

# A movement ecology approach for studying dispersal processes in changing environments

**Ran Nathan**

**The Hebrew University of Jerusalem**



MOVEMENT  
ECOLOGY  
LAB



Minerva Center for  
MOVEMENT ECOLOGY



MOVEMENT ECOLOGY

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*Everything Disperses to Miami*

**December 2012, Miami FL, USA**



# MOVEMENT ECOLOGY

Now accepting  
submissions!

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*Editors-in-Chief:* Ran Nathan (Israel) and Luca Giuggioli (UK)

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*Movement Ecology* is an open-access interdisciplinary journal publishing novel insights from empirical and theoretical approaches into the ecology of movement of the whole organism as the central theme. We welcome manuscripts on any taxa and any movement phenomena addressing important research questions on the patterns, mechanisms, causes and consequences of organismal movement. Manuscripts will be rigorously peer-reviewed to ensure novelty and high quality. We aim to bring together research across a number of disciplines, including:

-  Behavioural Ecology and sociobiology
-  Climate and environmental changes
-  Conservation and invasion biology
-  Population genetics and evolutionary biology
-  Theoretical and mathematical ecology
-  Dispersal, foraging and migration ecology

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**Movement - change in spatial position over time**



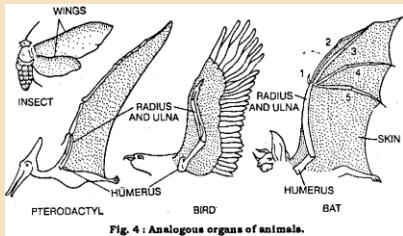
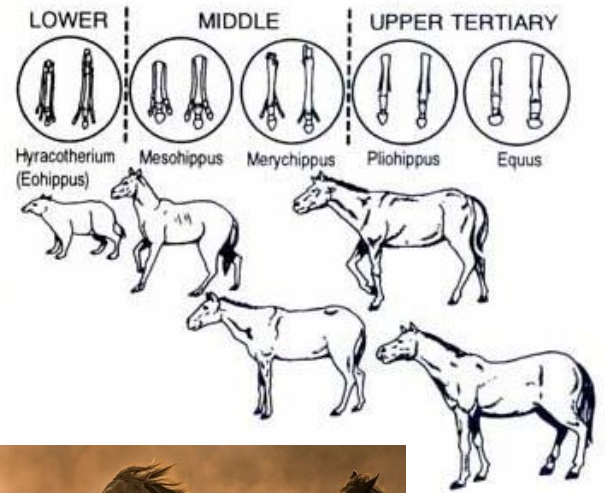
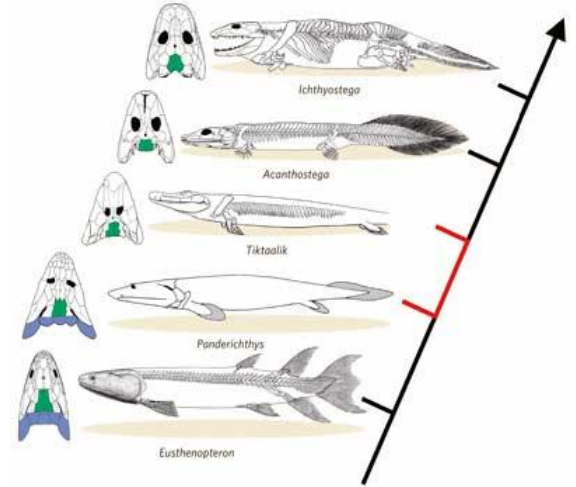
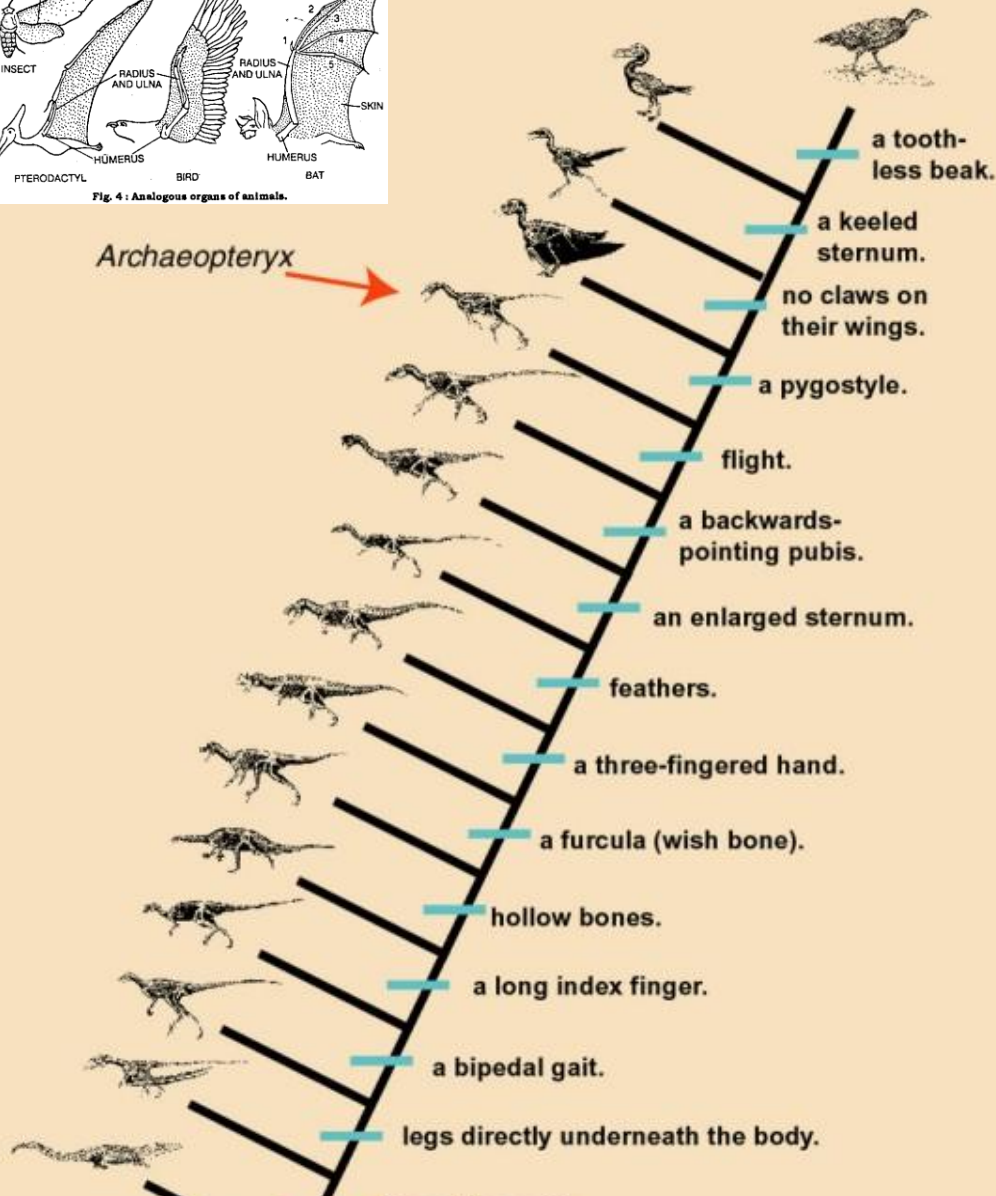
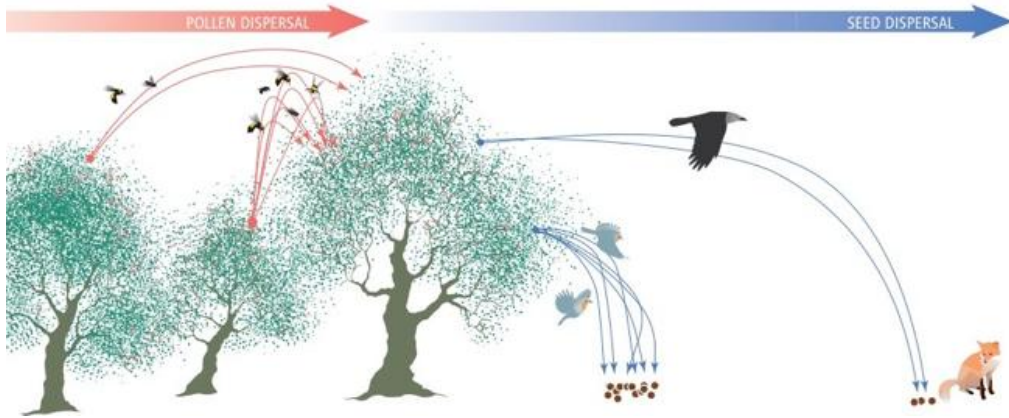
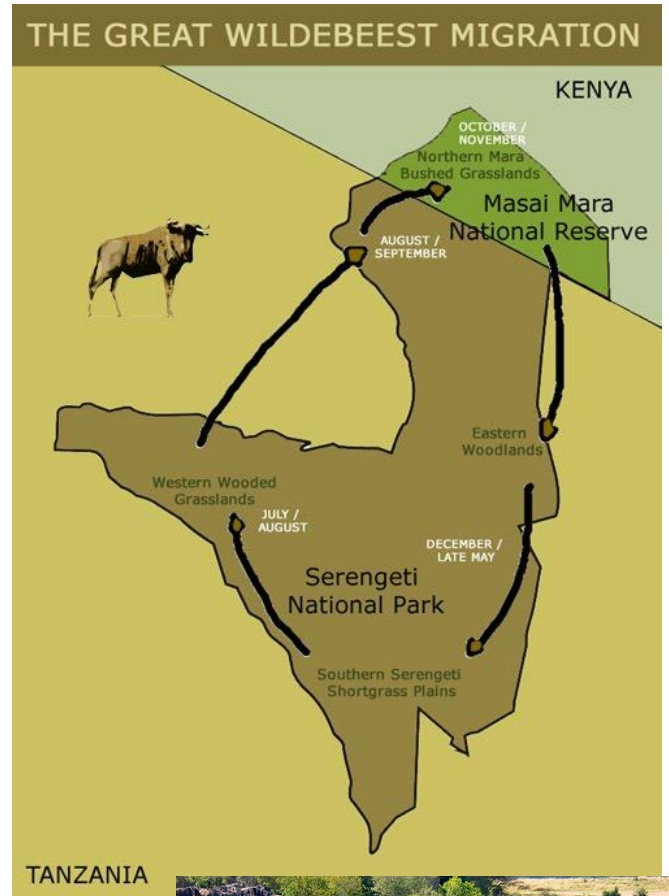
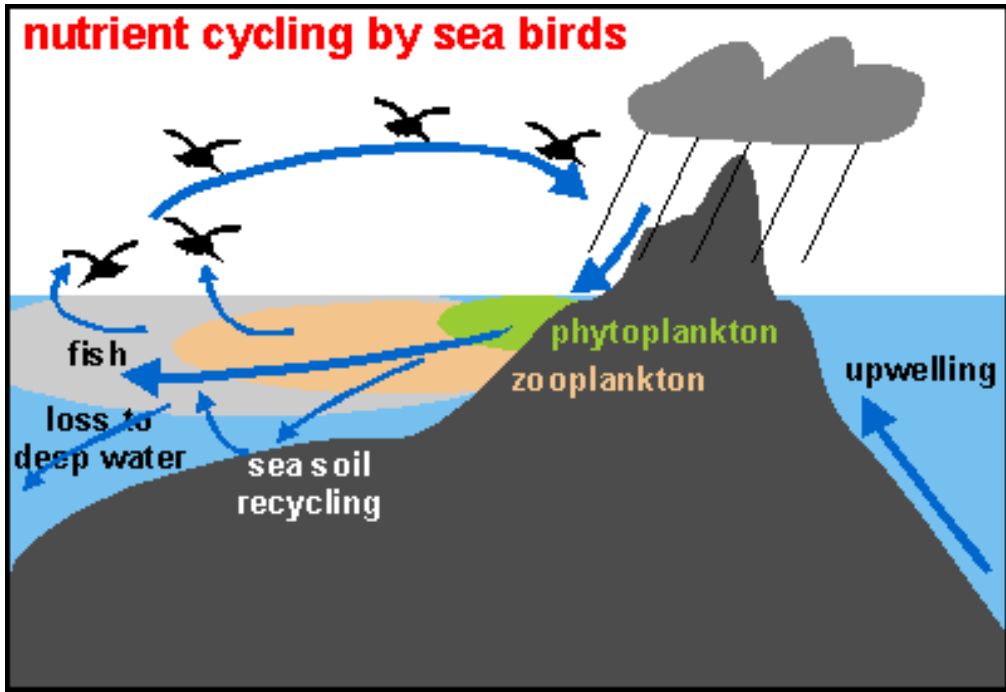


Fig. 4 : Analogous organs of animals.



**Movement is key to many evolutionary processes**



**Movement is essential to many ecological processes**



## Global Warming Projections

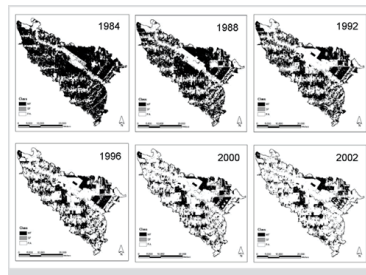
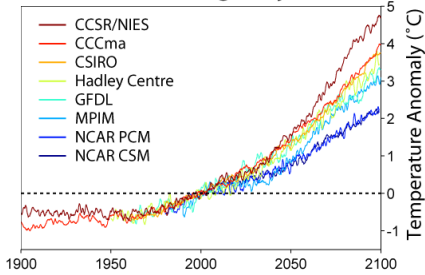
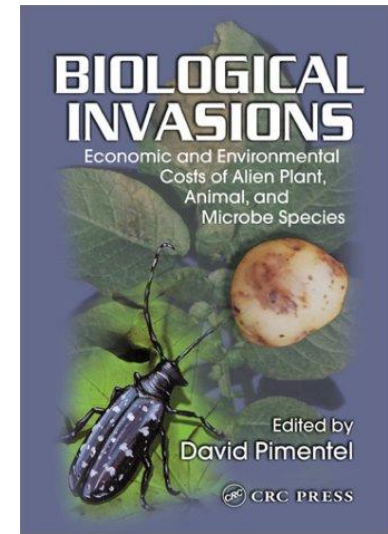
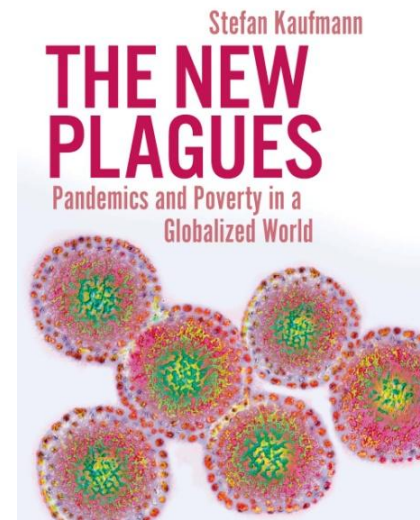
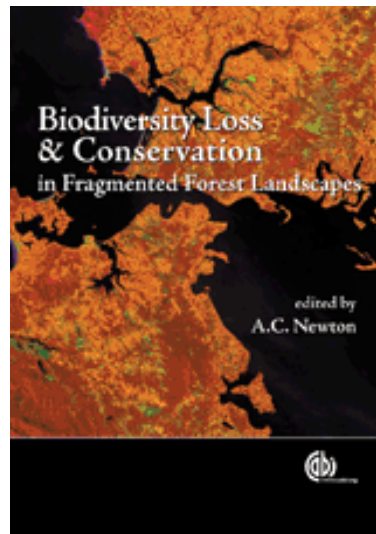
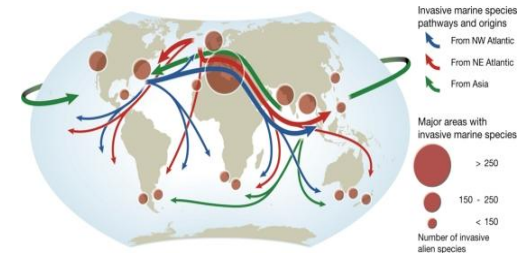
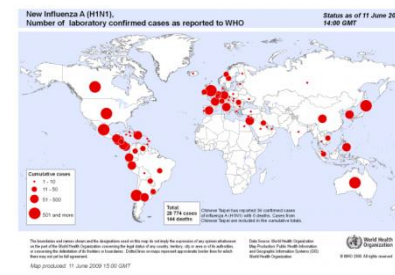
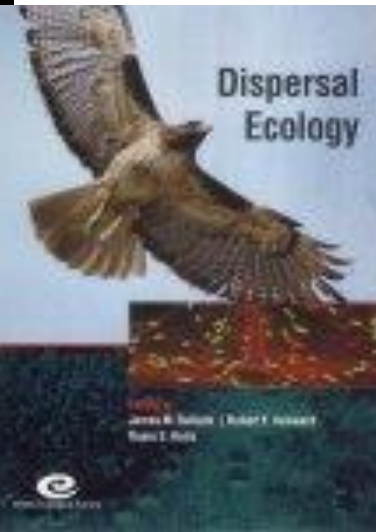
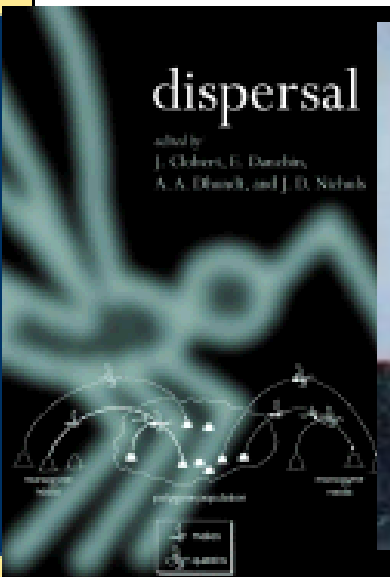
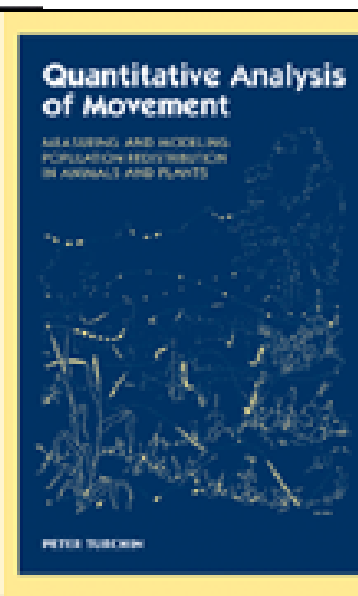
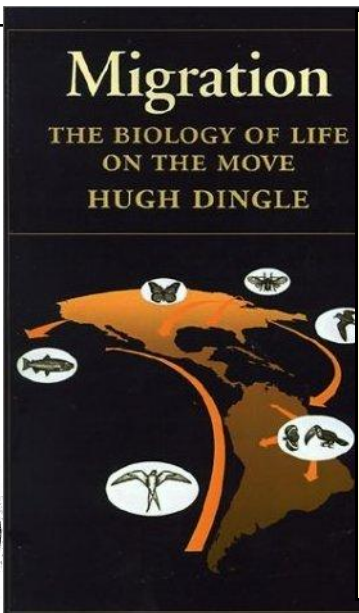
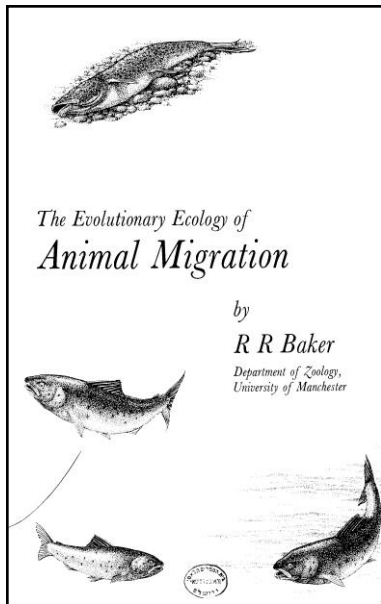


FIGURE 10.6 The loss and fragmentation of forest cover caused by clearing for small farms is illustrated in this time series of forest cover maps (MF = mature forest, SF = secondary forest, PA = pasture).

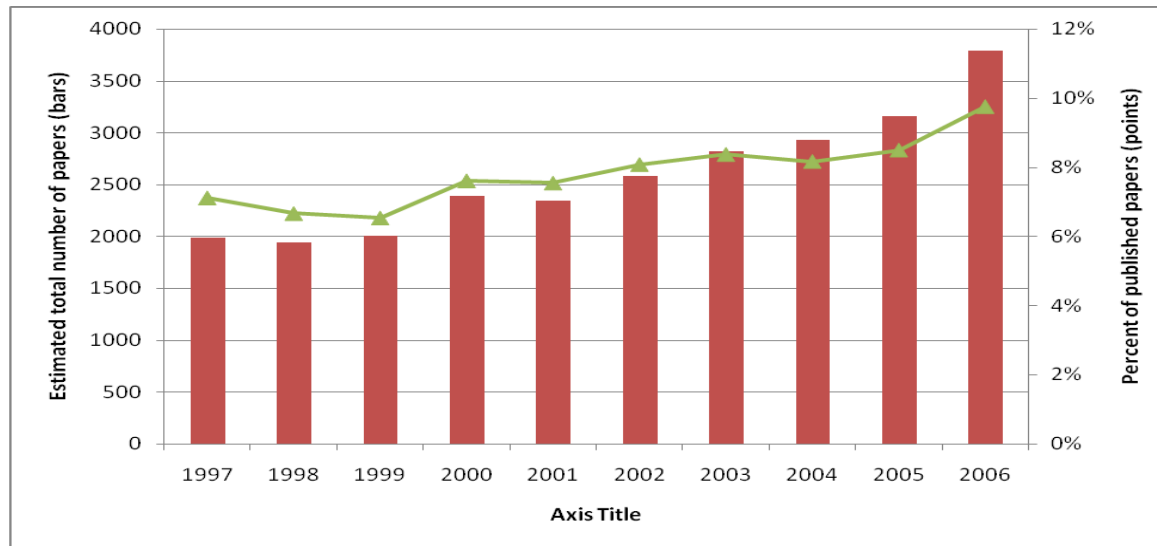


**Movement is critical to our major global concerns**





A total of ~26,000 relevant papers in 10 years (1997-2006)

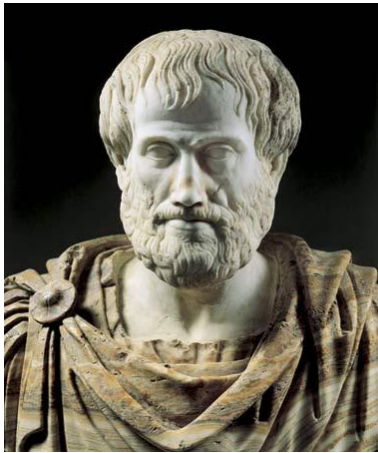


Holyoak et al. 2008 *PNAS*

*"Now we must consider in general the common reason for moving with any movement whatever."*

**Peri Zoon Kineseos  
(De Motu Animalium)**

**"On the Motion of Animals"**



**Aristotle  
(384 – 322 BC)**

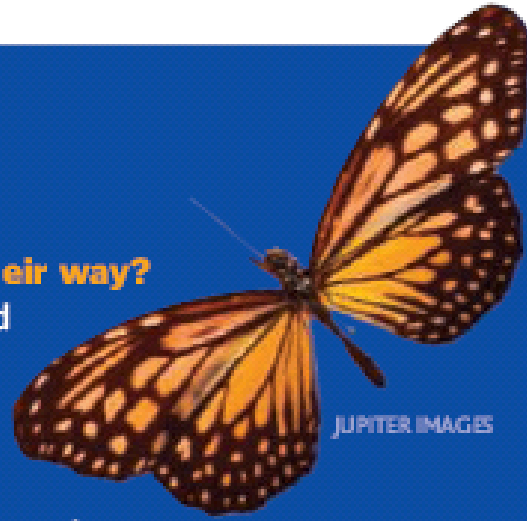


# In Praise of Hard Questions



## How do migrating organisms find their way?

Birds, butterflies, and whales make annual journeys of thousands of kilometers. They rely on cues such as stars and magnetic fields, but the details remain unclear.



**What determines the repertoire of movement modes used by an individual/population/species?**

**What drives the evolution of different movement phenomena?**

**How the basic components of movement differ among major taxonomic groups?**



# **The big opportunity for Movement Ecology**

**New technologies enable tracking  
movement in unprecedented  
detail and duration**

**New data analysis methods and tools  
facilitate new insights into the mechanisms  
underlying movement patterns**

**New transdisciplinary frameworks set  
the stage for developing a general  
theory of movement**

# **The big opportunity for Movement Ecology**

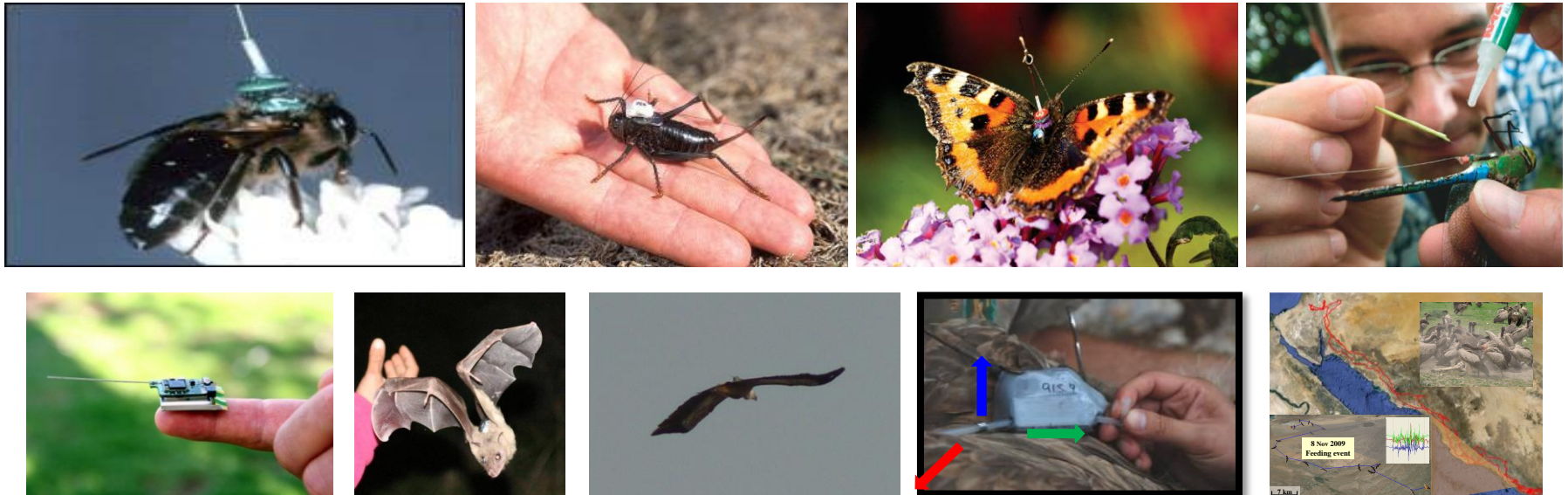
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# A golden era of great opportunities for movement research





# Now we can get rich datasets on free-ranging wild animals on the move



**Orr Spiegel**

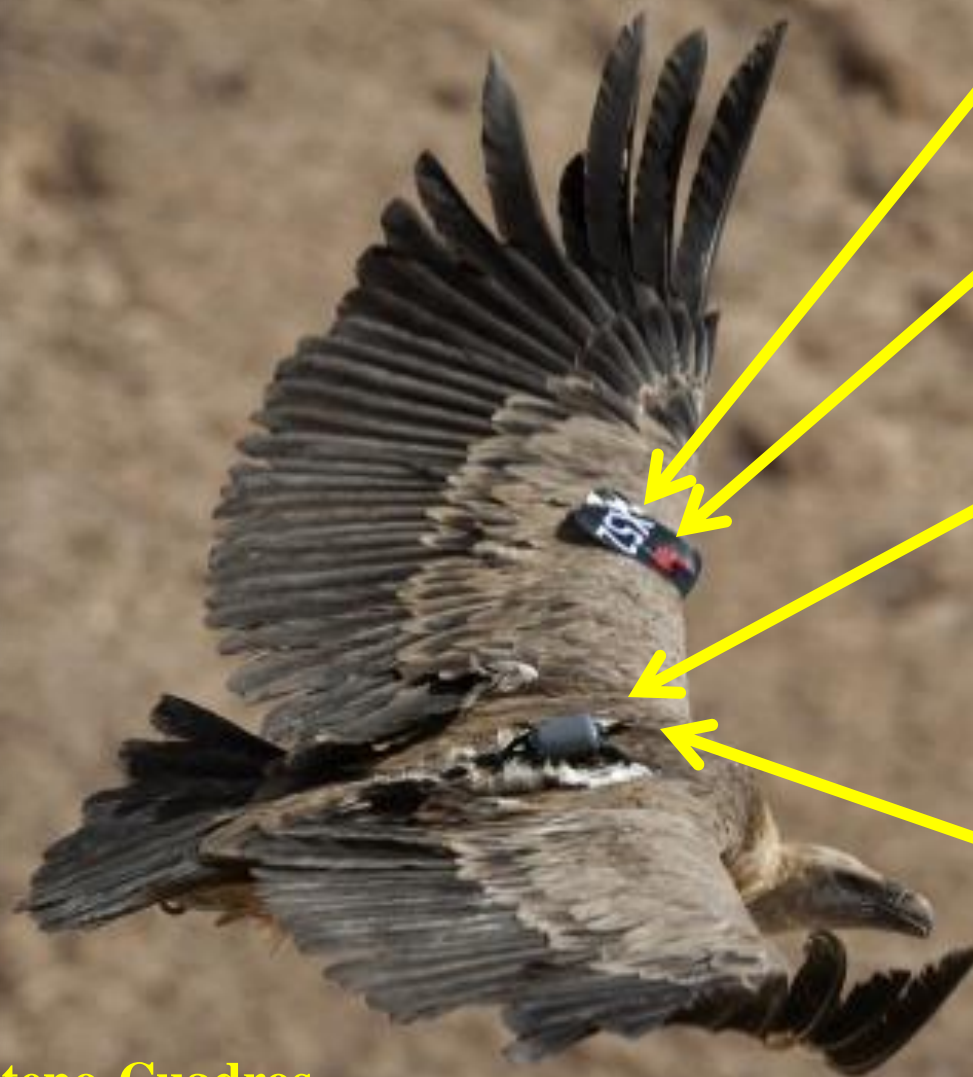


**Roi Harel**



**Alejandro Centeno-Cuadros**

**with Wayne Getz (UC Berkeley) and Ohad Hatzofe (NPA)**



**Wing tag (& leg band)**  
presence data  
from observations

**RFID tag**  
Automated  
presence/absence  
data in selected sites

**GPS tag**  
Highly accurate  
location, possibly in  
high sampling  
frequency or over long  
periods

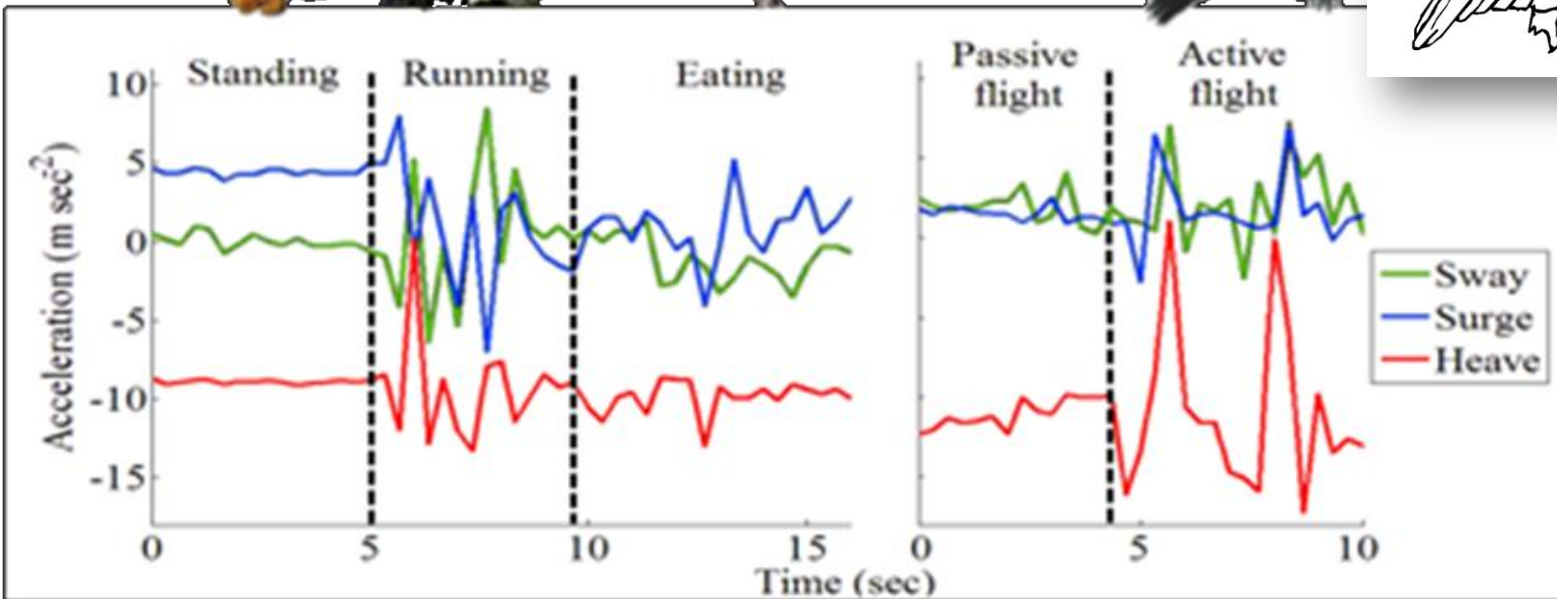
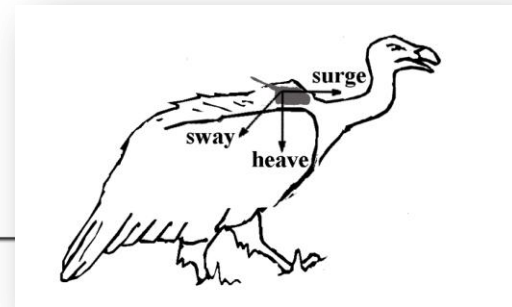
**ACC tag**  
Behavioral mode and  
energy expenditure

**Feathers / blood**  
Sex, relatedness,  
source(?), (stress)

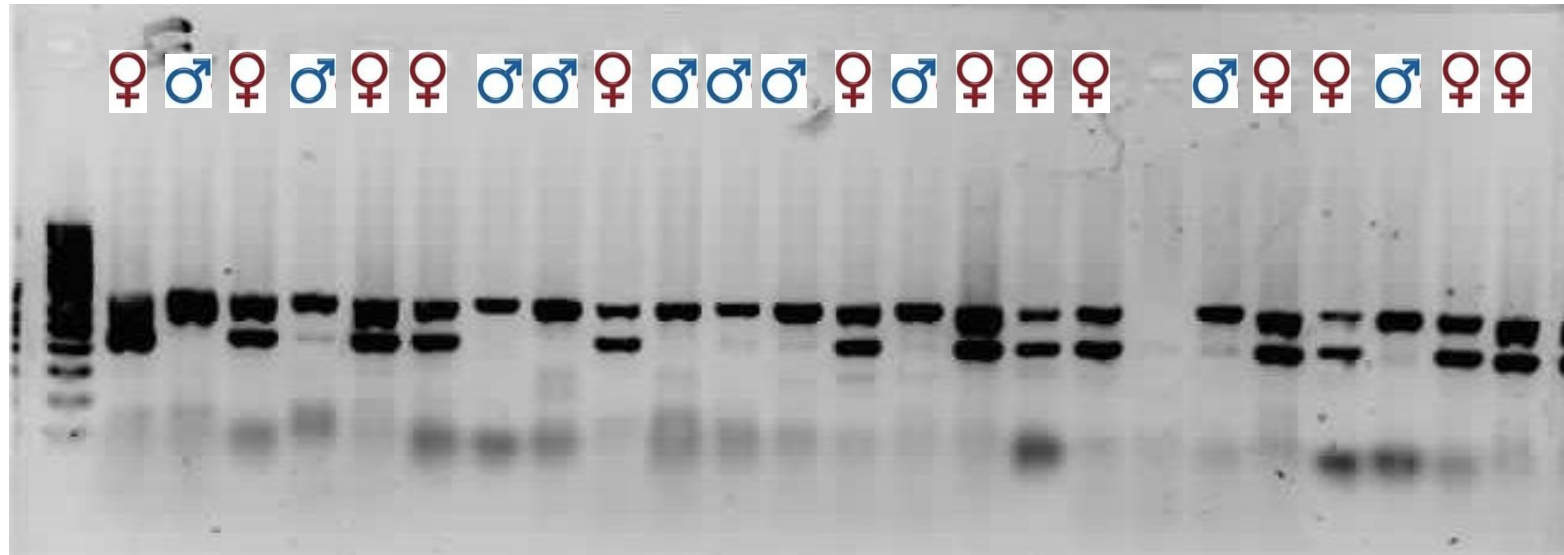
## REVIEW

# Using tri-axial acceleration data to identify behavioral modes of free-ranging animals: general concepts and tools illustrated for griffon vultures

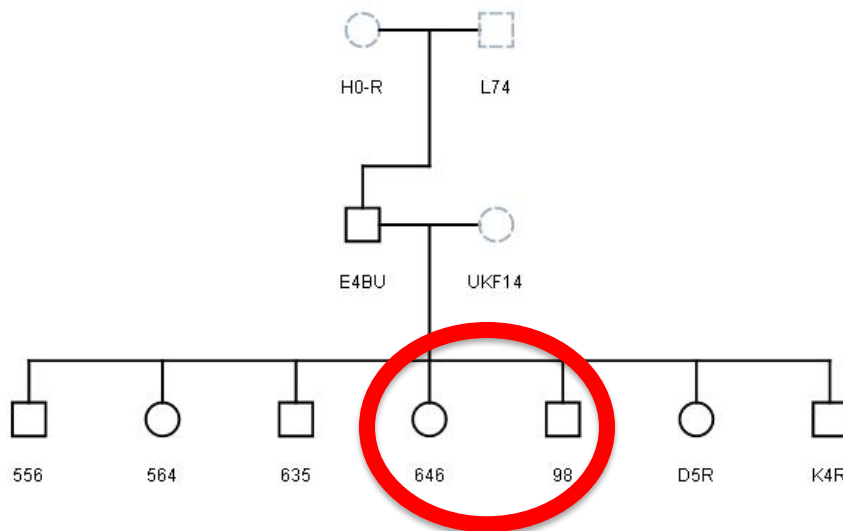
Ran Nathan<sup>1,\*</sup>, Orr Spiegel<sup>1</sup>, Scott Fortmann-Roe<sup>2</sup>, Roi Harel<sup>1</sup>, Martin Wikelski<sup>3,4</sup> and Wayne M. Getz<sup>2,5</sup>



# Molecular sex determination



# Pedigree analysis



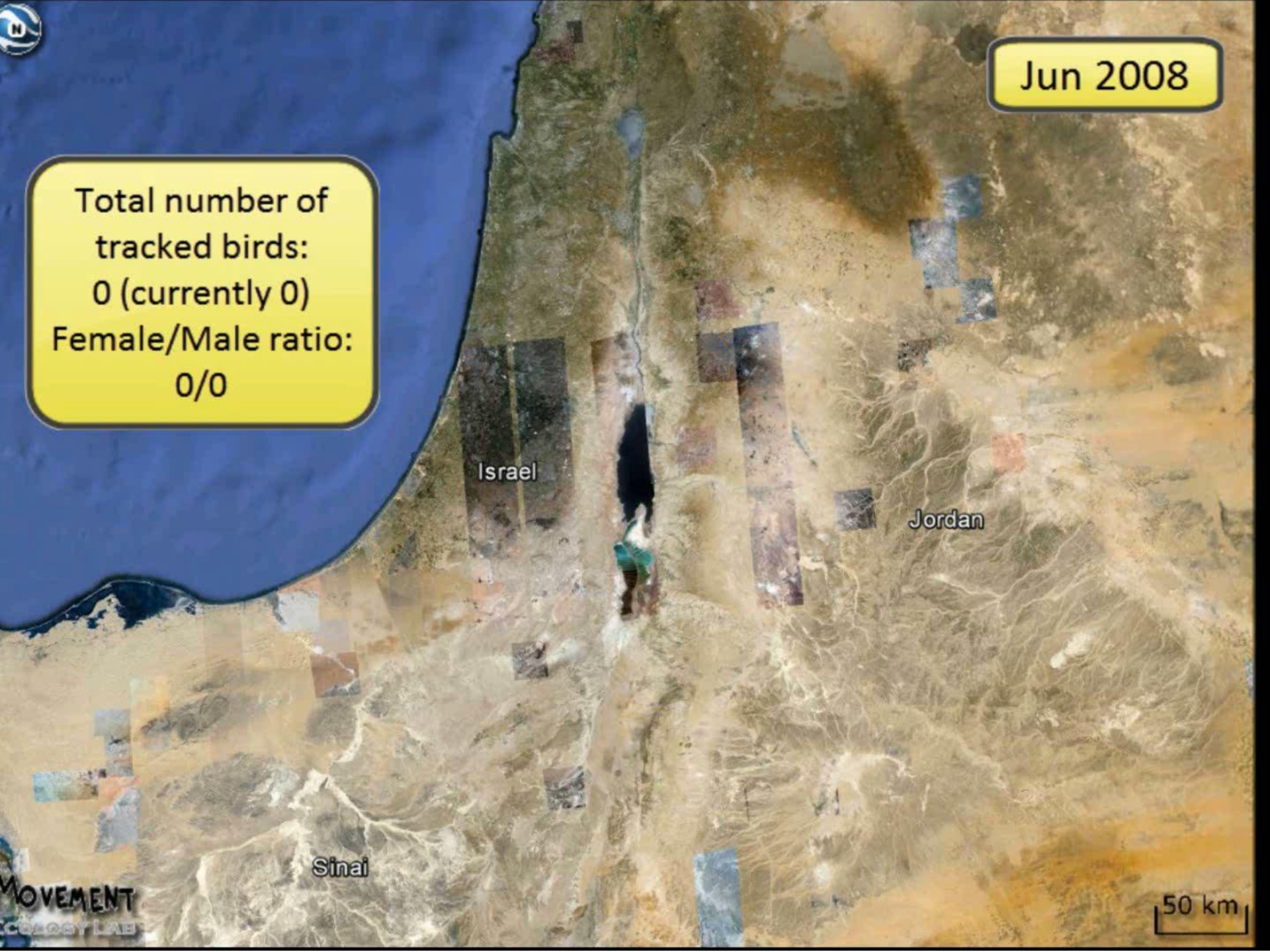
**Long-Range Foray  
(LRF) birds**





Jun 2008

Total number of tracked birds:  
0 (currently 0)  
Female/Male ratio:  
0/0



Israel

Jordan

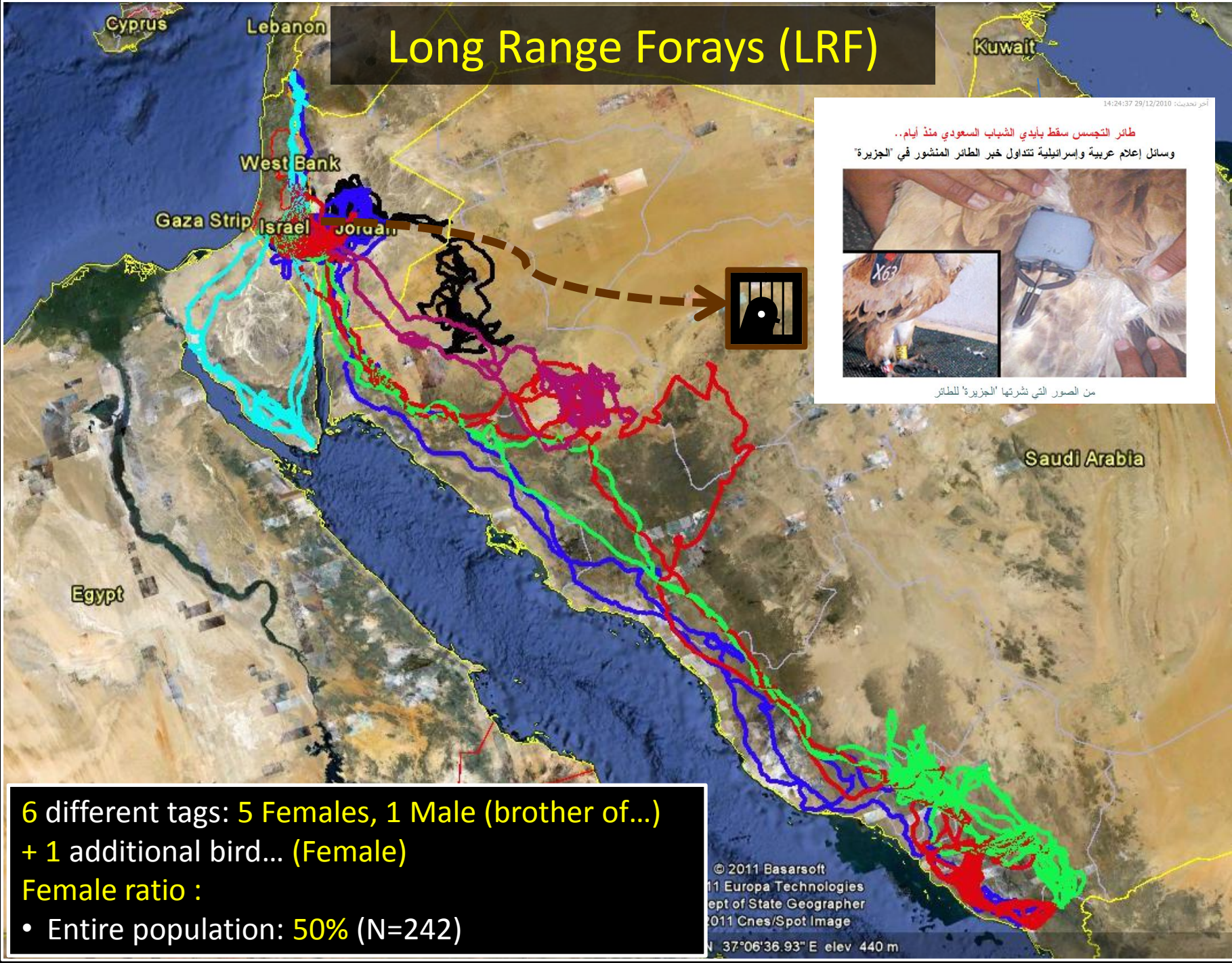
Sinai

50 km

MOVEMENT  
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# Long Range Forays (LRF)



6 different tags: 5 Females, 1 Male (brother of...)

+ 1 additional bird... (Female)

Female ratio :

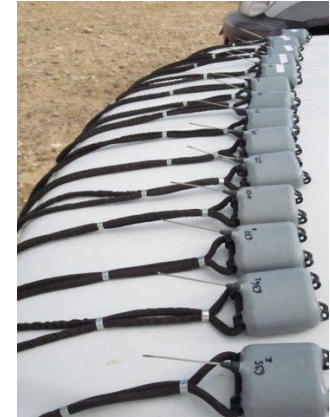
- Entire population: 50% (N=242)



طائر التجسس سقط بأيدي الشباب السعودي منذ أيام..  
وسائل إعلام عربية وإسرائيلية تتداول خبر الطائر المنشور في "الجزيرة"



www.aljazeera.net



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HOME / SAUDI ARABIA / VULTURE CAUGHT WITH A TRACKING DEVICE RAISES MANY QUESTIONS

Vulture caught with a tracking device raises many questions



# Sudan: Israeli 'spy vulture' nabbed during reconnaissance mission

By Nick Thompson and Nima Elbagir, CNN  
updated 9:41 AM EST, Wed December 12, 2012



Sudanese officials say a GPS-tagged vulture captured in the western part of the country was transmitting photos back to Israel.

HRUOUE POLIN/REX/GETTY IMAGES/FILE

## Sudan: Israel using 'spy vultures'

HIDE CAPTION

<< < 1 2 3 4

> >>

### STORY HIGHLIGHTS

Sudan: Israeli vulture with GPS-equipped camera caught by officials in western Sudan

Israeli scientists say a number of vultures tagged with GPS to study migration routes

Expert: GPS tracking of this sort used in hundreds of studies around the world

Griffon vultures are an endangered species in the Middle East, Hatzofe says

[Read a version of this story in Arabic.](#)

**(CNN)** -- A vulture captured by Sudanese authorities is actually an Israeli spy on a secret reconnaissance mission, a pro-government newspaper in the east African nation has claimed.

Government sources say the vulture, found in western Sudan, was tagged with a GPS-equipped camera to take and send pictures back to Israel, according to a December 8 story in the Alintibaha newspaper.

The bird also wore an ankle label reading "Hebrew University Jerusalem," "Israel Nature Service" and the contact details of an Israeli avian ecologist.

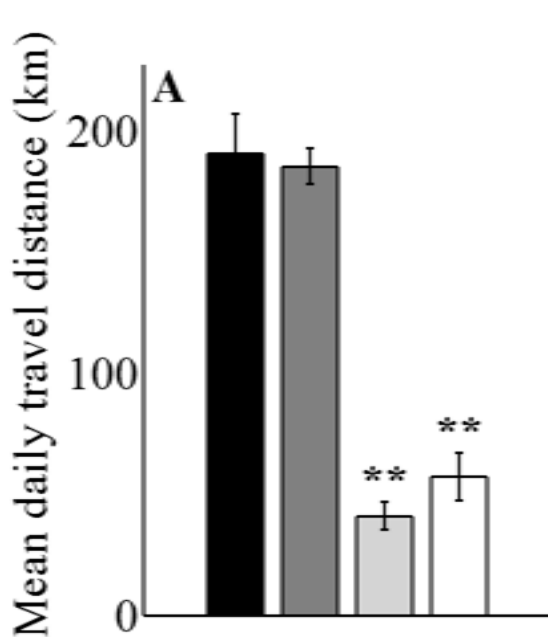
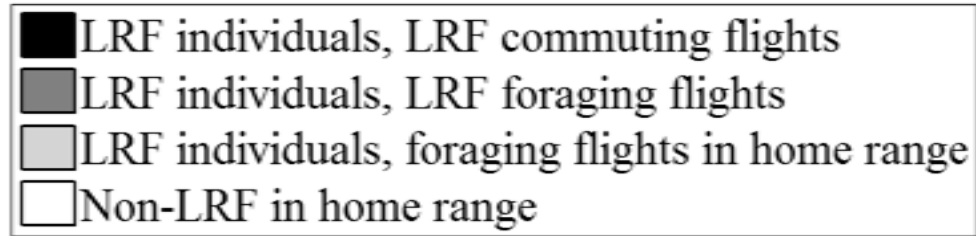


COURTESY/ANIMAP/CORBIS

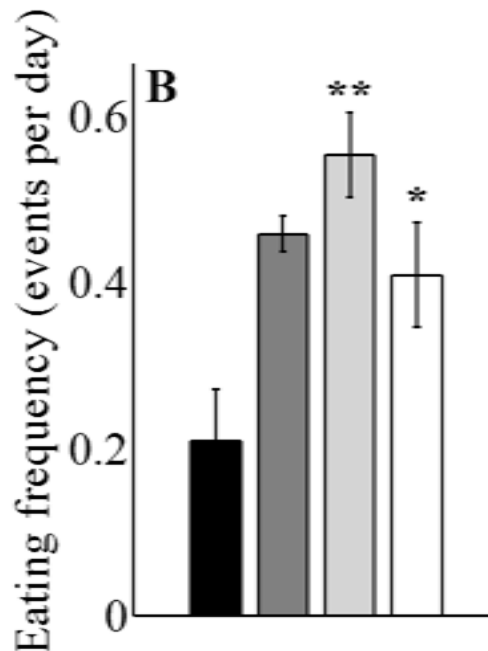




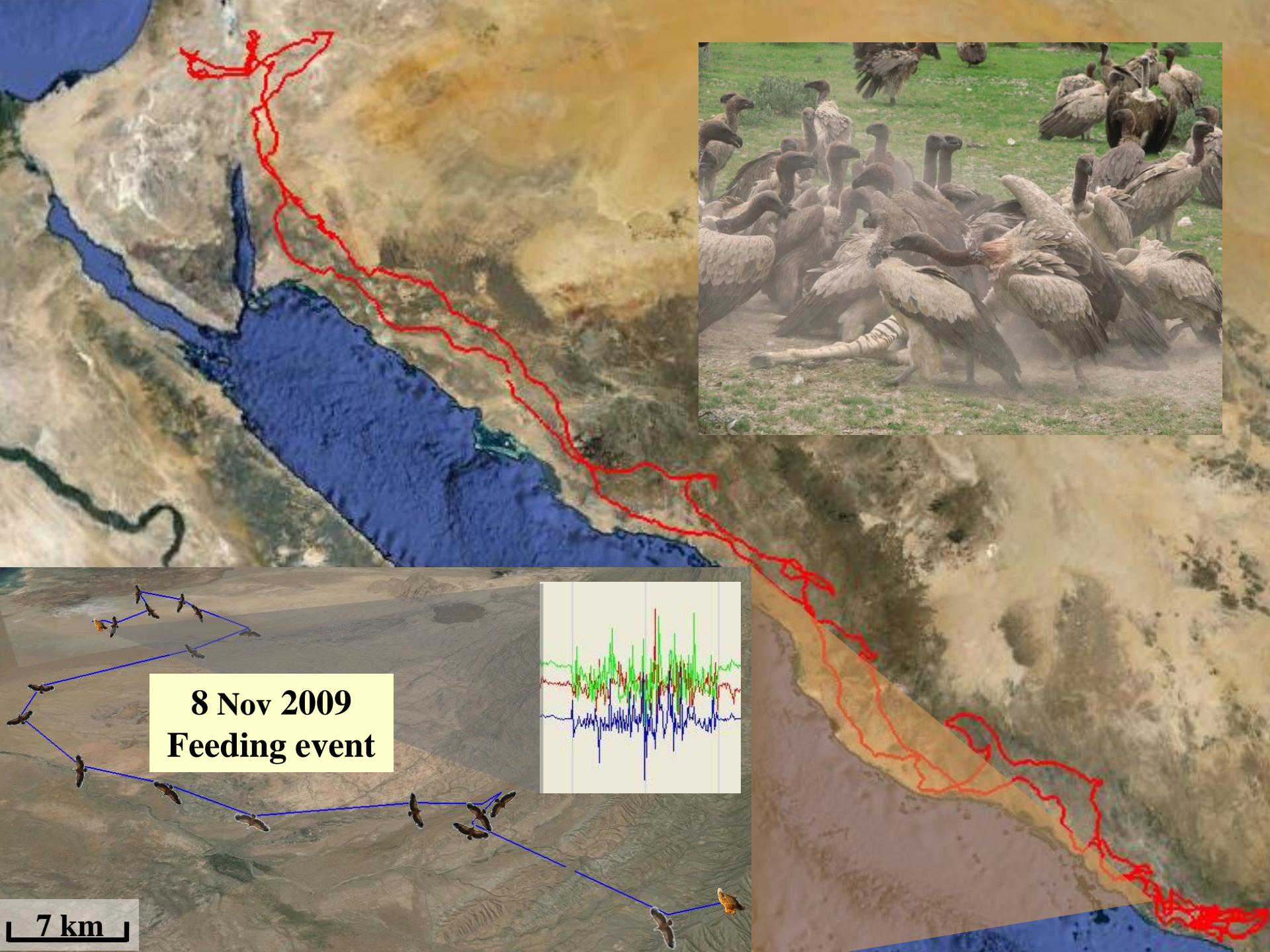
# What explains the rare long-range forays of adult vultures?



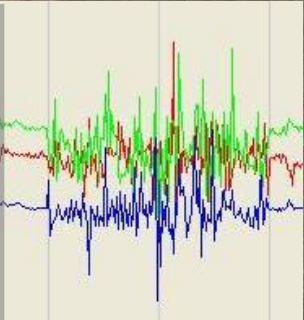
**They travel much more**



**They eat much less**

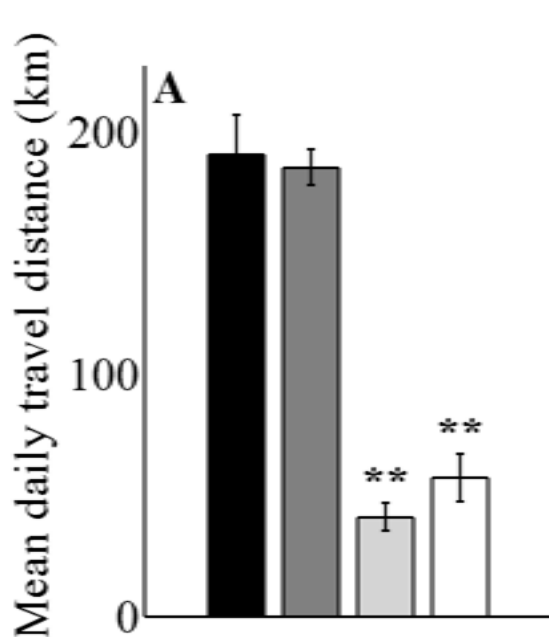
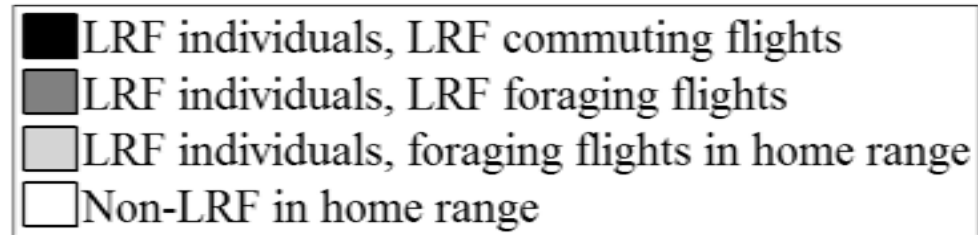


**8 Nov 2009  
Feeding event**

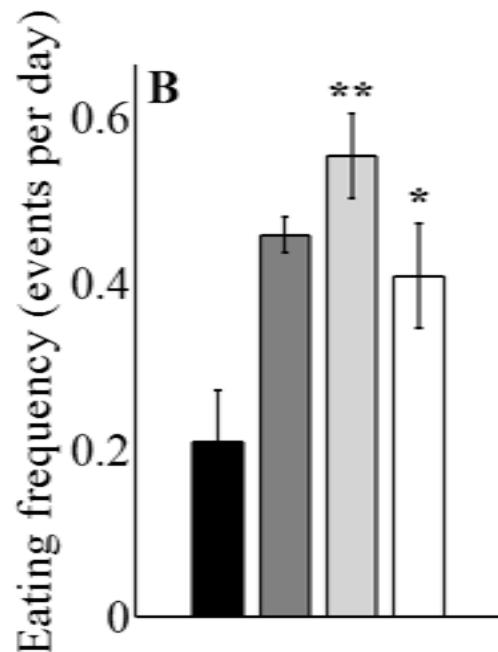


**7 km**

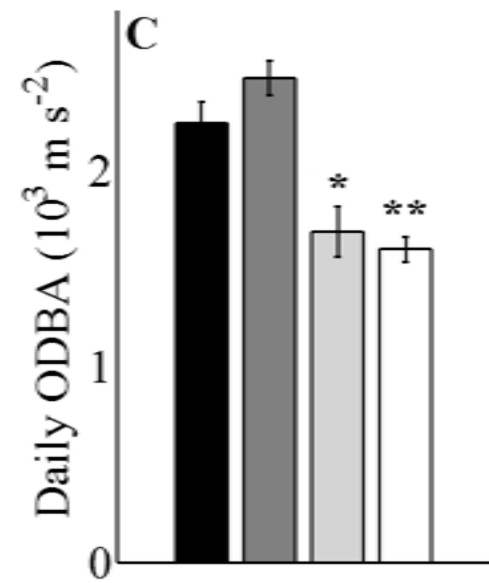
# What explains the rare long-range forays of adult vultures?



**They travel much more**



**They eat much less**



**They expend more energy**

# **The big opportunity for Movement Ecology**

New technologies enable tracking  
movement in unprecedented  
detail and duration

New data analysis methods and tools  
facilitate new insights into the mechanisms  
underlying movement patterns

**New transdisciplinary frameworks set  
the stage for developing a general  
theory of movement**



# Movement Ecology

A proposed unifying paradigm for studying the movement of organisms of all kinds

- (I) Stimulate the development and sharing of research tools
- (II) Promote understanding of the causes, consequences, mechanisms and patterns of movement
- (III) Set the stage for the development of a unifying theory of organismal movement

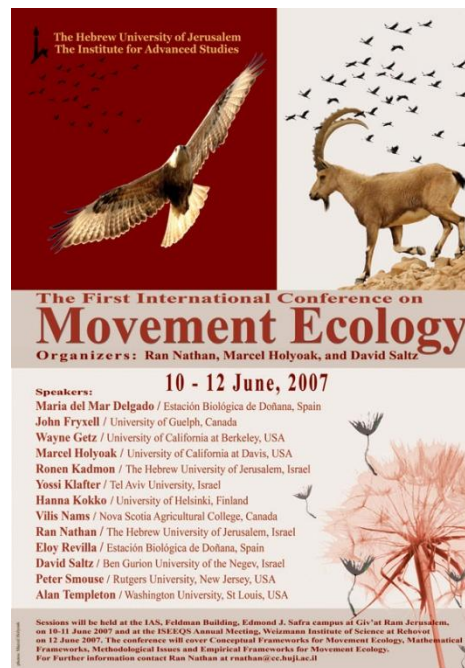
NEWS

## Inching Toward Movement Ecology

With ever more data coming out on migration, dispersal, and other movements, a few researchers say it's time for some synthesis

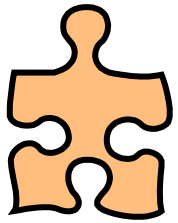


11 AUGUST 2006 VOL 313 SCIENCE

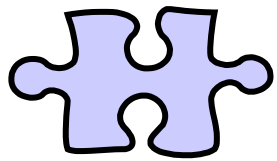
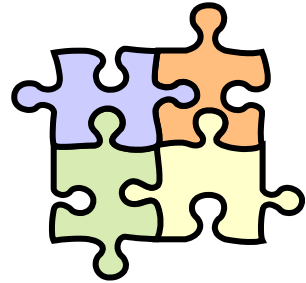


PNAS | December 9, 2008 | vol. 105 | no. 49

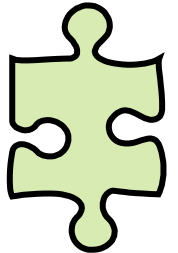
# The four basic components of Movement Ecology



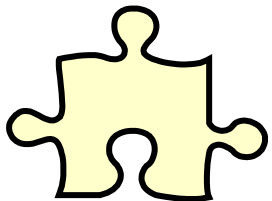
**1. Internal state (why?)**



**2. Motion mechanisms (how?)**



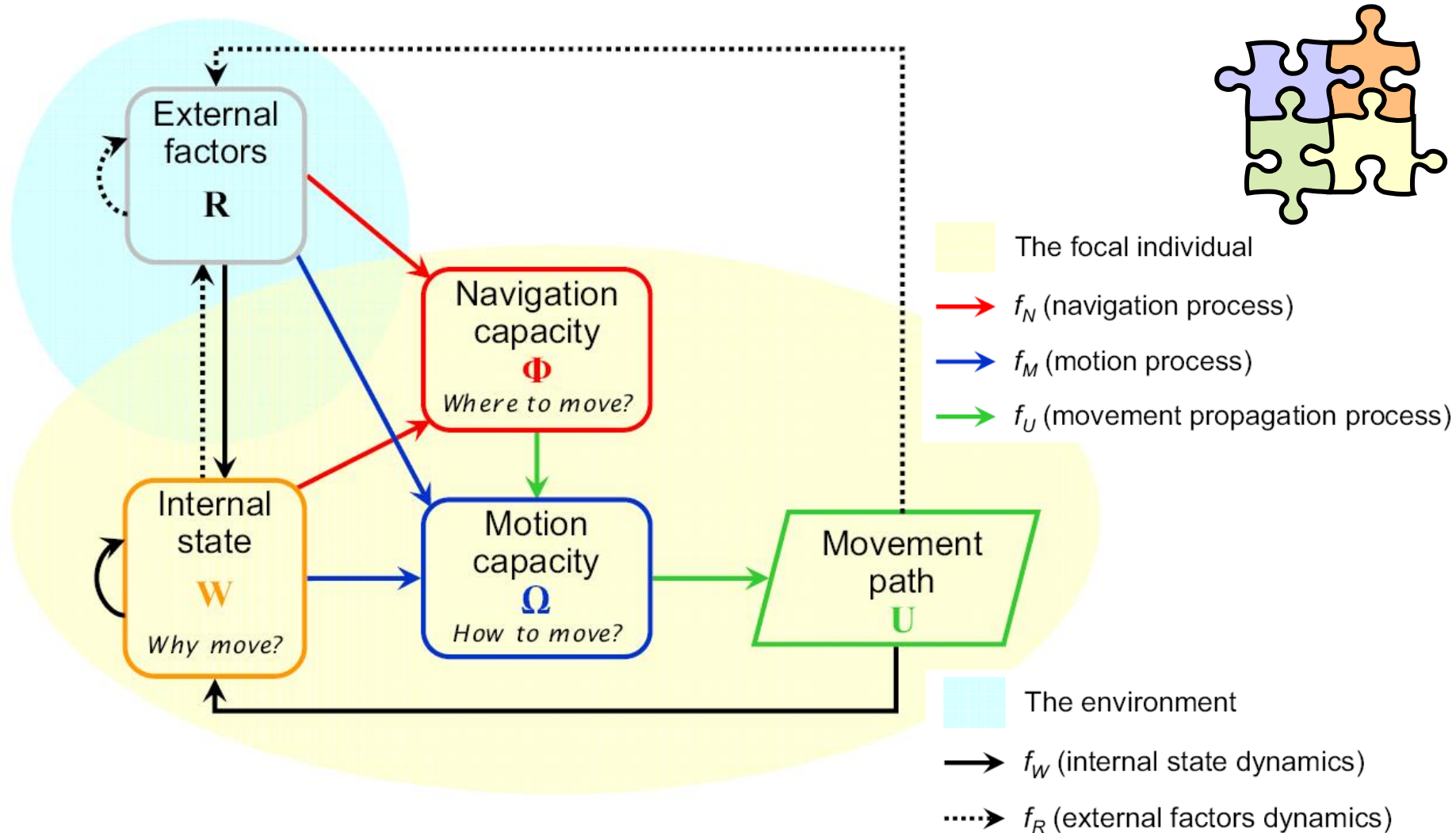
**3. Navigation mechanisms  
(when and where?)**



**4. External factors**

# A movement ecology paradigm for unifying organismal movement research

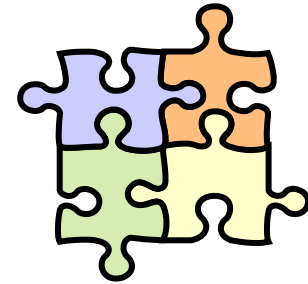
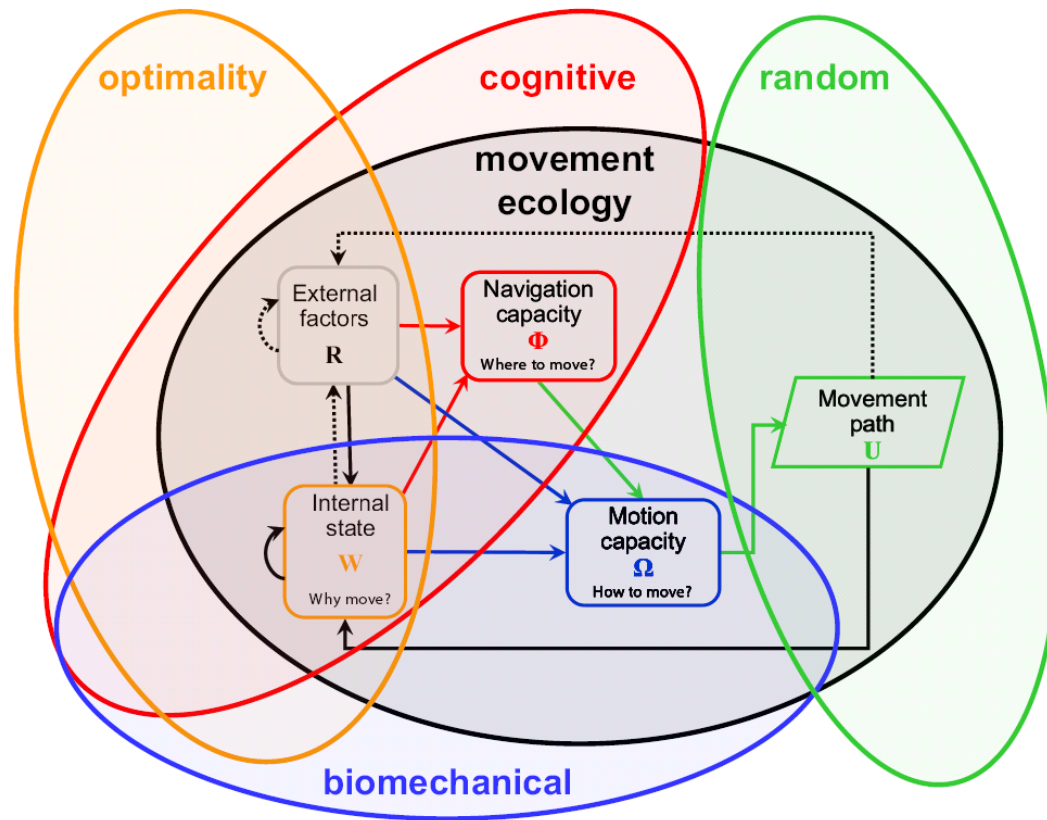
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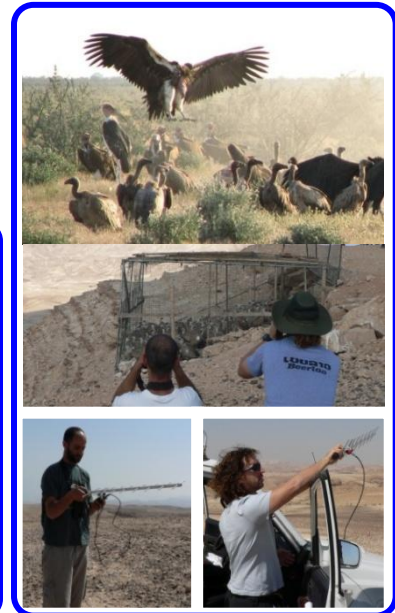
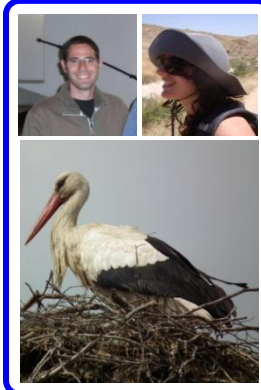
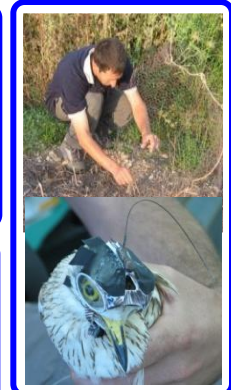
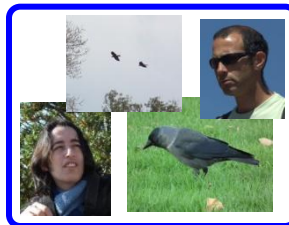
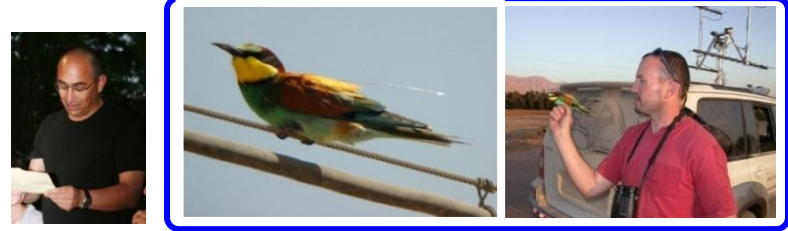
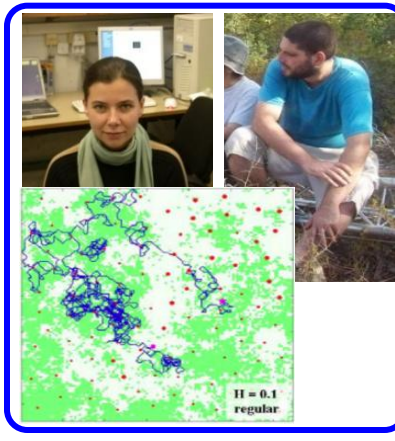
# A movement ecology paradigm for unifying organismal movement research

Ran Nathan<sup>a,1</sup>, Wayne M. Getz<sup>b</sup>, Eloy Revilla<sup>c</sup>, Marcel Holyoak<sup>d</sup>, Ronen Kadmon<sup>a</sup>, David Saltz<sup>e</sup>, and Peter E. Smouse<sup>f</sup>



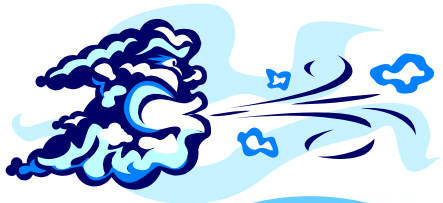
- The focal individual
- $f_N$  (navigation process)
- $f_M$  (motion process)
- $f_U$  (movement propagation process)
  
- The environment
- $f_W$  (internal state dynamics)
- ⋯→  $f_R$  (external factors dynamics)

# Movement research at the

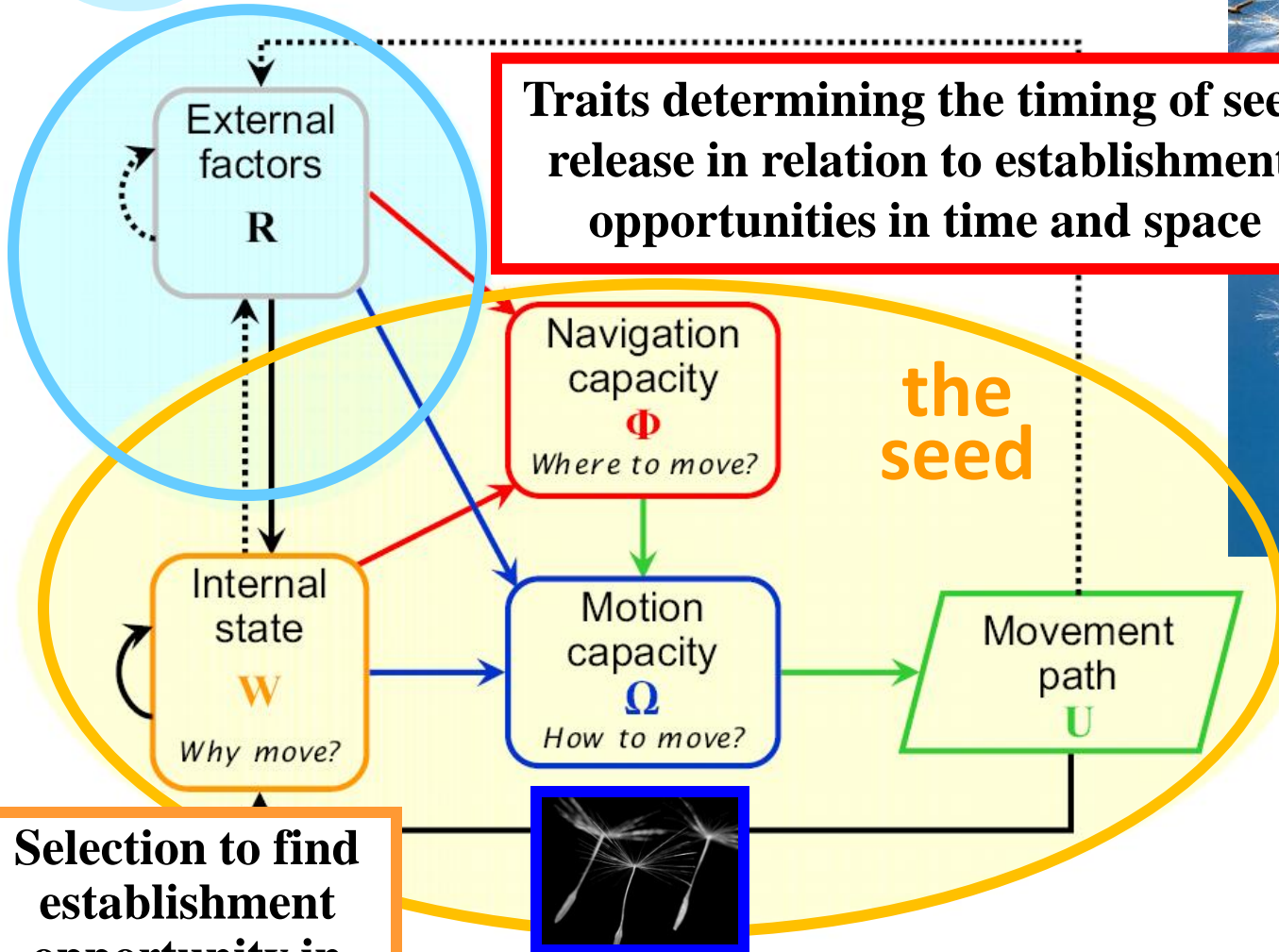




# Seed dispersal by wind



**Traits determining the timing of seed release in relation to establishment opportunities in time and space**



**Selection to find establishment opportunity in time and space**





# Mechanistic models of seed dispersal by wind

**complexity**

**Wald Analytical Long-distance Dispersal model (WALD)**

**Katul et al. 2005 *Am Nat***

$$f_{\text{wald}}(\rho) = \sqrt{\frac{\gamma}{2\pi\rho^3}} \exp\left[-\frac{\gamma(\rho-\mu)^2}{2\mu^2\rho}\right]$$

**Ballistic (WINDISPER)**

**Nathan et al. 2001 *Ecology*, Nathan et al. 2002 *CABI***



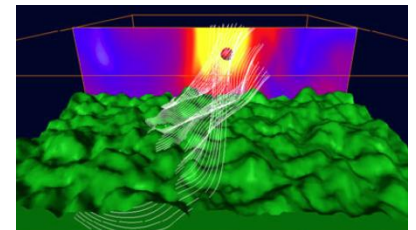
**Coupled Eulerian-Lagrangian Closure Model (CELC)**

**Nathan et al. 2002 *Nature*, Soons et al. 2004 *Ecology*,  
Nathan & Katul 2005 *PNAS*, Wright et al. 2008 *PNAS***



**RAMS-based Forest Large Eddy Simulation (RAFLES)**

**Bohrer et al. 2008 *J Ecol***



# Mechanistic Analytical Models for Long-Distance Seed Dispersal by Wind

G. G. Katul,<sup>1,2,\*</sup> A. Porporato,<sup>2,†</sup> R. Nathan,<sup>3,‡</sup> M. Siqueira,<sup>1,§</sup> M. B. Soons,<sup>4,||</sup> D. Poggi,<sup>1,5,#</sup> H. S. Horn,<sup>6,\*\*</sup> and S. A. Levin<sup>6,††</sup>

$$f_{wald}(\rho) = \sqrt{\frac{\gamma}{2\pi\rho^3}} \exp\left[-\frac{\gamma(\rho - \mu)^2}{2\mu^2\rho}\right]$$

$\rho$  Euclidean distance from the seed source

shape  $\gamma = \frac{\bar{u}(p_r h_t)^2}{2\kappa h_t \sigma_w}$  scale  $\mu = \frac{p_r h_t \bar{u}}{v_t}$

$h_t$  Mean tree height

$p_r$  Proportional height of seed release

$v_t$  Mean seed terminal falling velocity

$\bar{u}$  Mean horizontal windspeed

$\sigma_w$  Standard deviation of vertical wind velocity

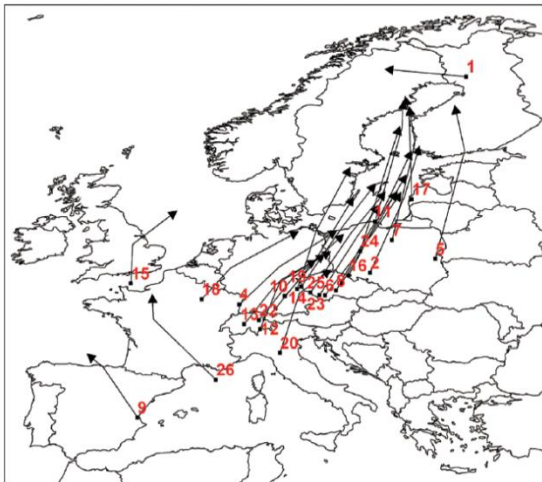
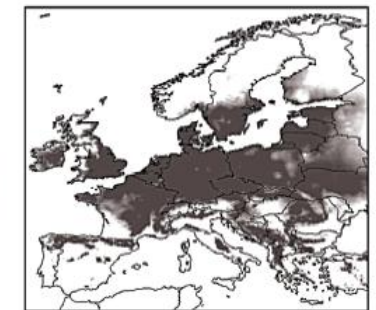
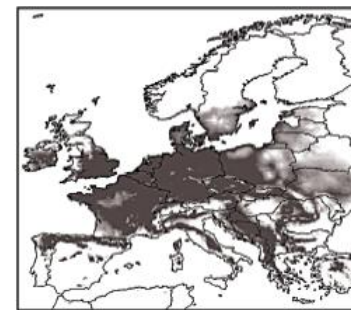
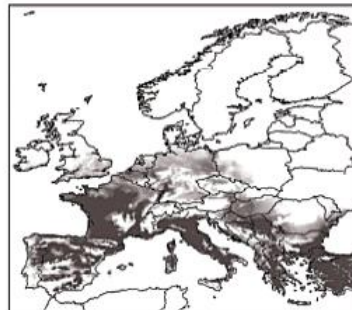
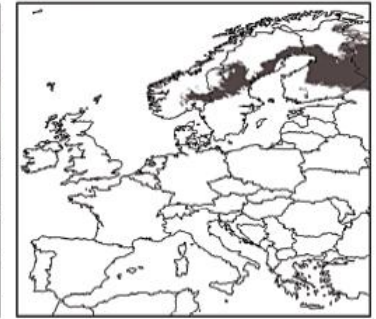
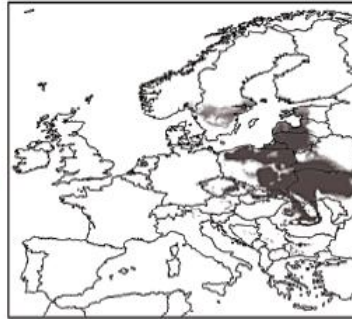
$\kappa$  Turbulence coefficient

# Forecasting plant response to climatic changes

Atlas Flora Europaea

Suitable climate 2000

Suitable climate B1 **2100** Suitable climate A2



**Required minimum spread rate for tracking the potential range shift:**

**B1 scenario: 2.1 km/year**

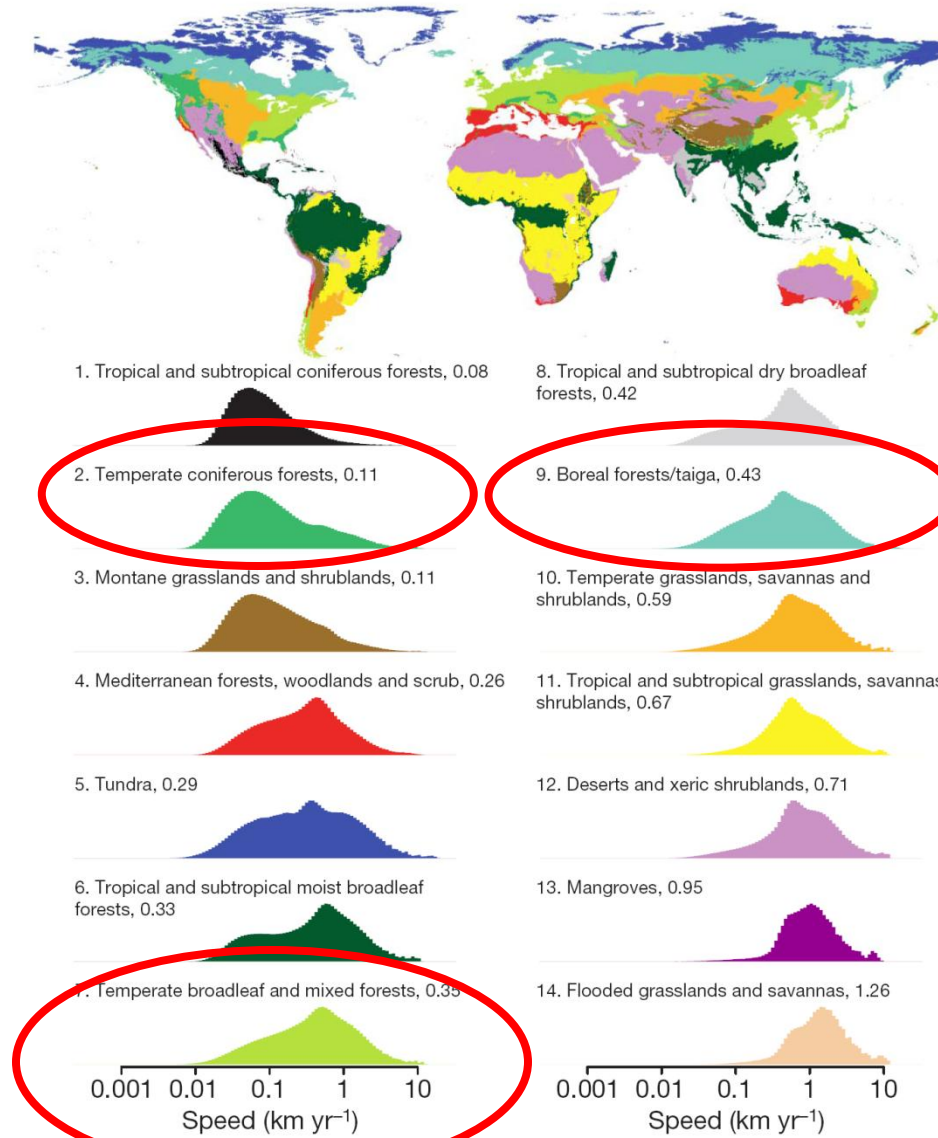
**A2 scenario: 3.9 km/year**

From: Skov & Svenning (2004), *Ecography*



# The velocity of climate change

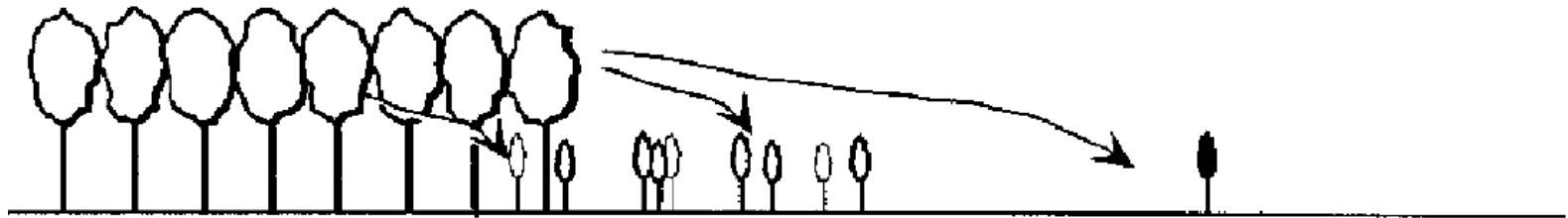
Scott R. Loarie<sup>1</sup>, Philip B. Duffy<sup>1,2</sup>, Healy Hamilton<sup>3</sup>, Gregory P. Asner<sup>1</sup>, Christopher B. Field<sup>1</sup> & David D. Ackerly<sup>4</sup>



# Invasion by Extremes: Population Spread with Variation in Dispersal and Reproduction

James S. Clark,<sup>1,\*</sup> Mark Lewis,<sup>2</sup> and Lajos Horvath<sup>2</sup>

A) Initial expansion from a population frontier ...

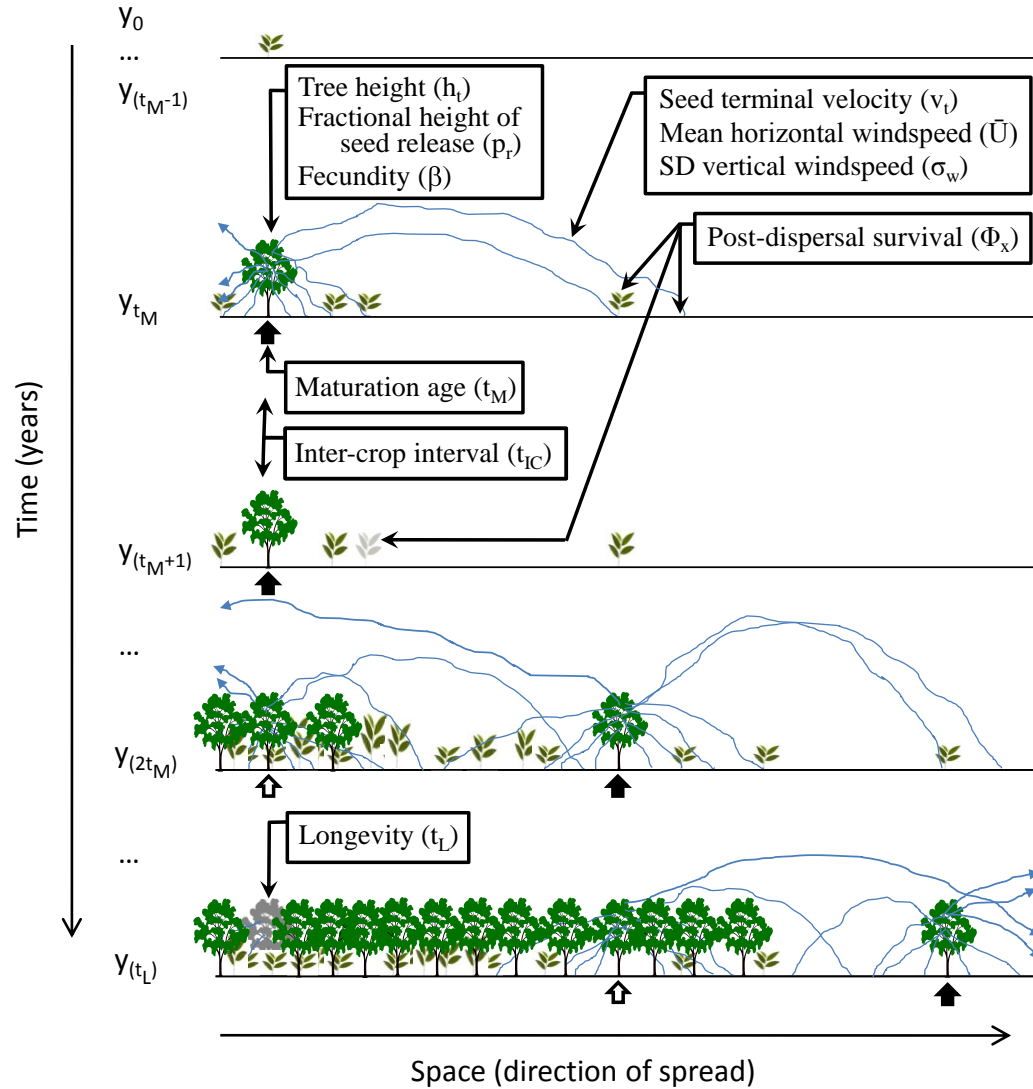


B) ... and spread by extremes



# Spread of North American wind-dispersed trees in future environments

Ran Nathan,<sup>1\*</sup> Nir Horvitz,<sup>1</sup>  
Yanping He,<sup>2</sup> Anna Kuparinen,<sup>3</sup>  
Frank M. Schurr<sup>4</sup> and Gabriel G. Katul<sup>5</sup>





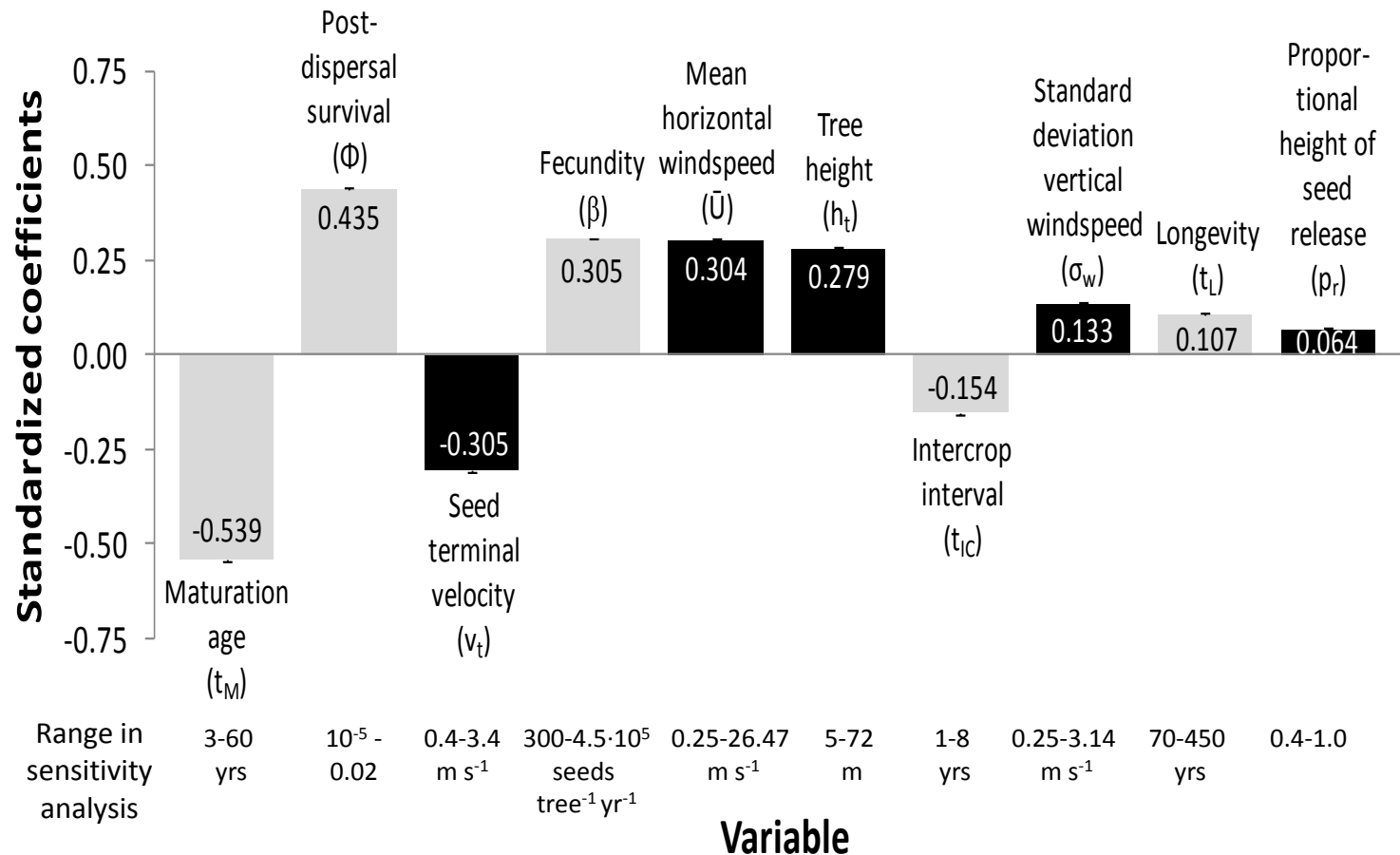
# Spread of North American wind-dispersed trees in future environments

Ran Nathan,<sup>1\*</sup> Nir Horvitz,<sup>1</sup>

Yanping He,<sup>2</sup> Anna Kuparinen,<sup>3</sup>

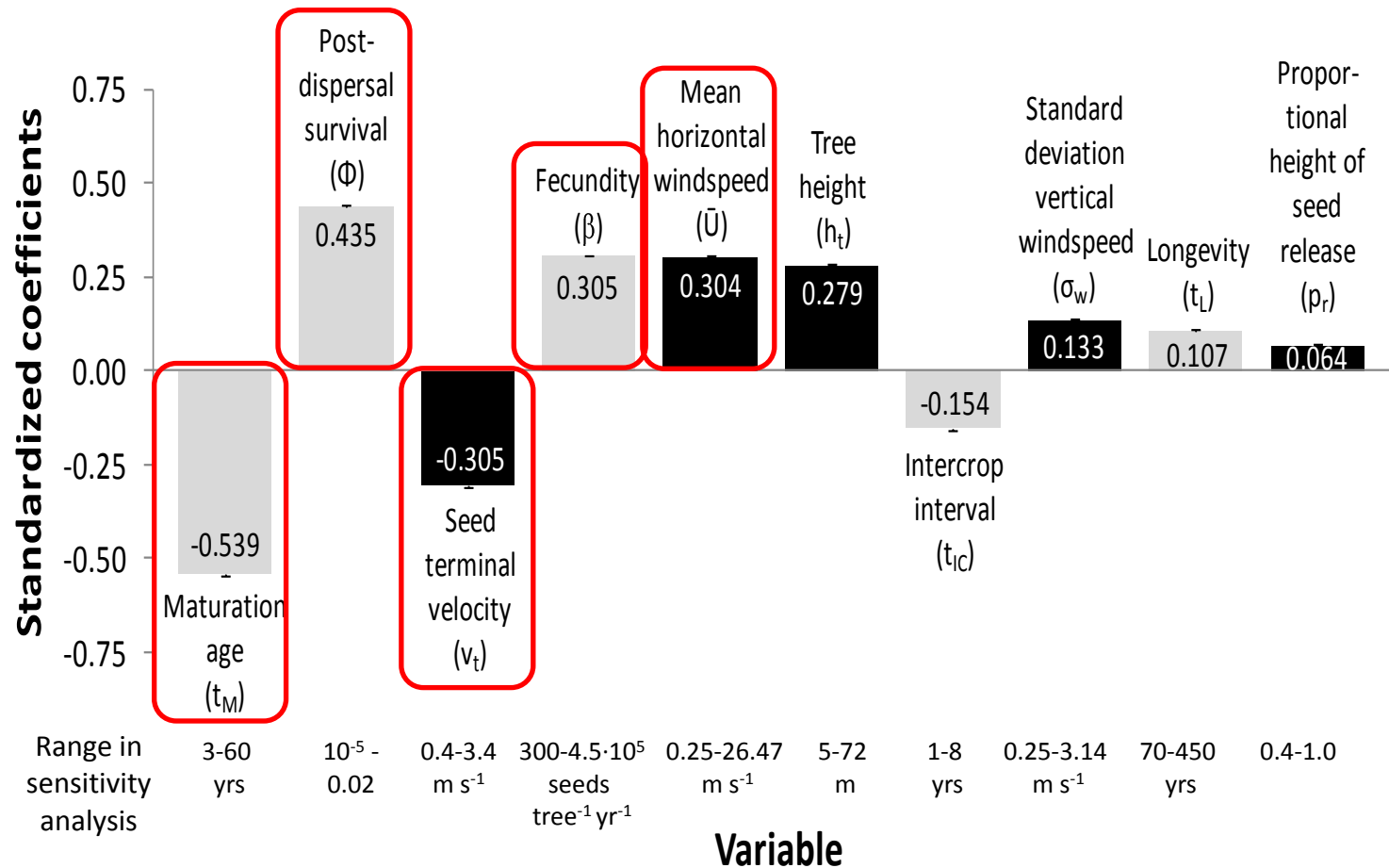
Frank M. Schurr<sup>4</sup> and Gabriel G.

Katul<sup>5</sup>



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Frank M. Schurr<sup>4</sup> and Gabriel G.  
Katul<sup>5</sup>

## Features of future (~2060) environments:

*Global Change Biology* (2006) **12**, 822–833, doi: 10.1111/j.1365-2486.2006.01137.x

Elevated CO<sub>2</sub> and tree fecundity: the role of tree size, interannual variability, and population heterogeneity

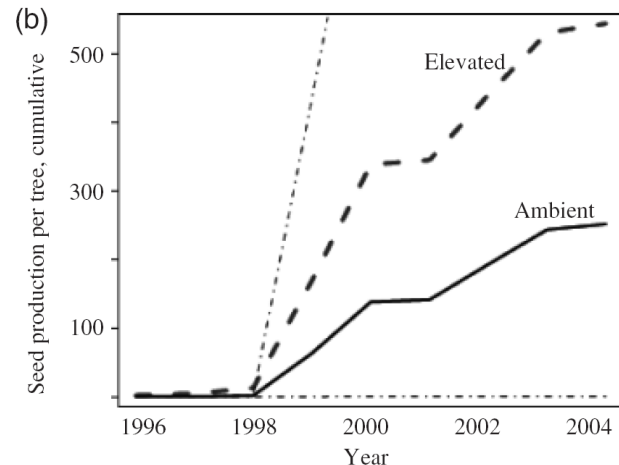
SHANNON L. LADEAU\* and JAMES S. CLARK\*†



**cf. S. Sultan, yesterday**

**FACE experiment at Duke Forest, NC, USA**

### 1. Atmospheric CO<sub>2</sub> enrichment → two-fold increase in fecundity





# Spread of North American wind-dispersed trees in future environments

Ran Nathan,<sup>1\*</sup> Nir Horvitz,<sup>1</sup>  
Yanping He,<sup>2</sup> Anna Kuparinen,<sup>3</sup>  
Frank M. Schurr<sup>4</sup> and Gabriel G.  
Katul<sup>5</sup>

## Features of future (~2060) environments:

*Global Change Biology* (2006) **12**, 822–833, doi: 10.1111/j.1365-2486.2006.01137.x

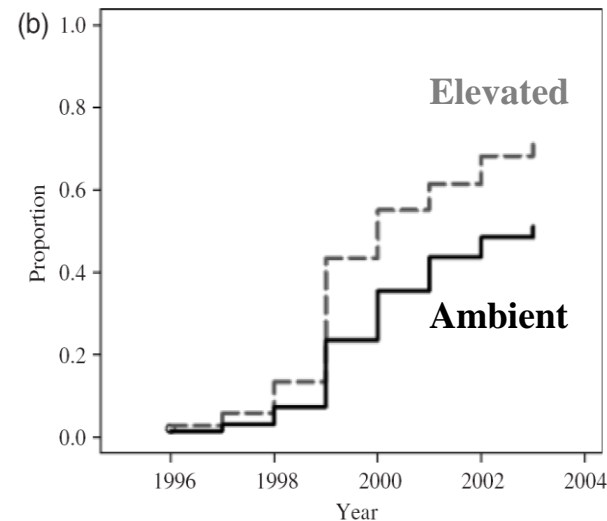
### Elevated CO<sub>2</sub> and tree fecundity: the role of tree size, interannual variability, and population heterogeneity

SHANNON L. LADEAU\* and JAMES S. CLARK\*†



**FACE experiment at Duke Forest, NC, USA**

## 2. Atmospheric CO<sub>2</sub> enrichment → 7% earlier maturation

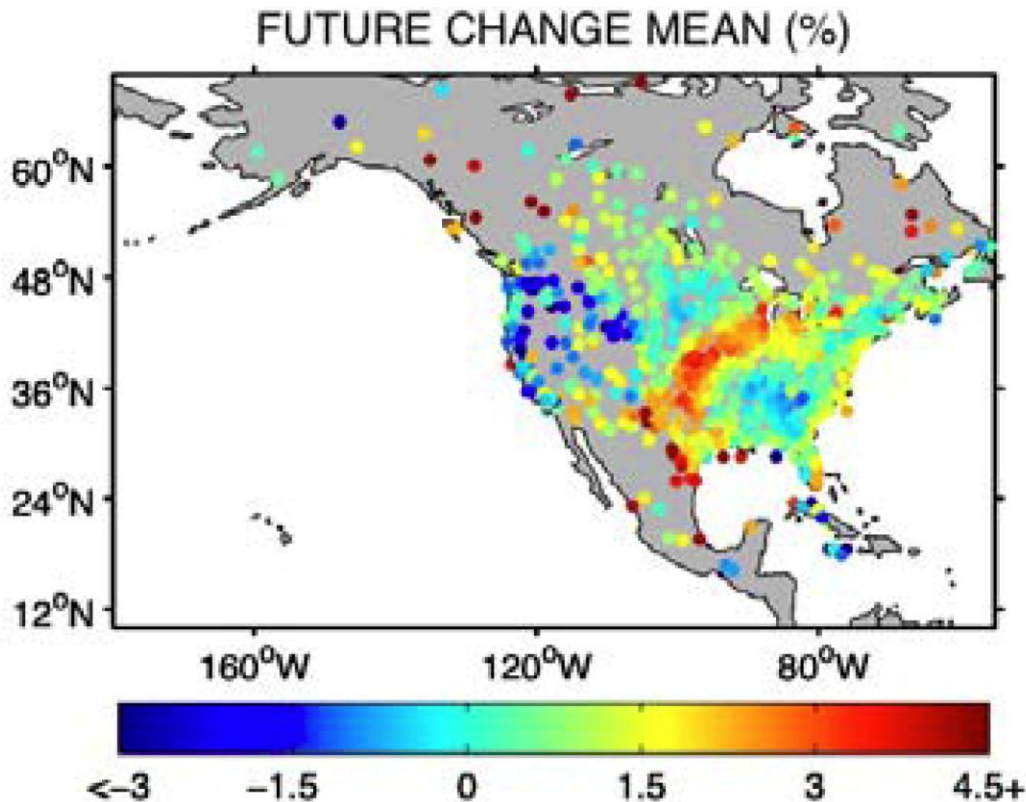


# Spread of North American wind-dispersed trees in future environments

Ran Nathan,<sup>1\*</sup> Nir Horvitz,<sup>1</sup>  
Yanping He,<sup>2</sup> Anna Kuparinen,<sup>3</sup>  
Frank M. Schurr<sup>4</sup> and Gabriel G.  
Katul<sup>5</sup>

## Features of future (~2060) environments:

### 3. Increase or reduction in surface windspeed



**Proportional change in  
mean surface windspeed**

**Canadian Regional Climate  
Model version 4 driven by  
the third generation  
Canadian Global  
Circulation Model under  
the A2 emissions scenario**





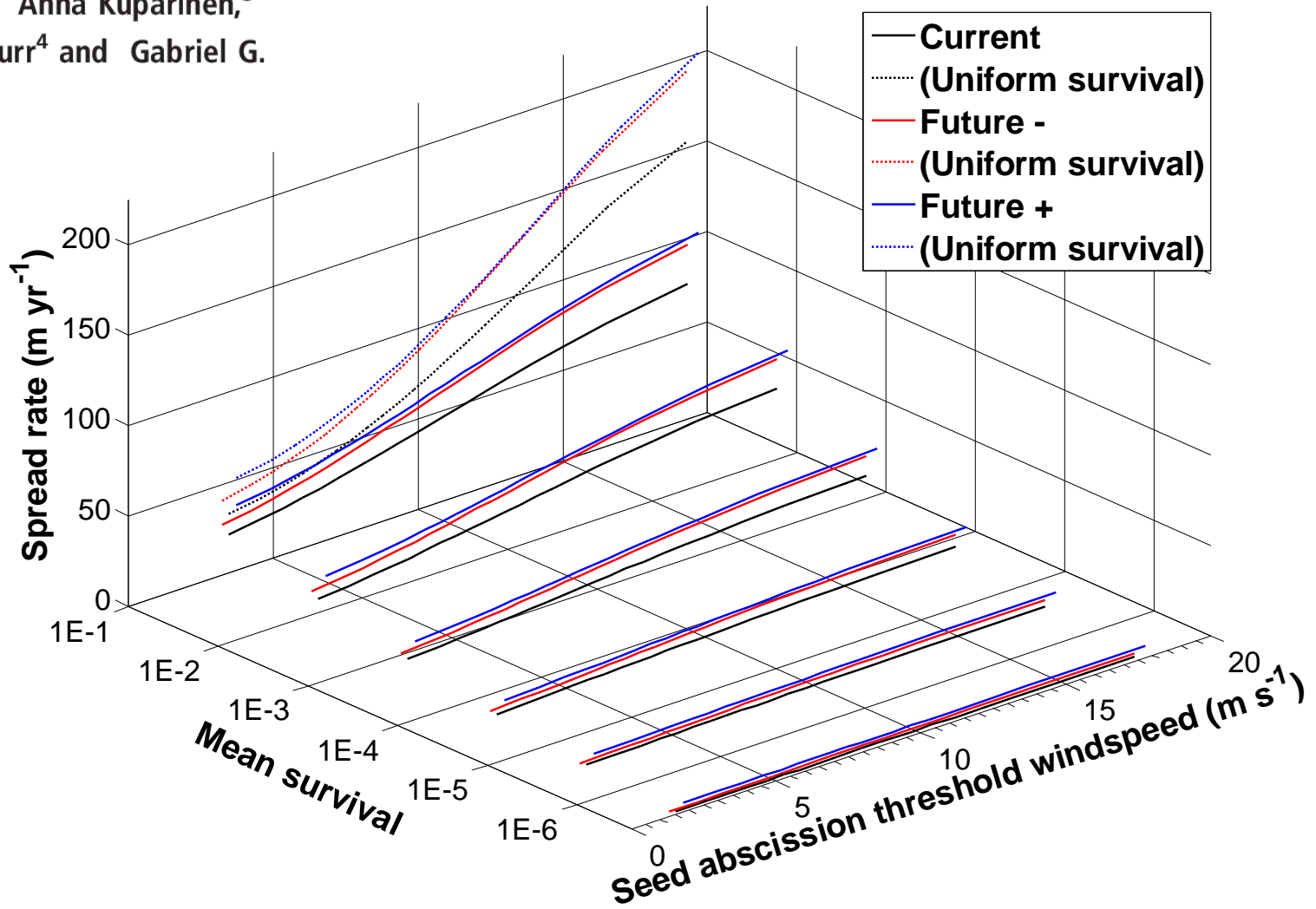
# Spread of North American wind-dispersed trees in future environments

Ran Nathan,<sup>1\*</sup> Nir Horvitz,<sup>1</sup>

Yanping He,<sup>2</sup> Anna Kuparinen,<sup>3</sup>

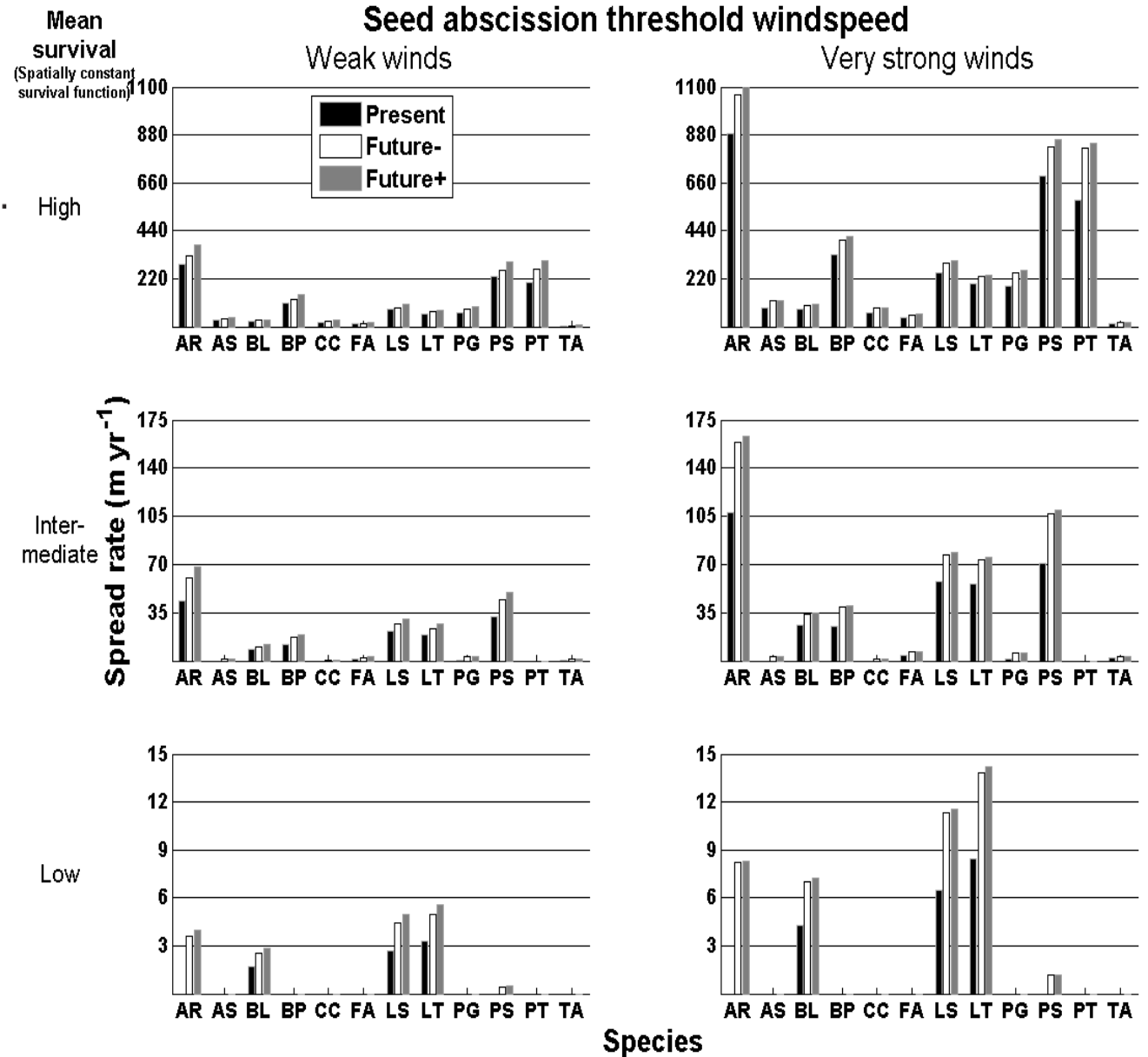
Frank M. Schurr<sup>4</sup> and Gabriel G.

Katul<sup>5</sup>



# Spread of North American wind-dispersed trees in future environments

Ran Nathan,<sup>1\*</sup> Nir Horvitz,<sup>1</sup>  
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 Frank M. Schurr<sup>4</sup> and Gabriel G. Katul<sup>5</sup>



*Acer rubrum*



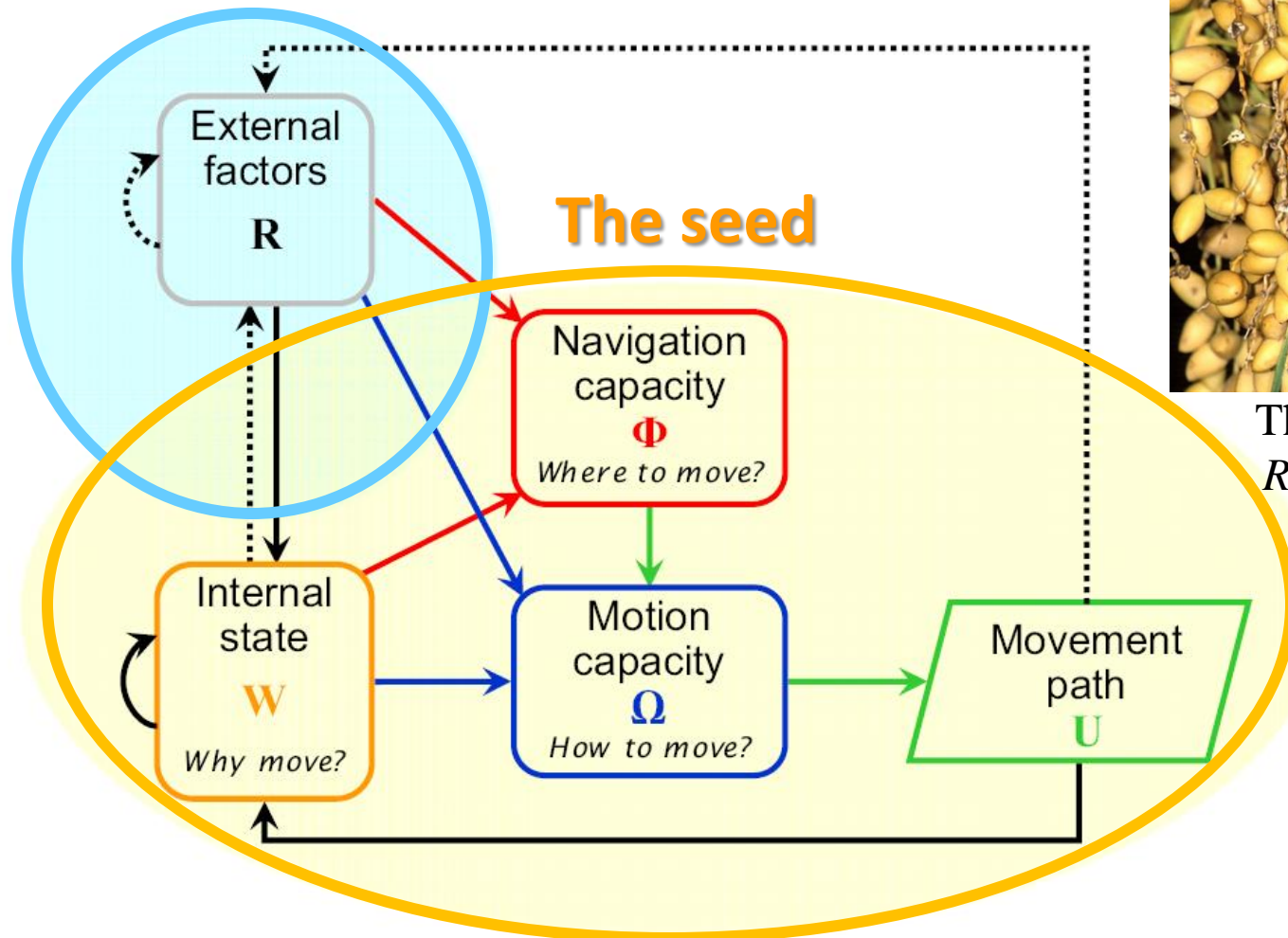


# Movements of bats and their role in seed dispersal

Asaf Tsoar

with Nachum Ulanovsky, Weizmann Inst

## The bat



© Amram Tsabari

The Egyptian Fruit Bat  
*Rousettus aegyptiacus*



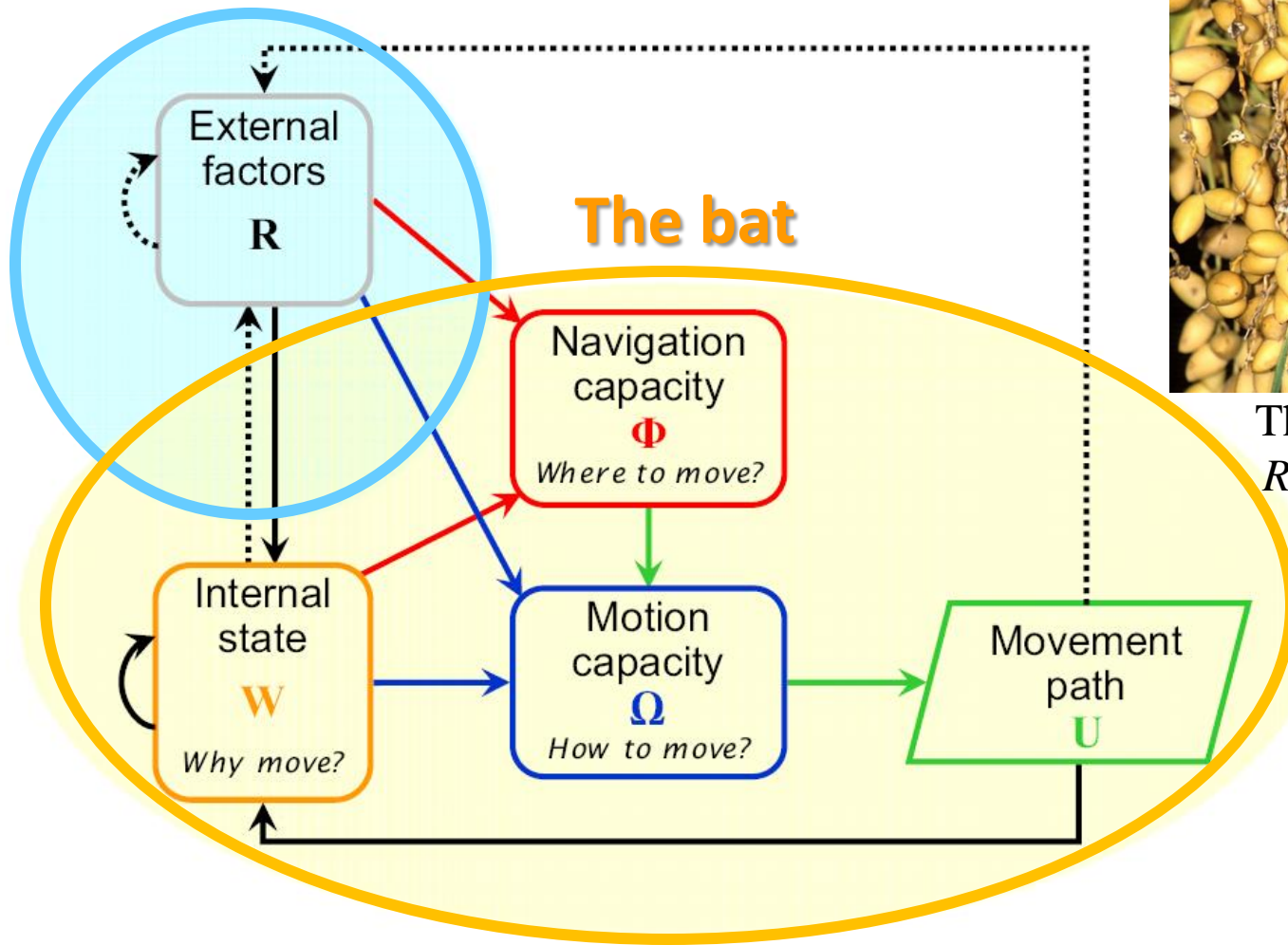
© Fenton

# Movements of bats and their role in seed dispersal

Asaf Tsoar

with Nachum Ulanovsky, Weizmann Inst

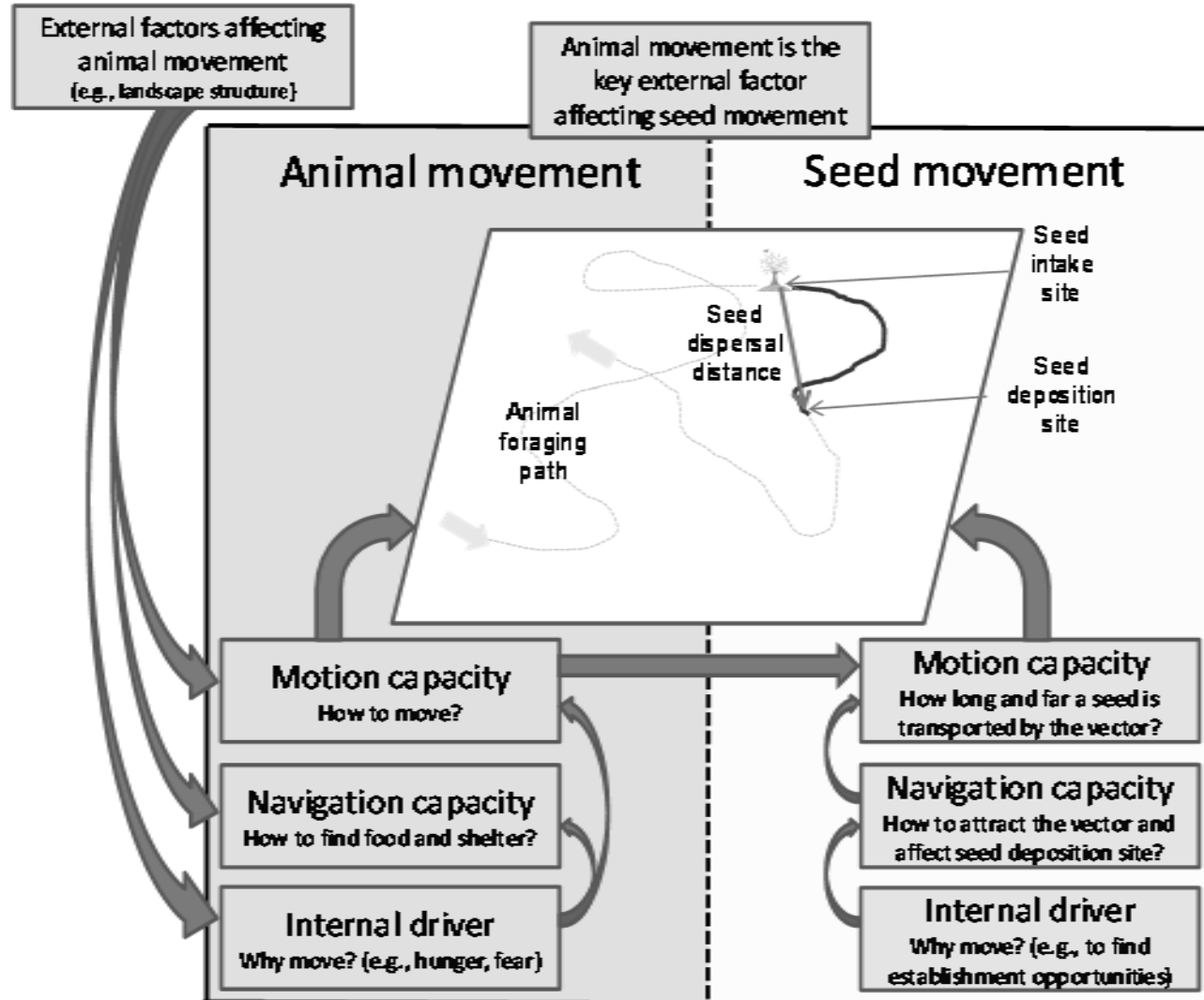
Fruits and trees



The Egyptian Fruit Bat  
*Rousettus aegyptiacus*



# A movement ecology twofold nested design for animal-dispersed plants



Tsoar et al. (2011) In: Fifty years of invasion ecology: the legacy of Charles Elton



# Large-scale navigational map in a mammal

Asaf Tsoar<sup>a,1,2</sup>, Ran Nathan<sup>a,2,3</sup>, Yoav Bartan<sup>a</sup>, Alexei Vyssotski<sup>b</sup>, Giacomo Dell’Omo<sup>c</sup>, and Nachum Ulanovsky<sup>d,2,3</sup>

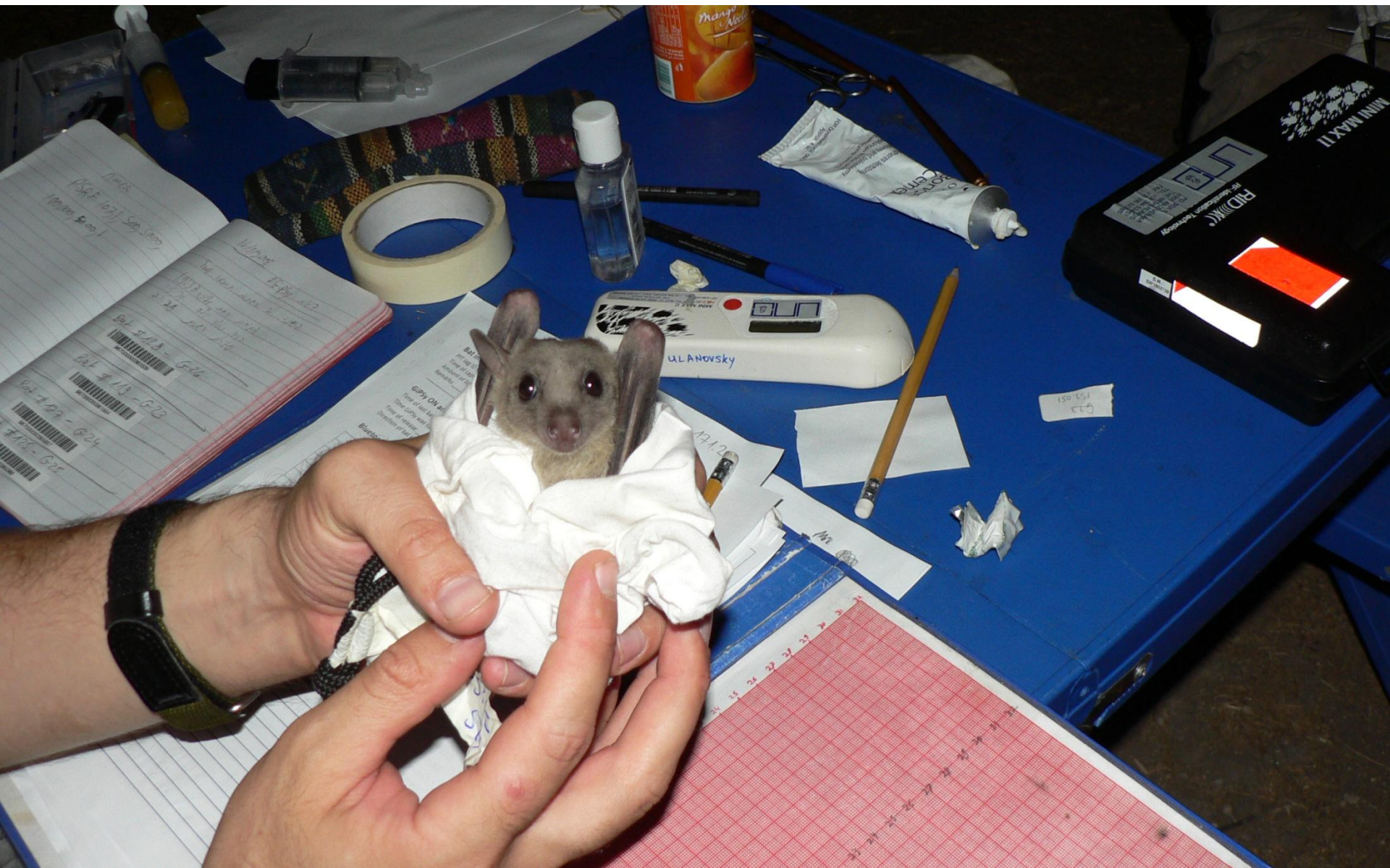
**Asaf Tsoar**





# Large-scale navigational map in a mammal

Asaf Tsoar<sup>a,1,2</sup>, Ran Nathan<sup>a,2,3</sup>, Yoav Bartan<sup>a</sup>, Alexei Vyssotski<sup>b</sup>, Giacomo Dell’Omo<sup>c</sup>, and Nachum Ulanovsky<sup>d,2,3</sup>





# Large-scale navigational map in a mammal

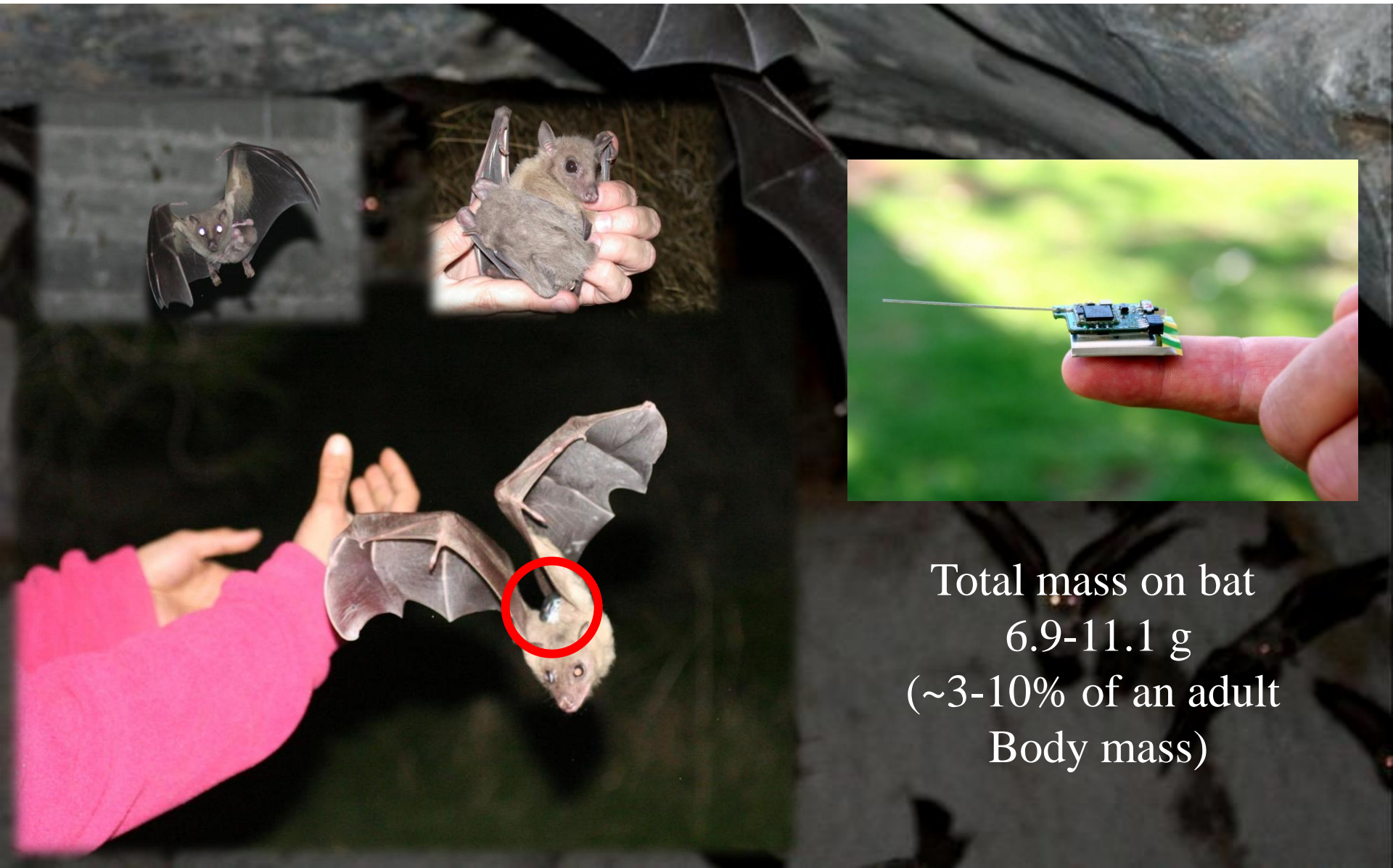
Asaf Tsoar<sup>a,1,2</sup>, Ran Nathan<sup>a,2,3</sup>, Yoav Bartan<sup>a</sup>, Alexei Vyssotski<sup>b</sup>, Giacomo Dell’Omo<sup>c</sup>, and Nachum Ulanovsky<sup>d,2,3</sup>





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Asaf Tsoar<sup>a,1,2</sup>, Ran Nathan<sup>a,2,3</sup>, Yoav Bartan<sup>a</sup>, Alexei Vyssotski<sup>b</sup>, Giacomo Dell’Omo<sup>c</sup>, and Nachum Ulanovsky<sup>d,2,3</sup>



Total mass on bat  
6.9-11.1 g  
(~3-10% of an adult  
Body mass)

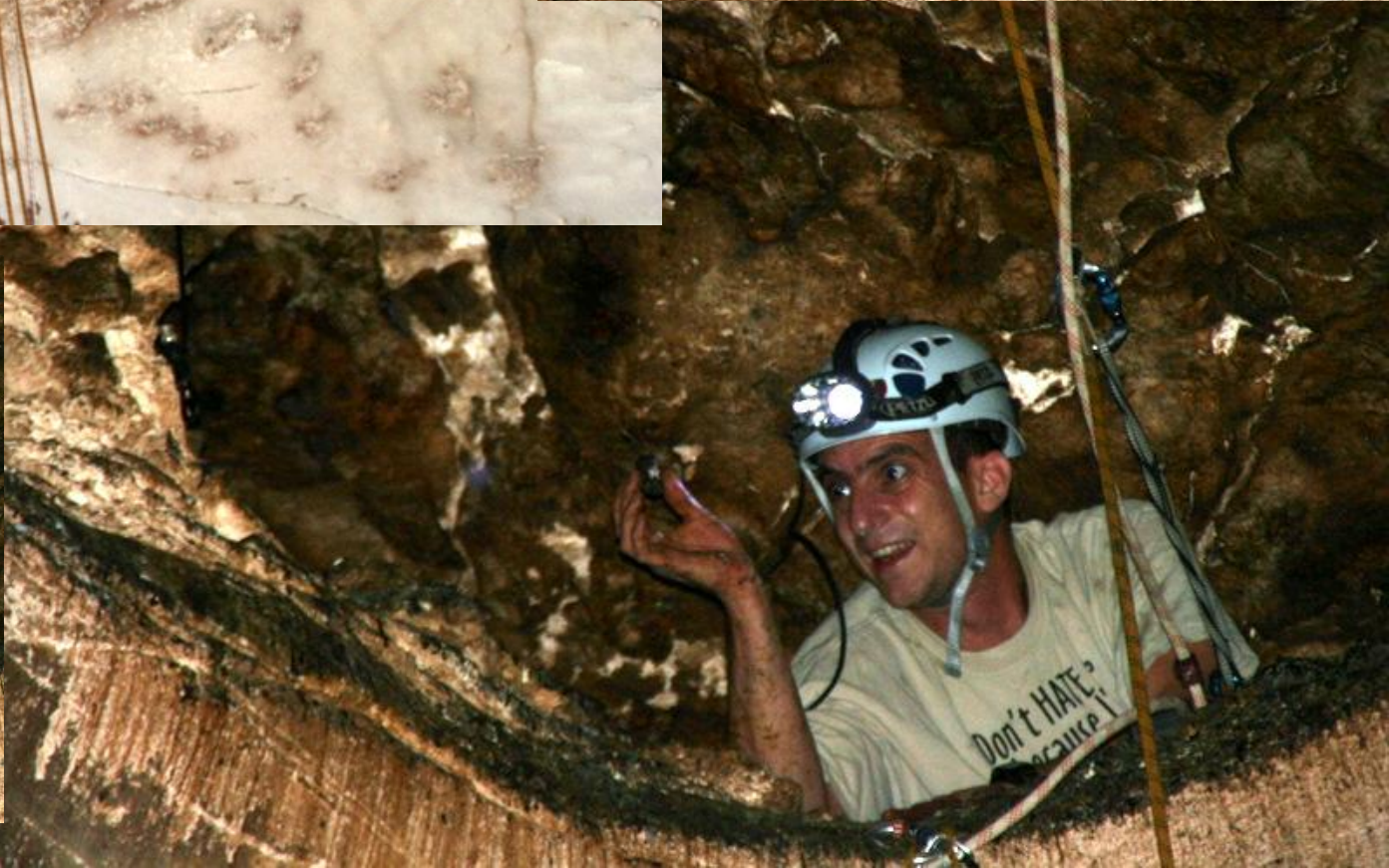














# Commuting flight of bat 079, 21 May 2008





Sgafim roost Morus nigra

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image © 2009 DigitalGlobe  
© 2009 Cnes/Spot Image  
Image © 2009 TerraMetrics

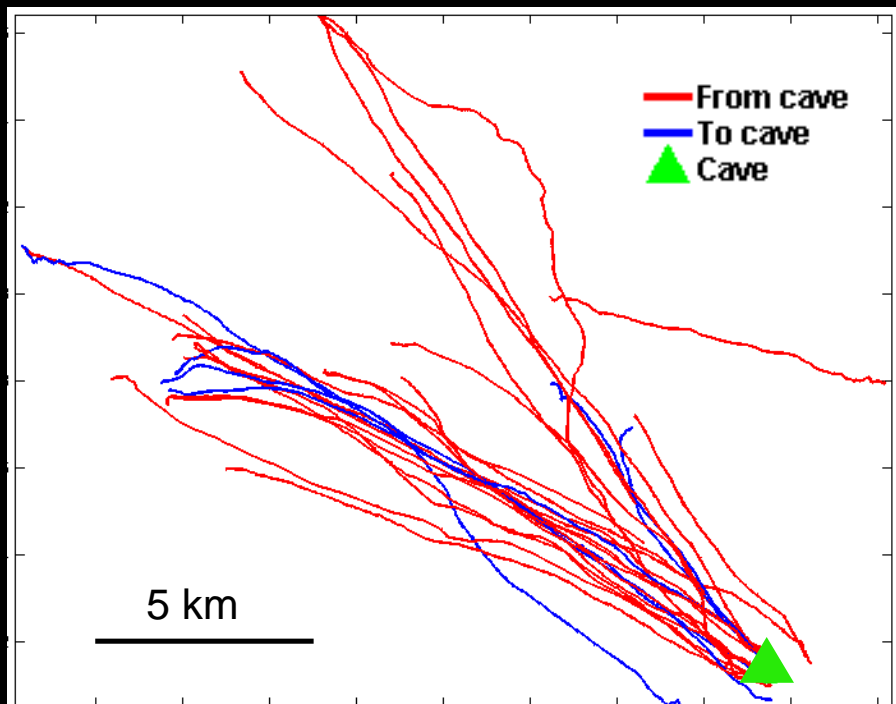
© 2009



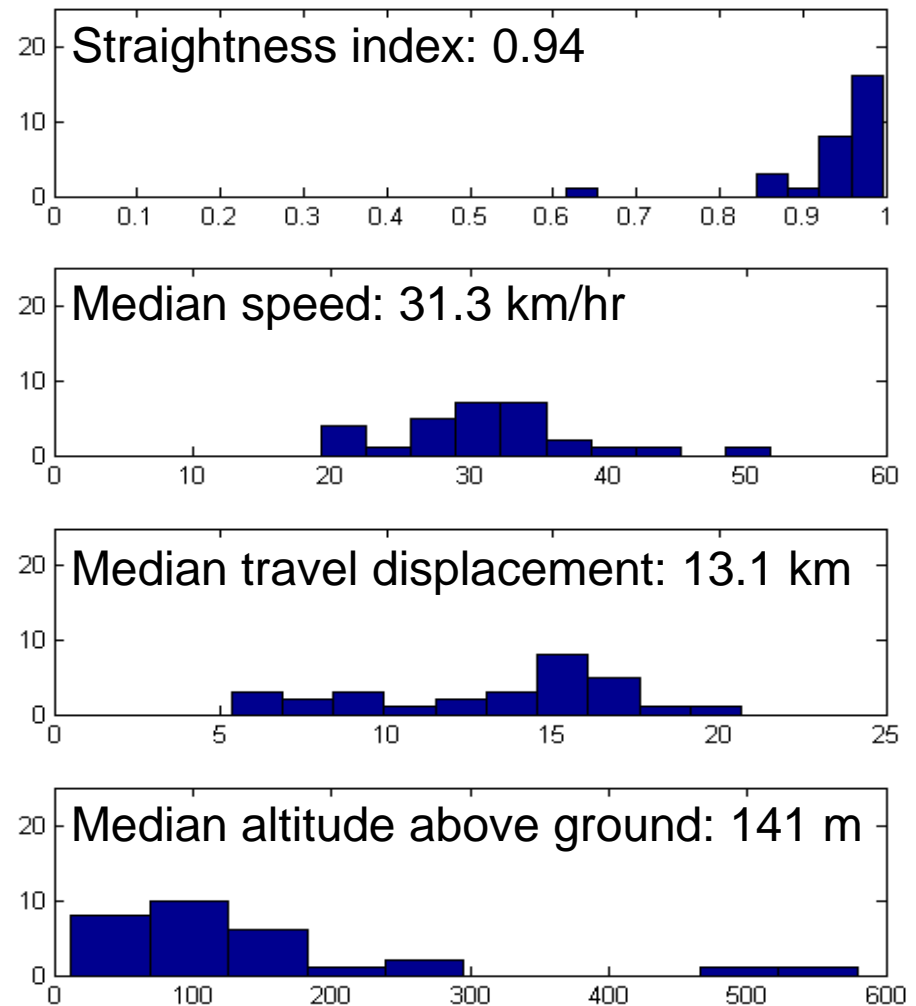
Commuting flight was observed in 95.8% of all foraging bats

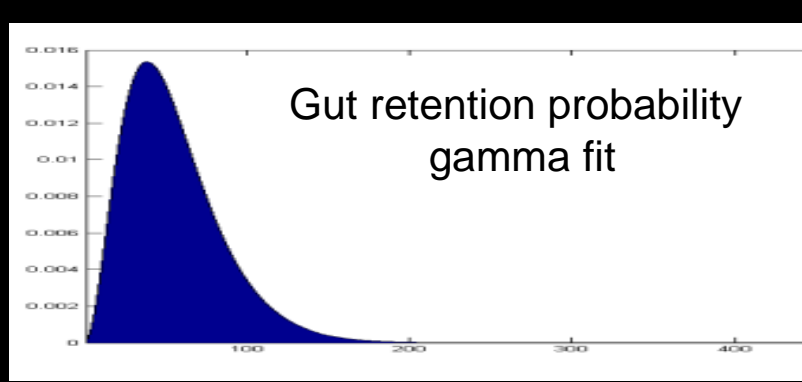


### Synopsis of commuting flights

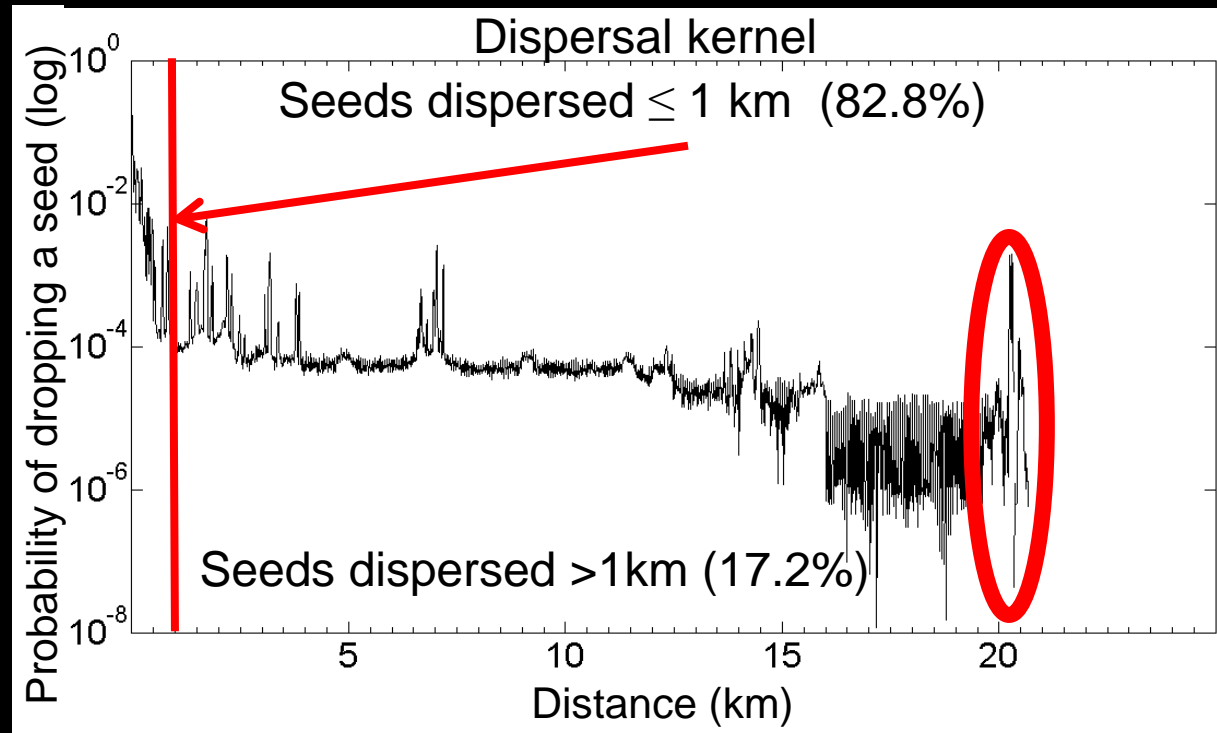
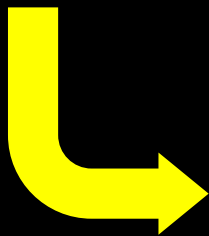
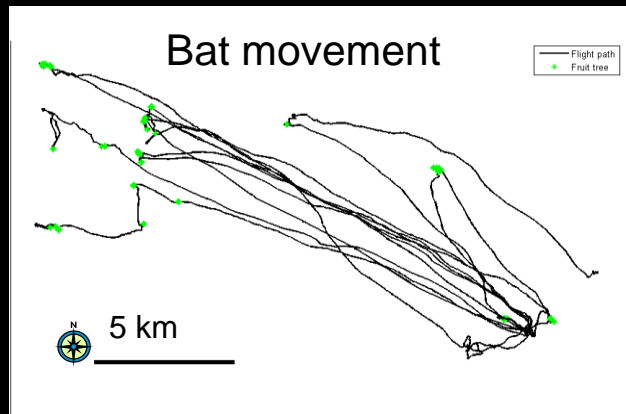


### Statistics of commuting flights

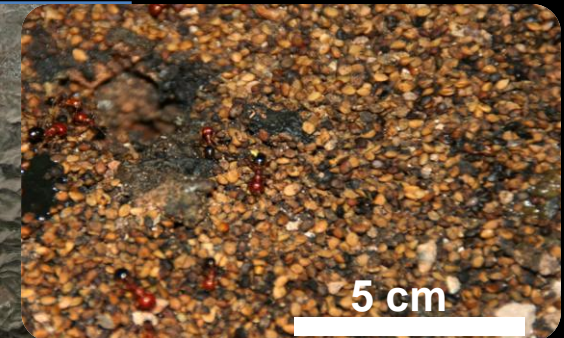
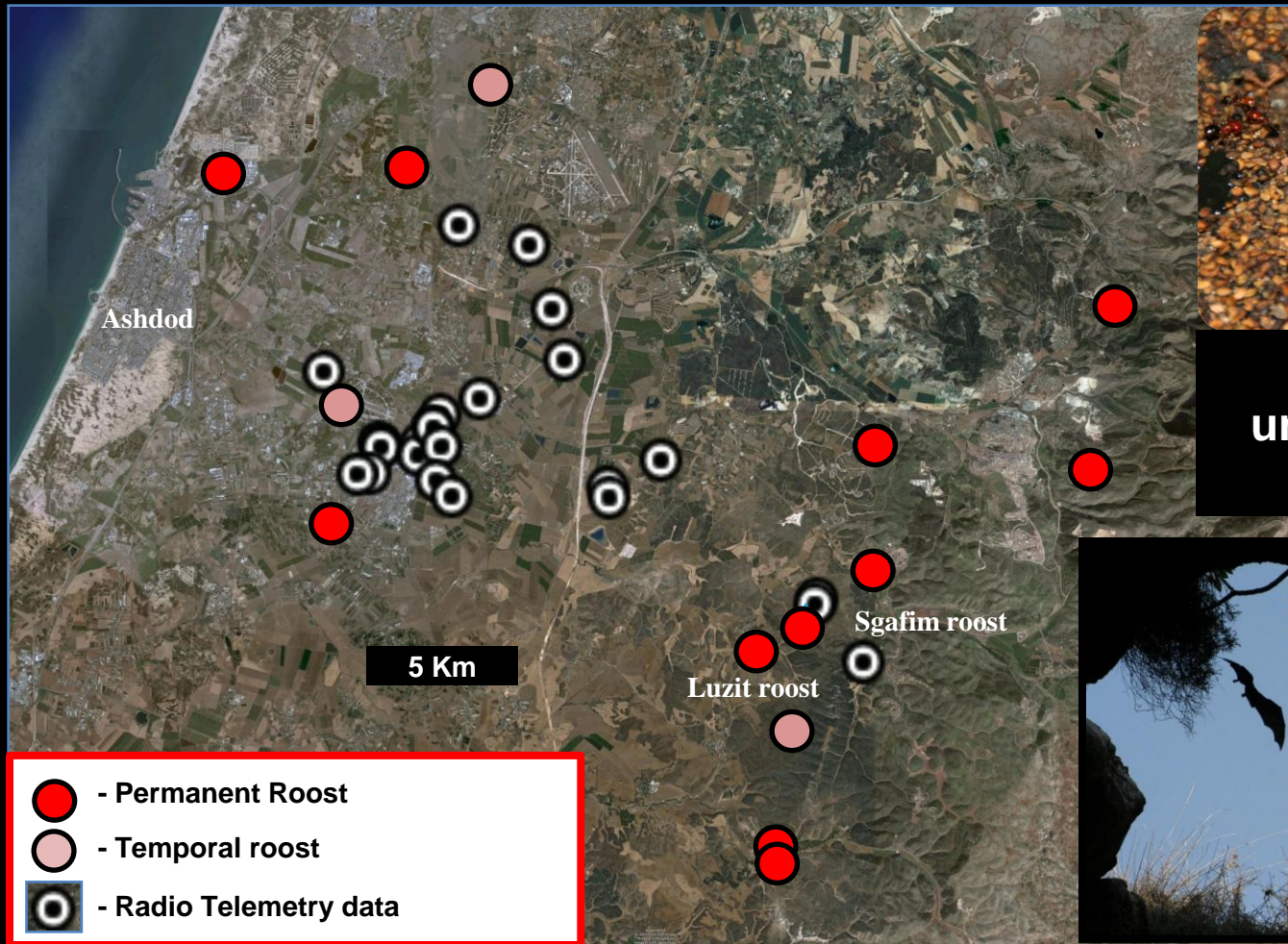




**X**



# Bat roosts (colonies) at Britain Park, Judean lowlands, ISRAEL



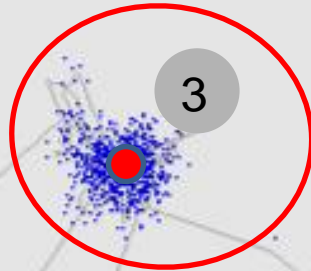
*Morus* seeds  
under a bat colony  
within a cave



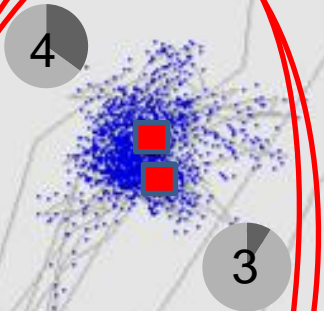


# Overlapping seed shadow

Seeds from many trees are also deposited near non-fruiting trees



Most seeds deposited near the canopy of a fruit tree are from other fruit trees



Seeds from many trees are deposited near the canopy of each fruit tree



50 meters

## Legend

● Non fruiting tree

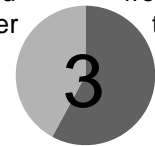
■ Fruiting tree

■ Seed deposition site

~ Bat flight path

Seeds originated from other trees

Seeds from this tree



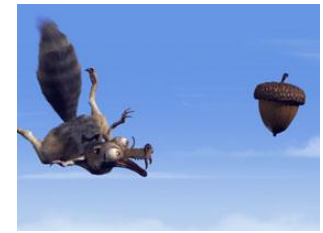
Number of different trees contributing to the seed rain

Mean number of trees visited by a bat per night:

4.8 2.4



# Thanks!



- *The Institute for Advanced Studies, HUIJ, Jerusalem*
- *Movement Ecology Lab members*

Na'ama Aljadeff, Ofir Altstein, Inbal Arieli, Tal Avgar, Yoav Bartan, Luba Broitman, Alejandro Centeno-Cuadros, Ron Chen, Anael Engel, Sondra Feldman, Itamar Giladi, Roi Harel, Nir Horvitz, Niva Lechtman, Yoav Motro, Yotam Orchan, Sasha Pekarsky, Shay Rotics, Nir Sapir, Itai Shanni, David Shohami, Orr Spiegel, Ofer Steinitz, Ana Trakhtenbrot, David Troupin, Asaf Tsoar and Moshe Zagury

- *Movement Ecology IAS Group members and guests*

Wayne Getz, Marcel Holyoak, Ronen Kadmon, Eloy Revilla, David Saltz and Peter Smouse

- *Other key collaborators*

Julio Blas, Katrin Böhning-Gaese, Gil Bohrer, Yvonne Buckley, Renato Casagrandi, Neal Enright, Ohad Hatzofe, Florian Jeltsch, Gaby Katul, Simon Levin, Helene Muller-Landau, Gidi Ne'eman, Frank Schurr, Merel Soons, Nachum Ulanovsky, Martin Wikelski & Joe Wright

*Grants: BSF, DIP, GIF, ISF, Minerva & US-NSF*

- *...and thank you for your attention*





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-  Climate and environmental changes
-  Conservation and invasion biology
-  Population genetics and evolutionary biology
-  Theoretical and mathematical ecology
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