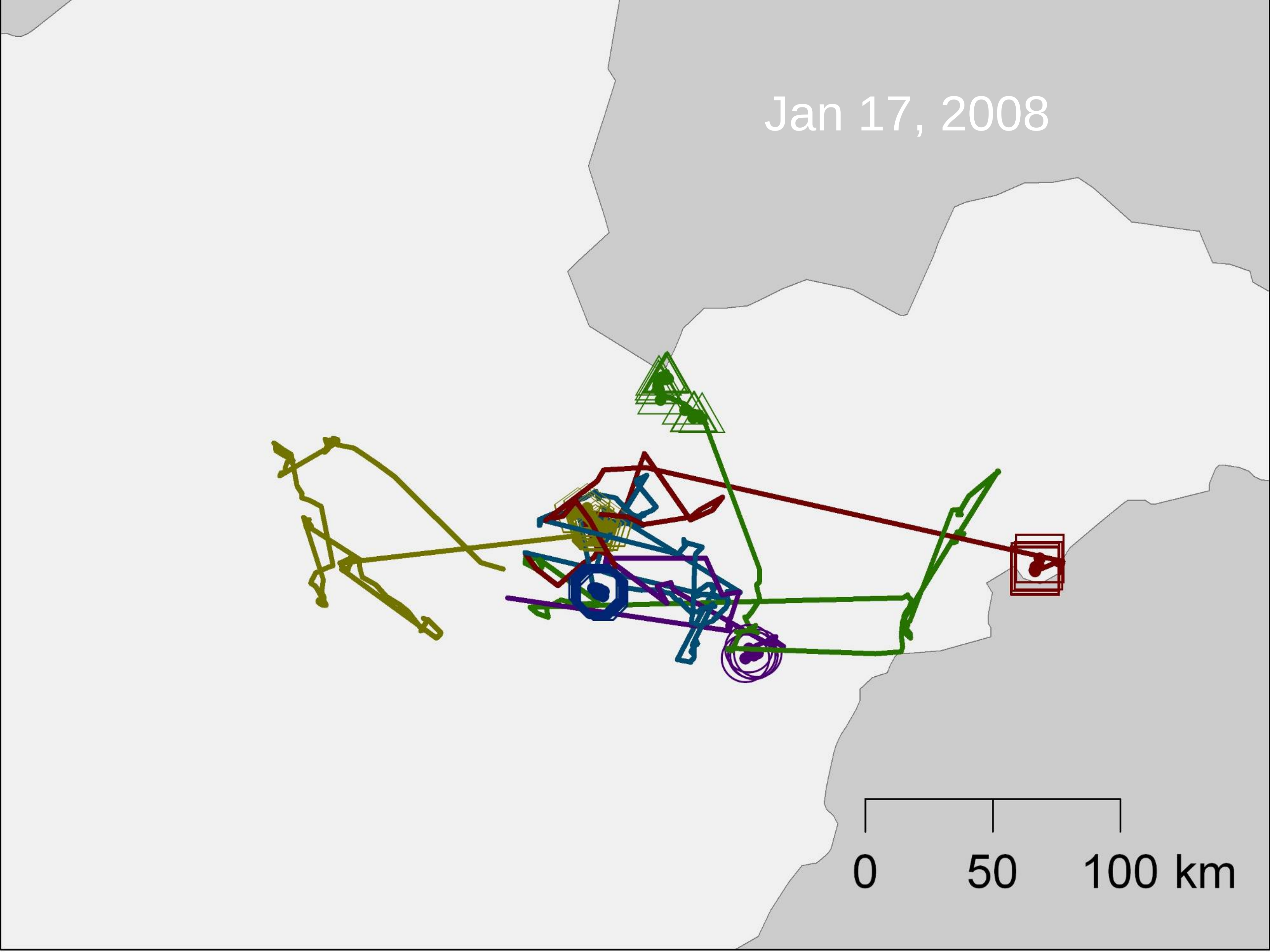

Nov 17, 2007
0
50
100 km



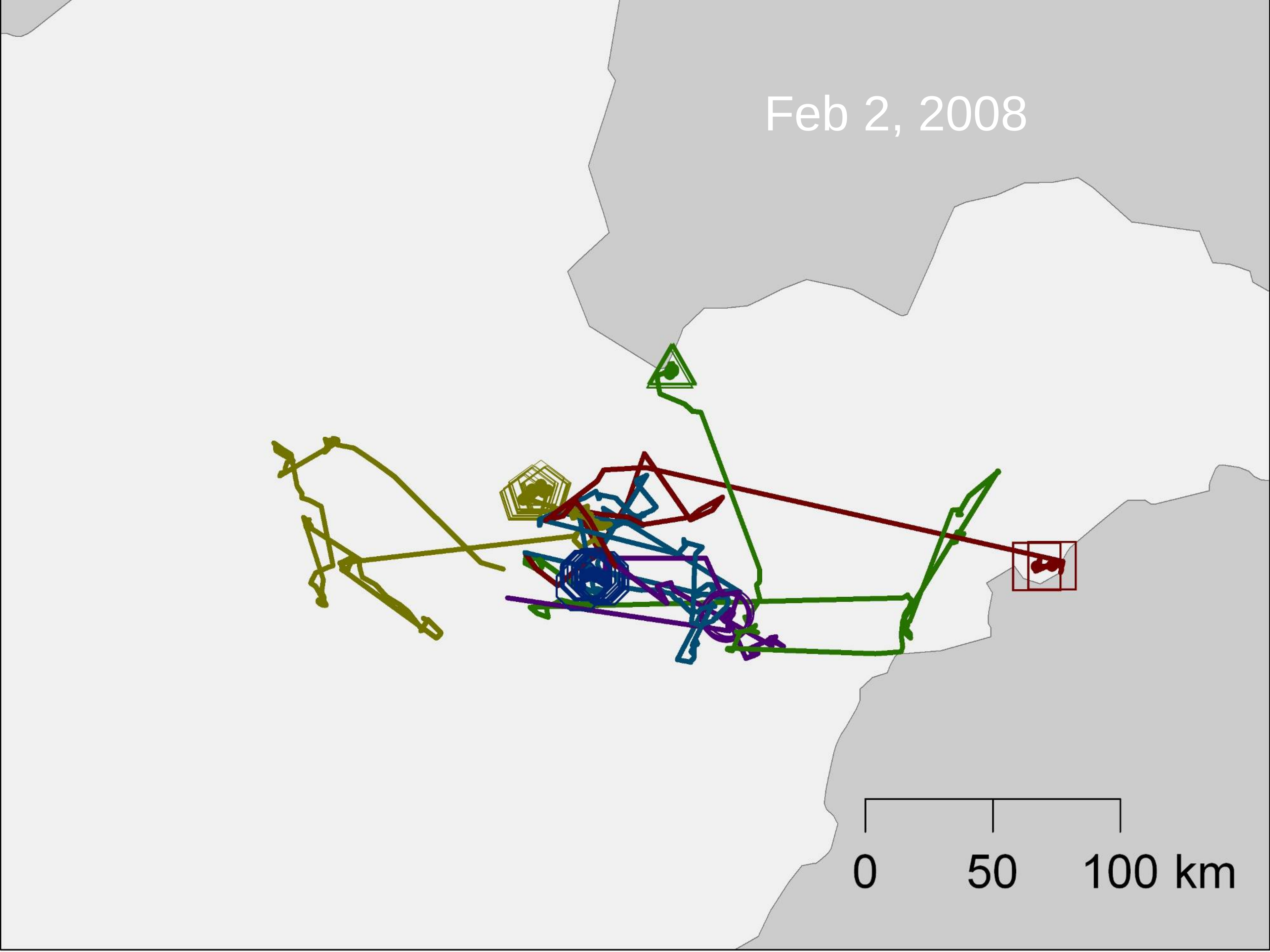
Dec 3, 2007
0
50
100 km

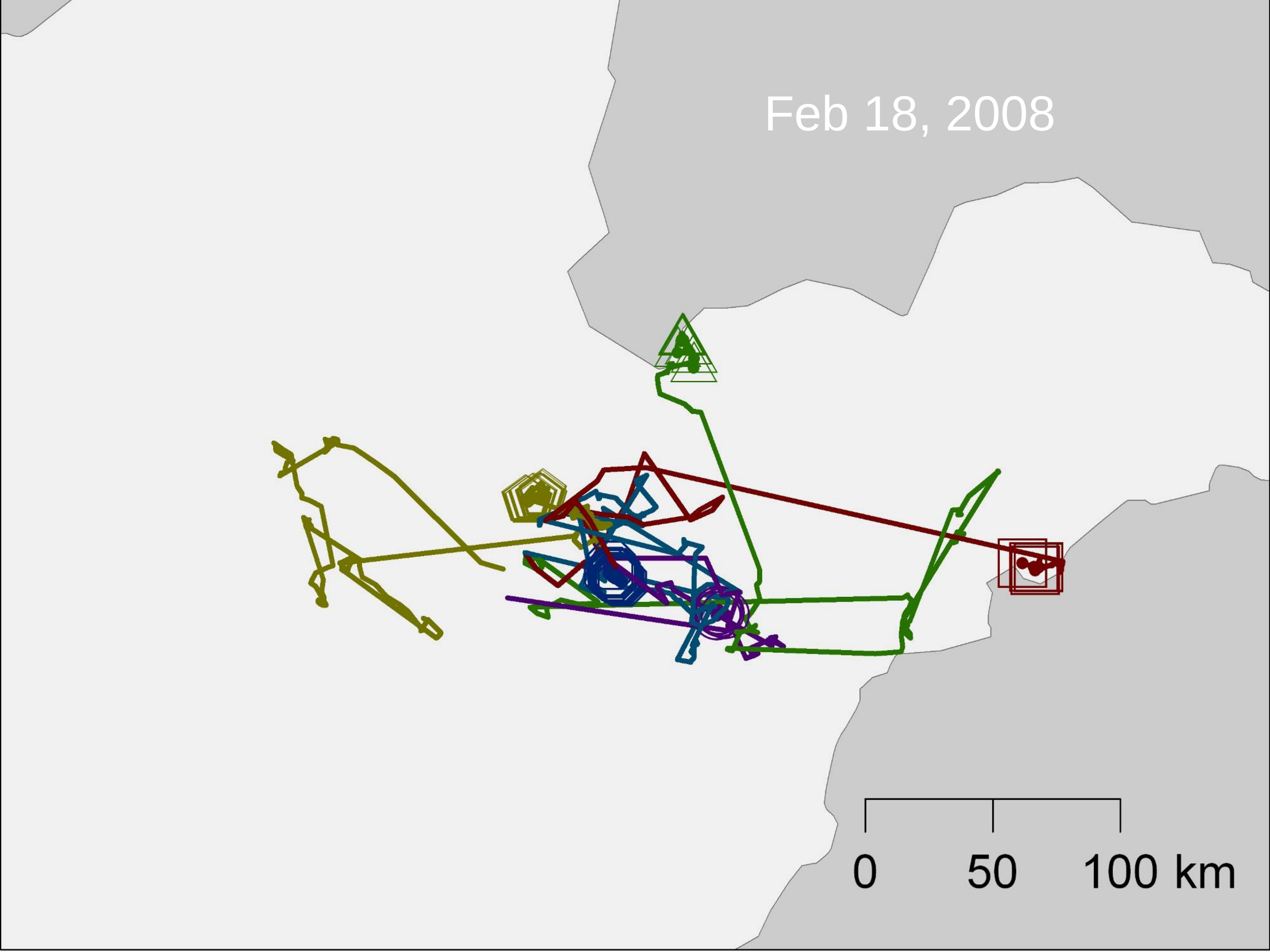

Dec 19, 2007
0
50
100 km

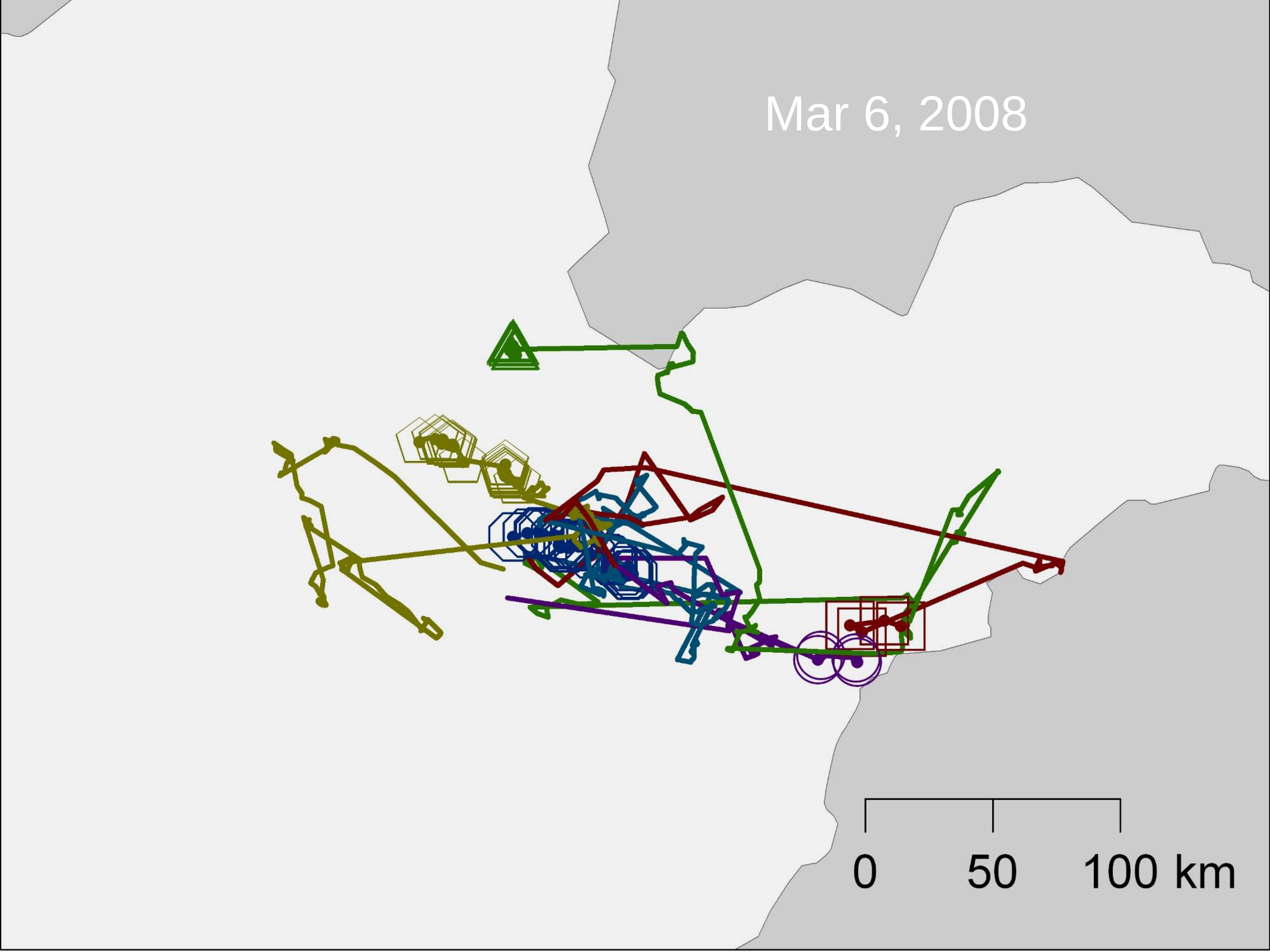

Jan 1, 2008
0
50
100 km

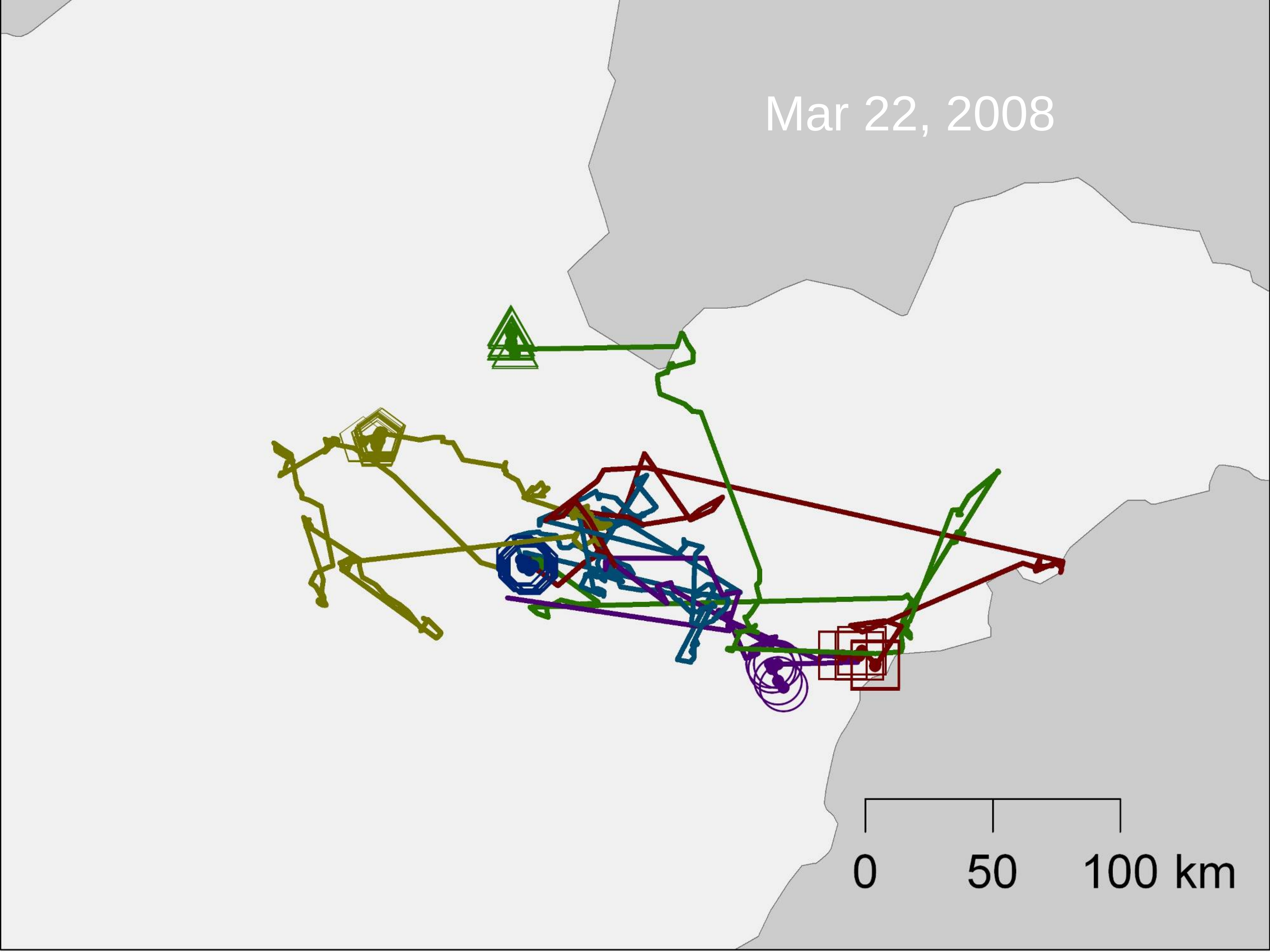


Jan 17, 2008
0
50
100 km

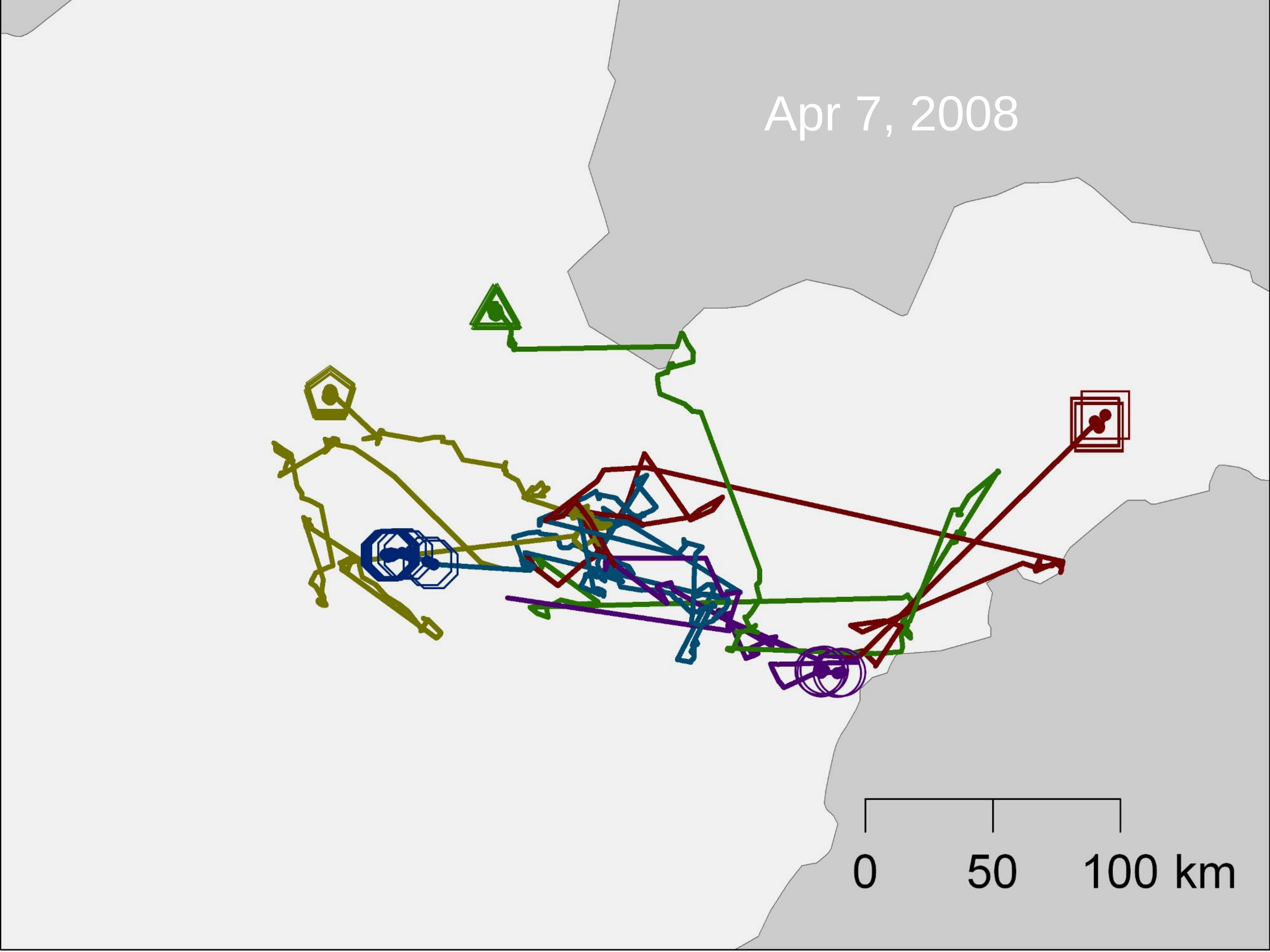

Feb 2, 2008
0
50
100 km

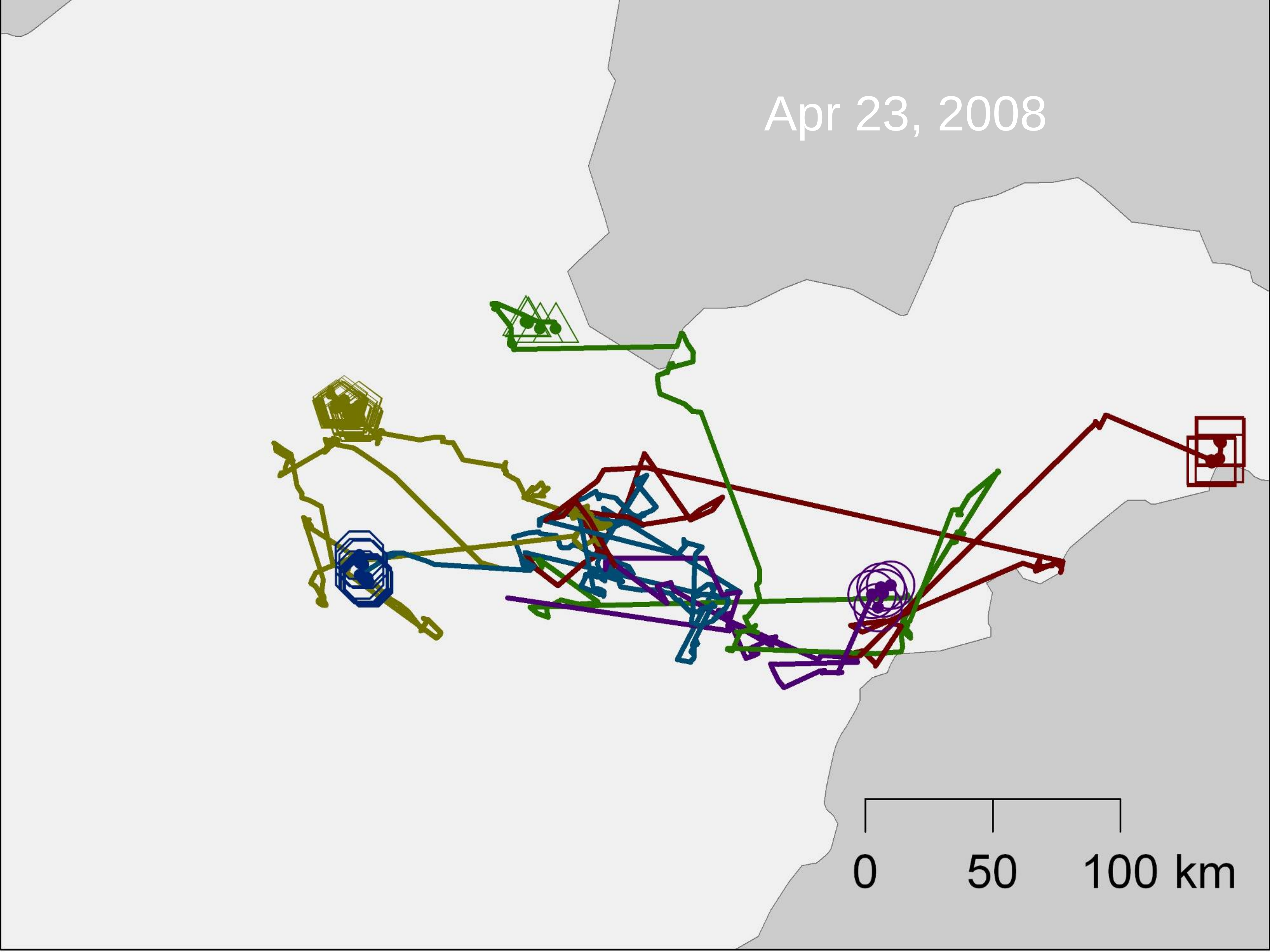

Feb 18, 2008
0
50
100 km

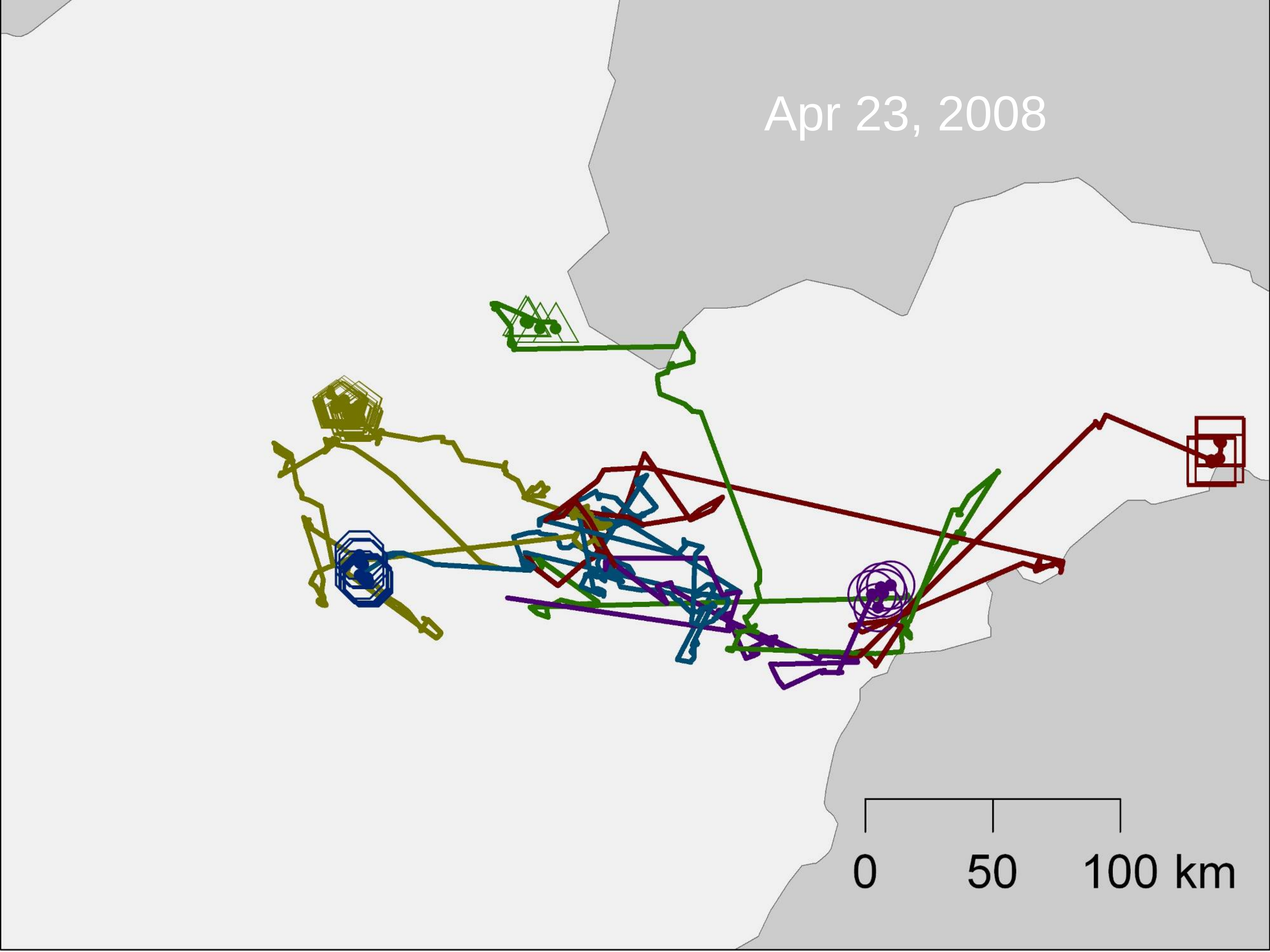

Mar 6, 2008
0
50
100 km

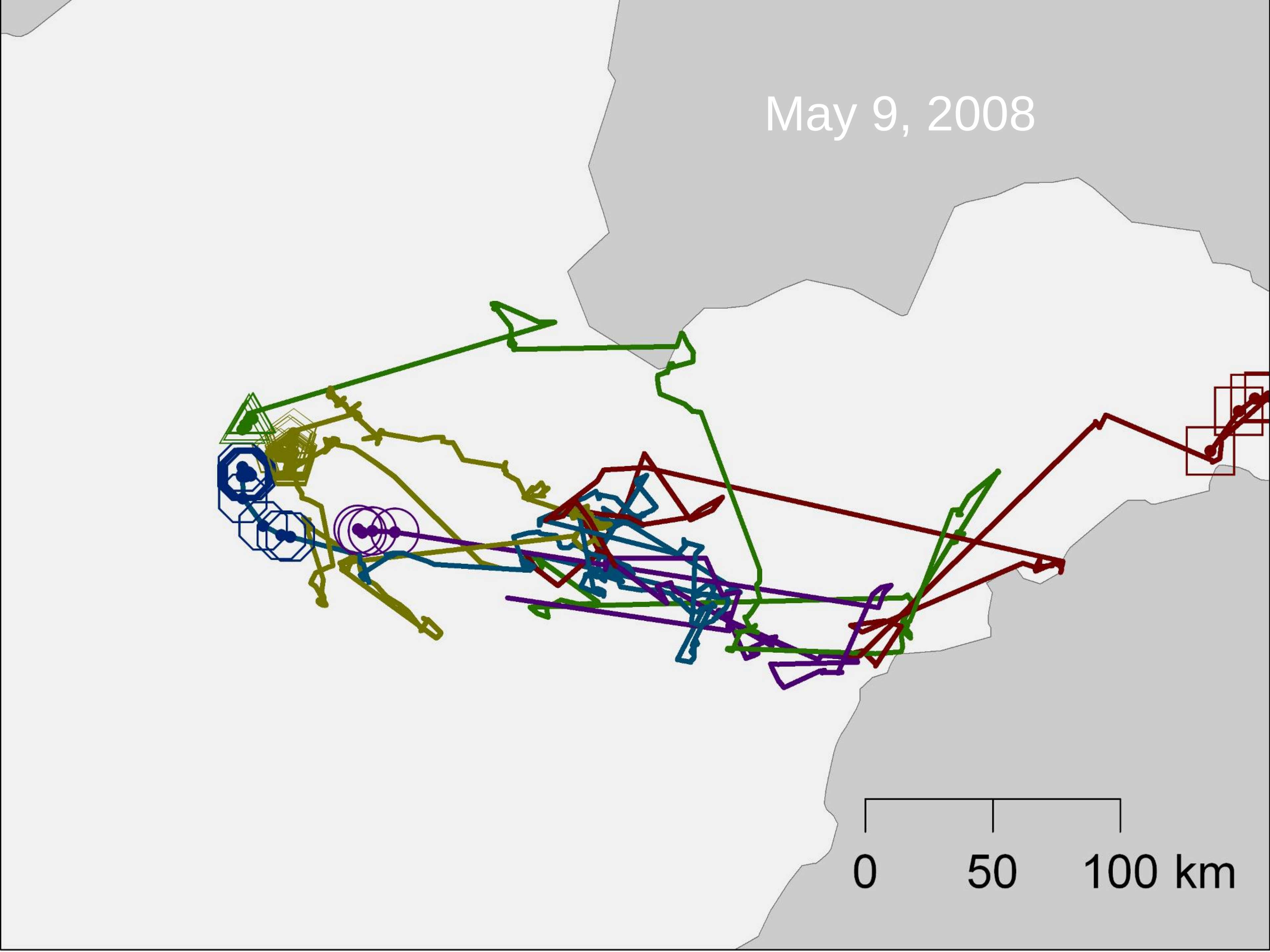


Mar 22, 2008
0
50
100 km

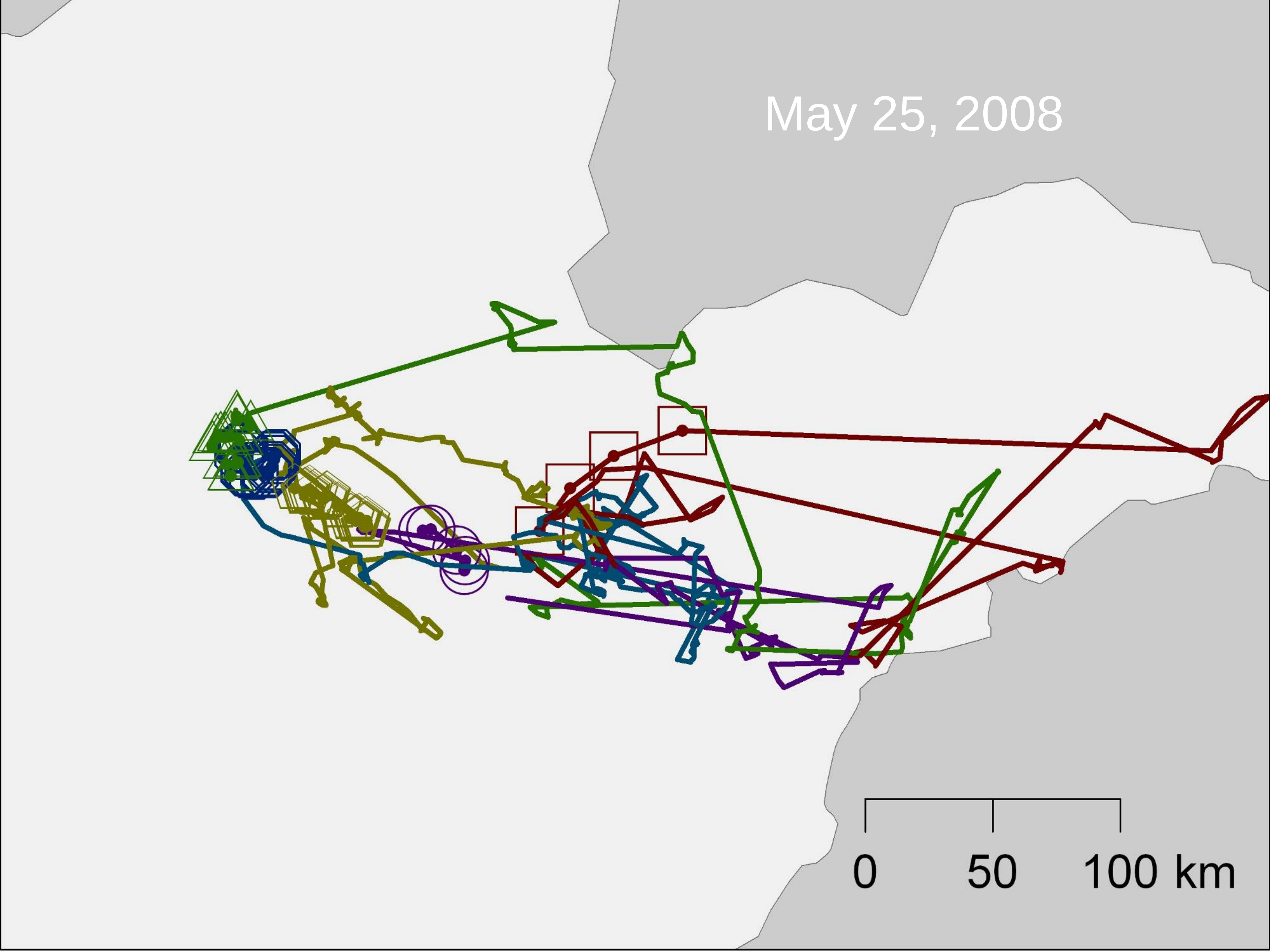

Apr 7, 2008
0
50
100 km


Apr 23, 2008
0
50
100 km

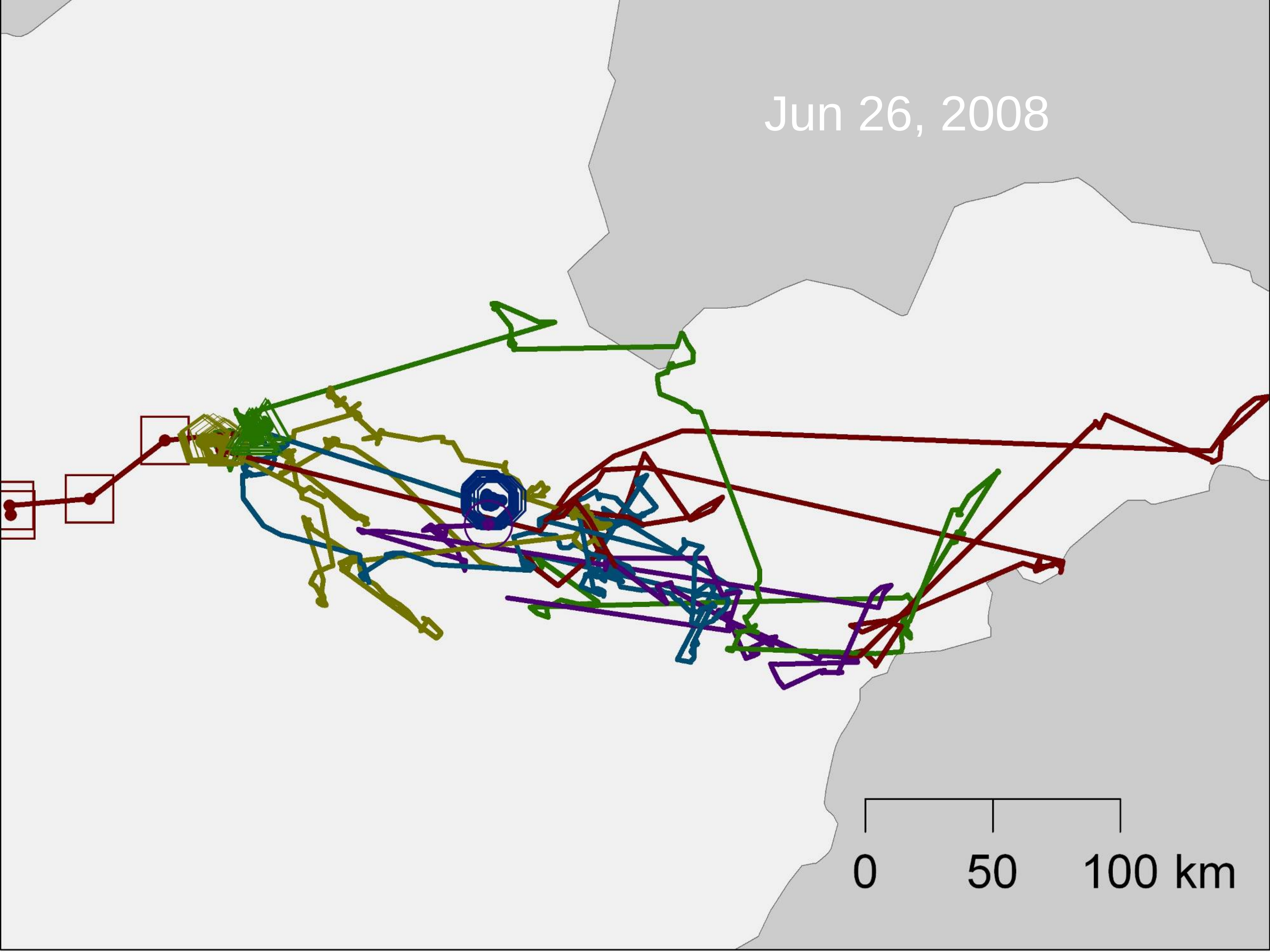

Apr 23, 2008
0
50
100 km



May 9, 2008
0
50
100 km



May 25, 2008
0
50
100 km


Jun 26, 2008
0
50
100 km


Whooping Crane Eastern Flock
Spring Migration, 2004
Necedah National Wildlife Refuge
Apr. 17
Apr. 21
Apr. 16
Apr. 17 - 22
Apr. 17
Apr. 18
Apr. 25 - 26
Apr. 9
Apr. 16
Apr. 10
Apr. 8 - 8
Apr. 9
Apr. 10 - 24
Apr. 16
Apr. 16
Apr. 15
Apr. 15
Apr. 9
Apr. 11 - 26
Apr. 15
Apr. 10
Apr. 14
Apr. 1 - 3
Apr. 10
Mar. 31
Apr. 9
Apr. 9
Apr. 9
Apr. 9
Apr. 8
Mar. 30
Mar 30 - Apr 6
Apr 7
Chassahowitzka National Wildlife Refuge
Start and End Points
Fall 2003 Migration Route
HY2003 Whooping Crane Stopovers
Group 1A (301, 305, 309, 318, 319)
Group 1B (303, 312, 316)
Group 1 (301, 303, 305, 309, 312, 316, 318, 319)
Group 2 (202, 204, 206, 207, 210, 211, 213, 217)
Group 2A (304, 306, 317)
Group 2B (310, 313)
Crane #302
Crane #307
Crane #311
0 400 800 Kilometers
0 400 800 Miles
Copyright 2001-2004 Journey North 1:21500000

Discussion

<u>Conservation Strategies Nomadism versus Migration</u>:

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

<u>Coping with changes in patterns of primary productivity as a consequence of climate change</u>:

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