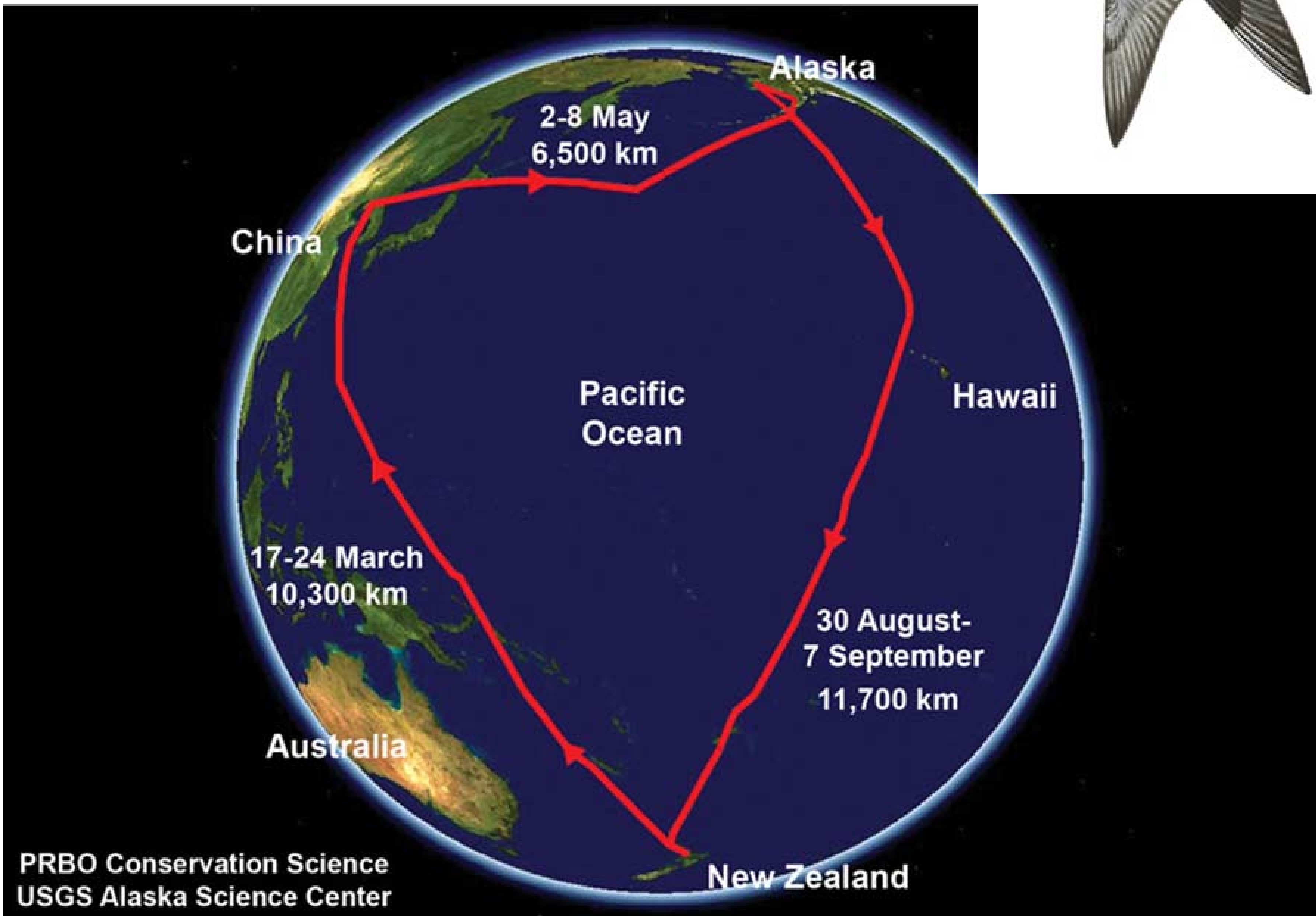
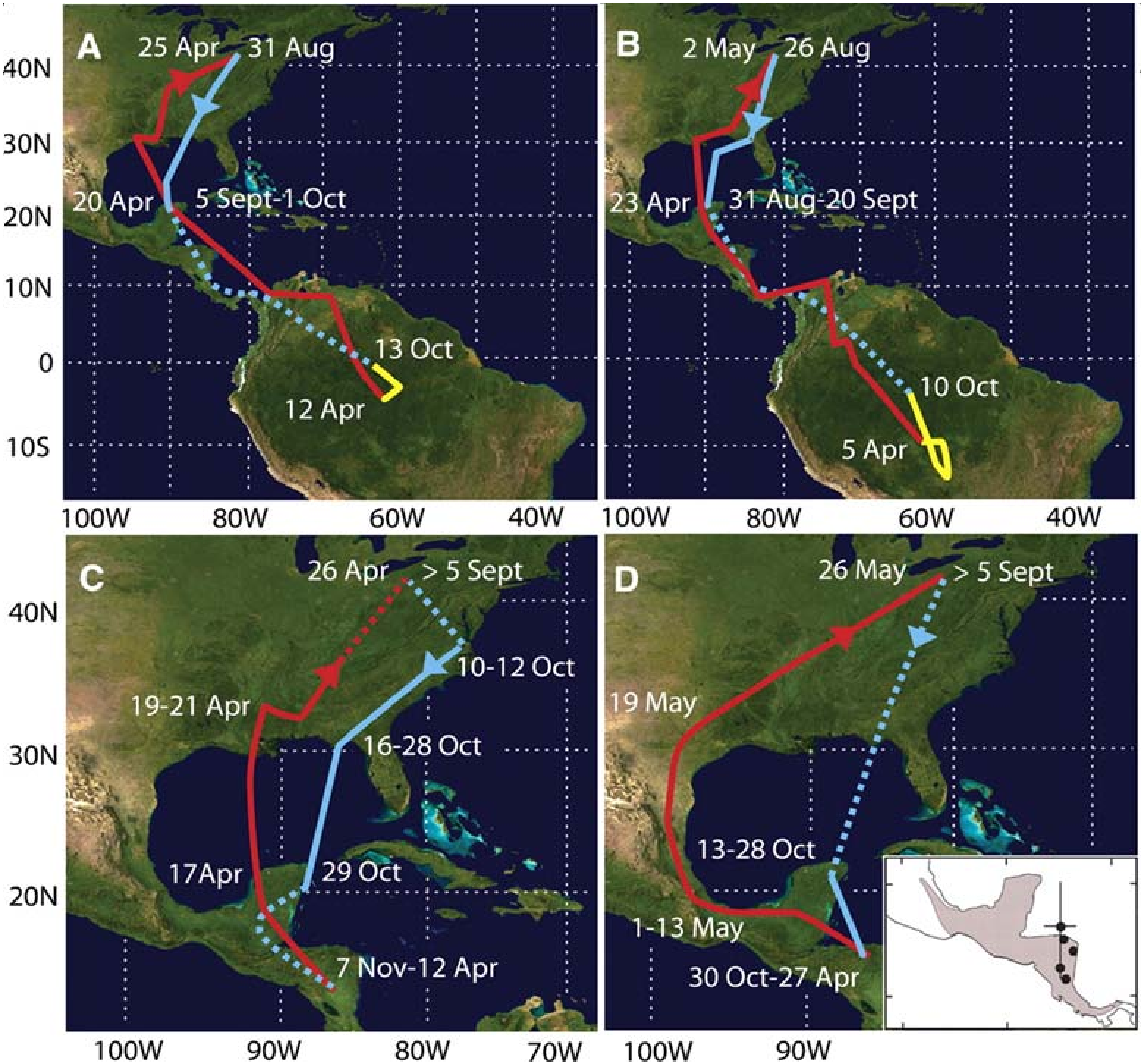
MIGRATION:

A life history event of many organisms, and one of the most fascinating and dramatic of all animal behaviors

- MIGRATE is a network of scientists pursuing an integrated understanding of animal migration.
- The MIGRATE network brings together specialists in multiple disparate approaches to the study of animal migration to foster cross-disciplinary advances in the accuracy and precision with which long-distance movement data can be collected and analyzed.
- MIGRATE is a question drive network *vis-à-vis* our need to advance animal tracking technology.

Bar-tailed Godwit: E7

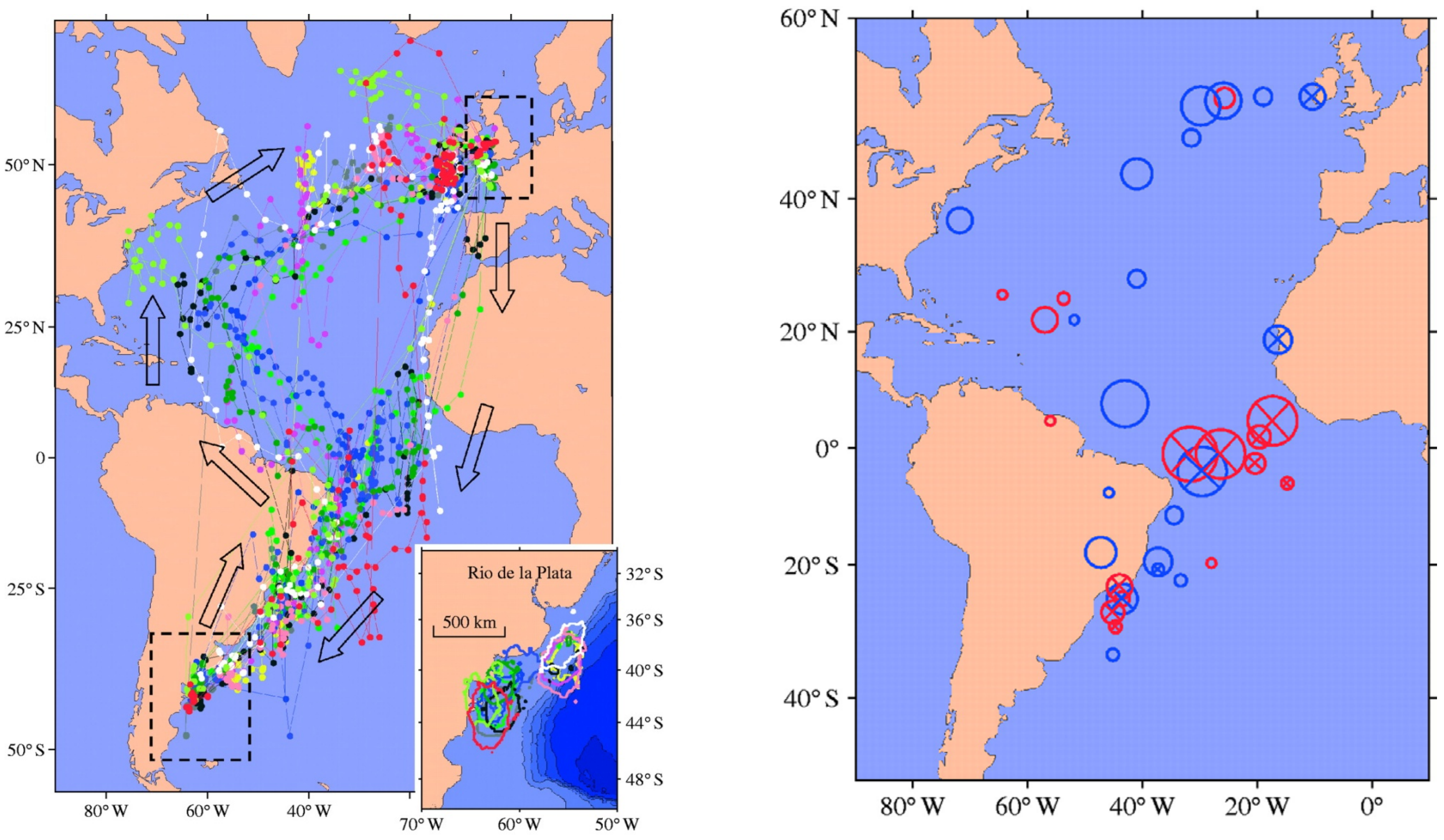




Geolocators track migration: PUMA (A,B) WOTH (C,D) Blue: fall migration. Yellow: winter movement. Red: spring migration.

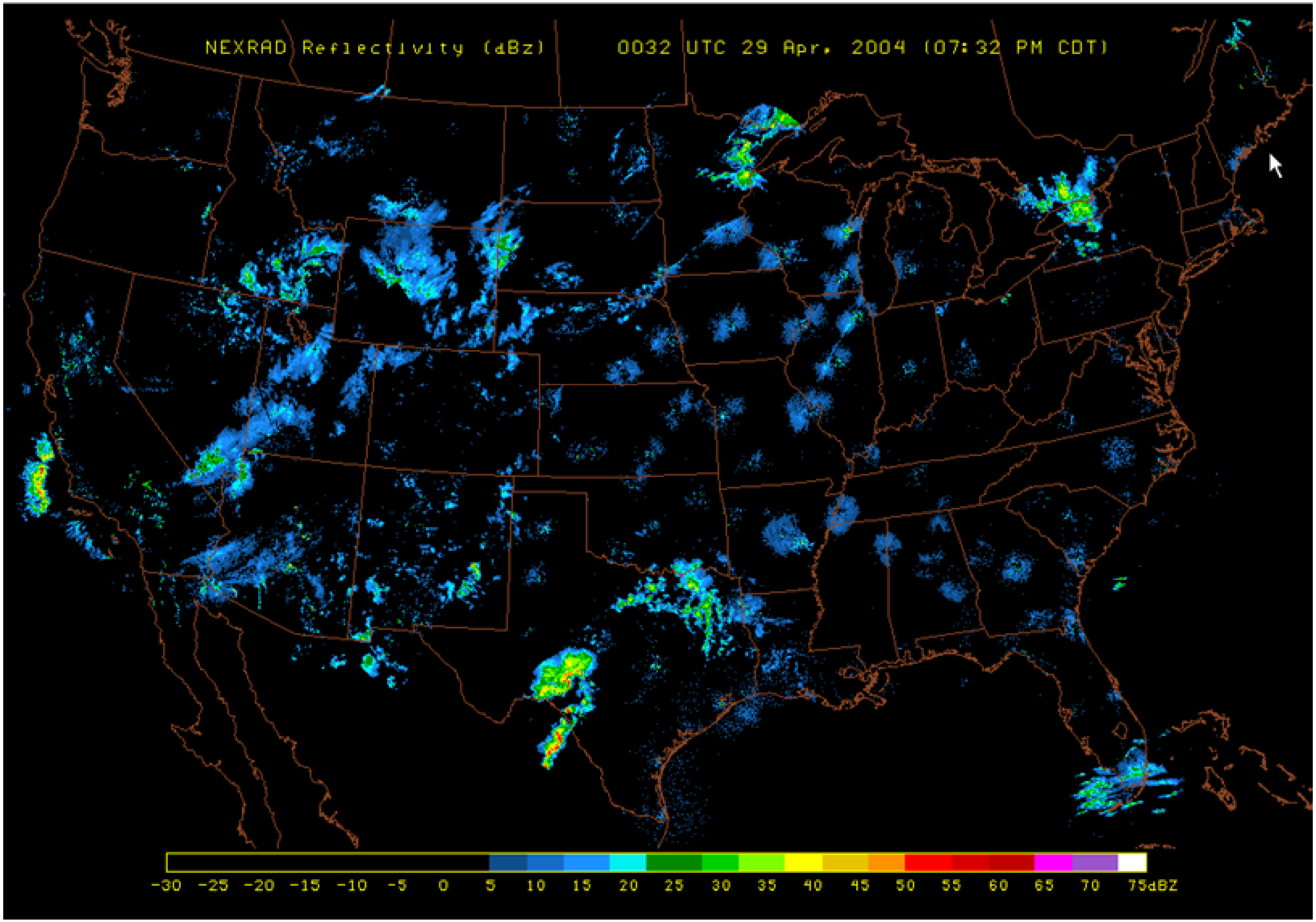
Stutchbury *et al*. Science 232: 2009.

MIGRATION AND STOPOVER OF MANX SHEARWATERS



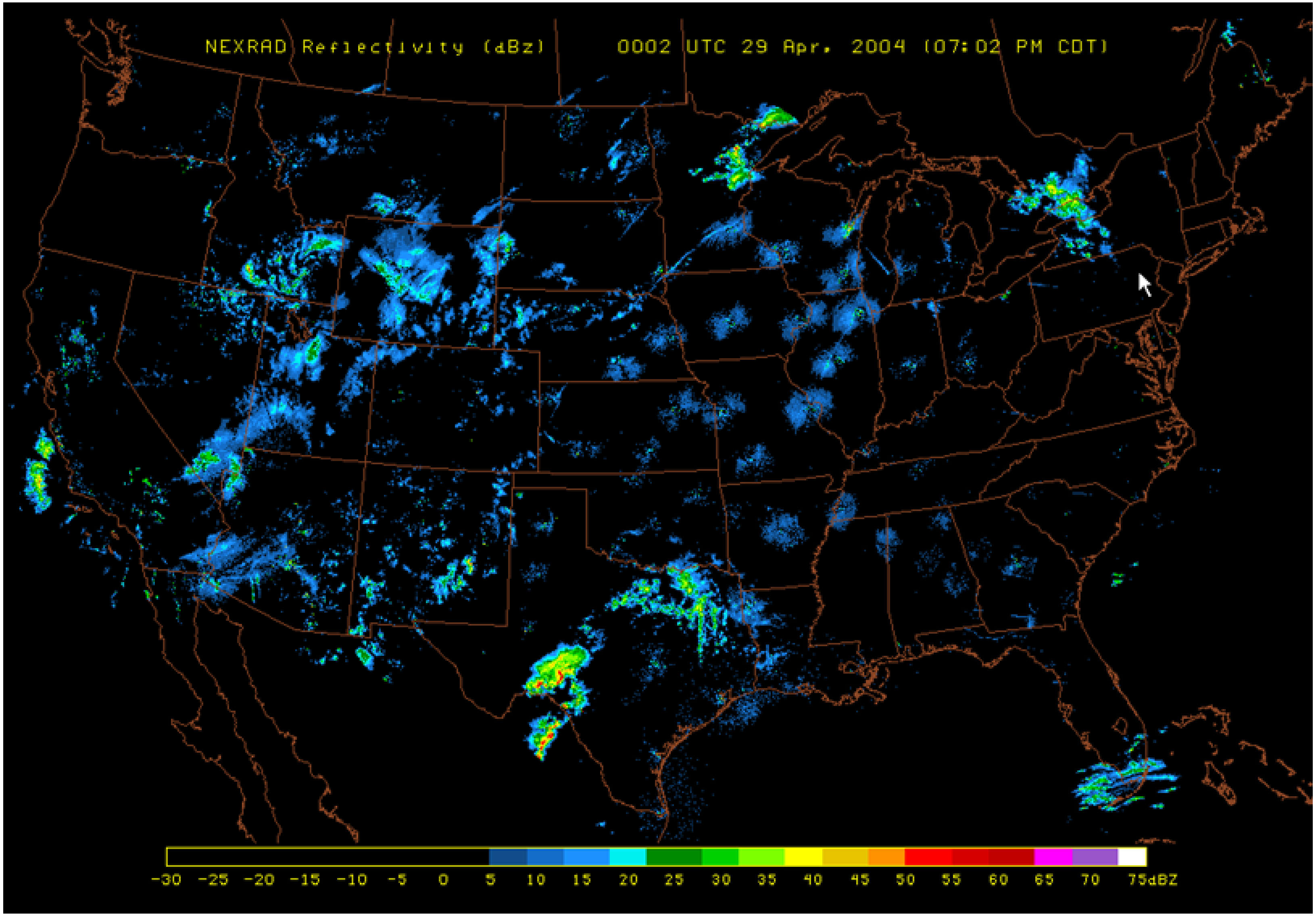
Guillford et al. 2009. Proceedings Royal Society B.

TEMPORAL PATTERN TO MIGRATION

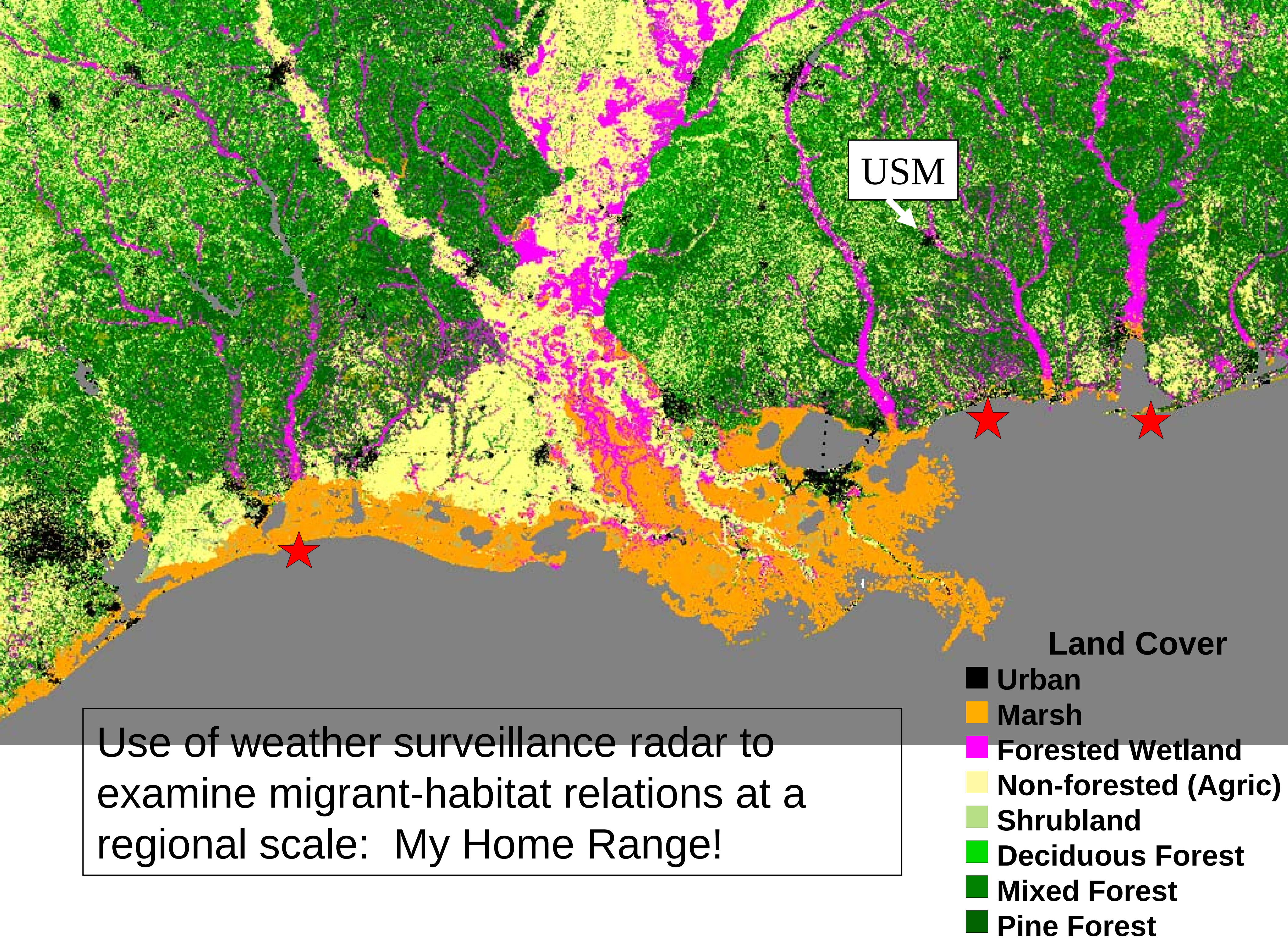


NEXRAD Reflectivity National Composite: Robert Diehl. Personal communication

TEMPORAL PATTERN TO MIGRATION

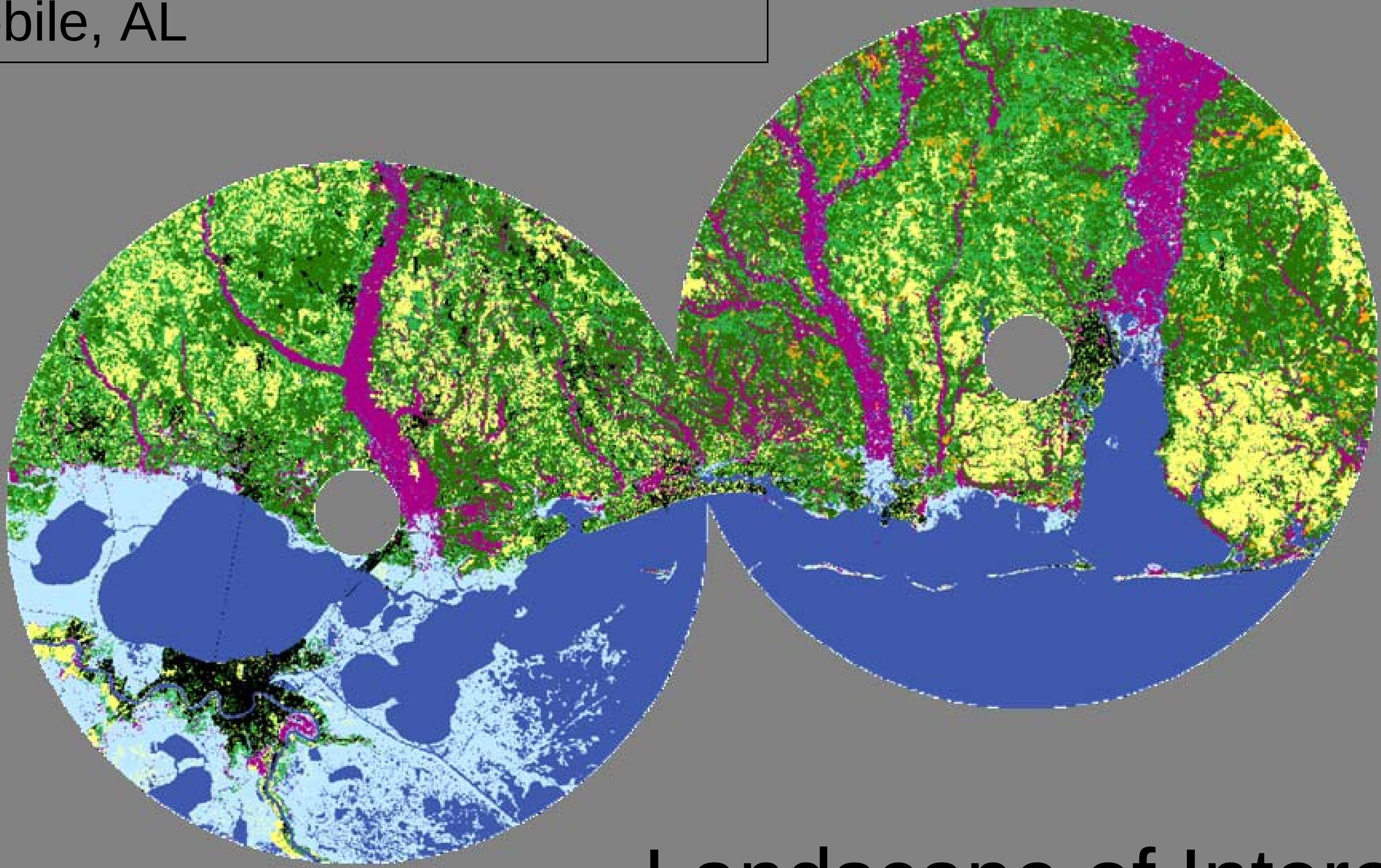


NEXRAD Reflectivity National Composite: Robert Diehl. Personal communication



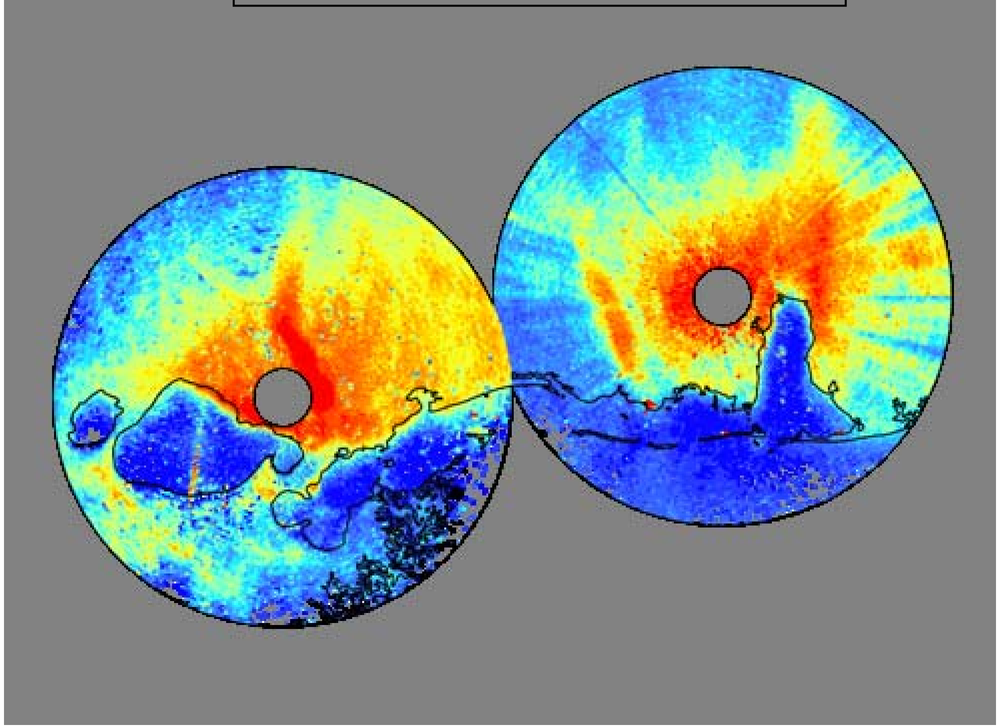
Use of weather surveillance radar to examine migrant-habitat relations at a regional scale: My Home Range!

Weather surveillance radar sites near New Orleans, LA, and Mobile, AL

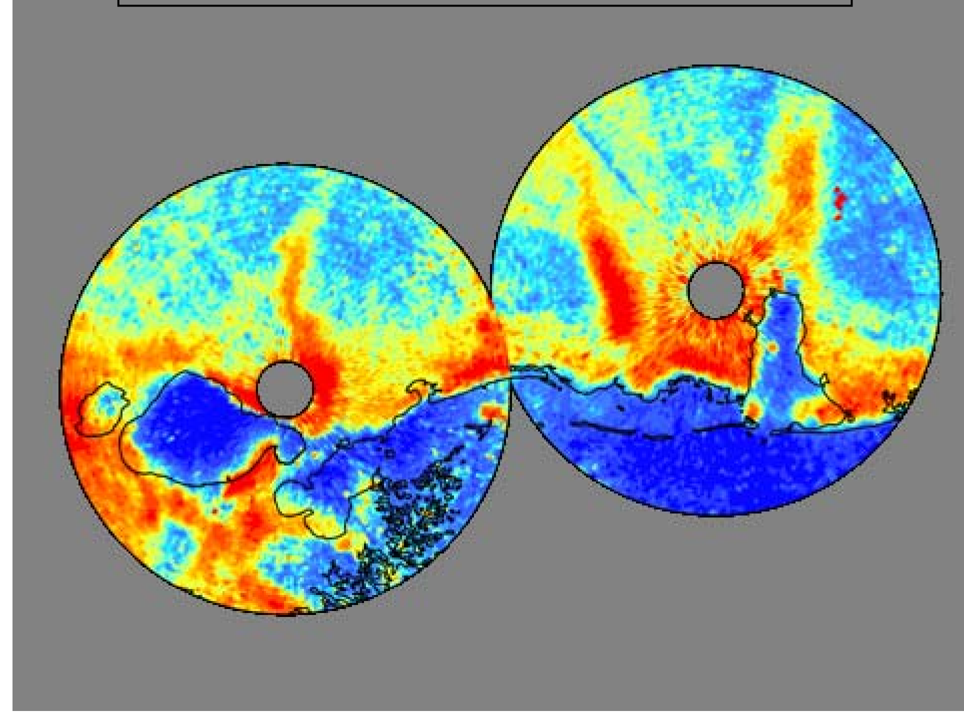


Landscape of Interest

Fall Migration
Bird Density



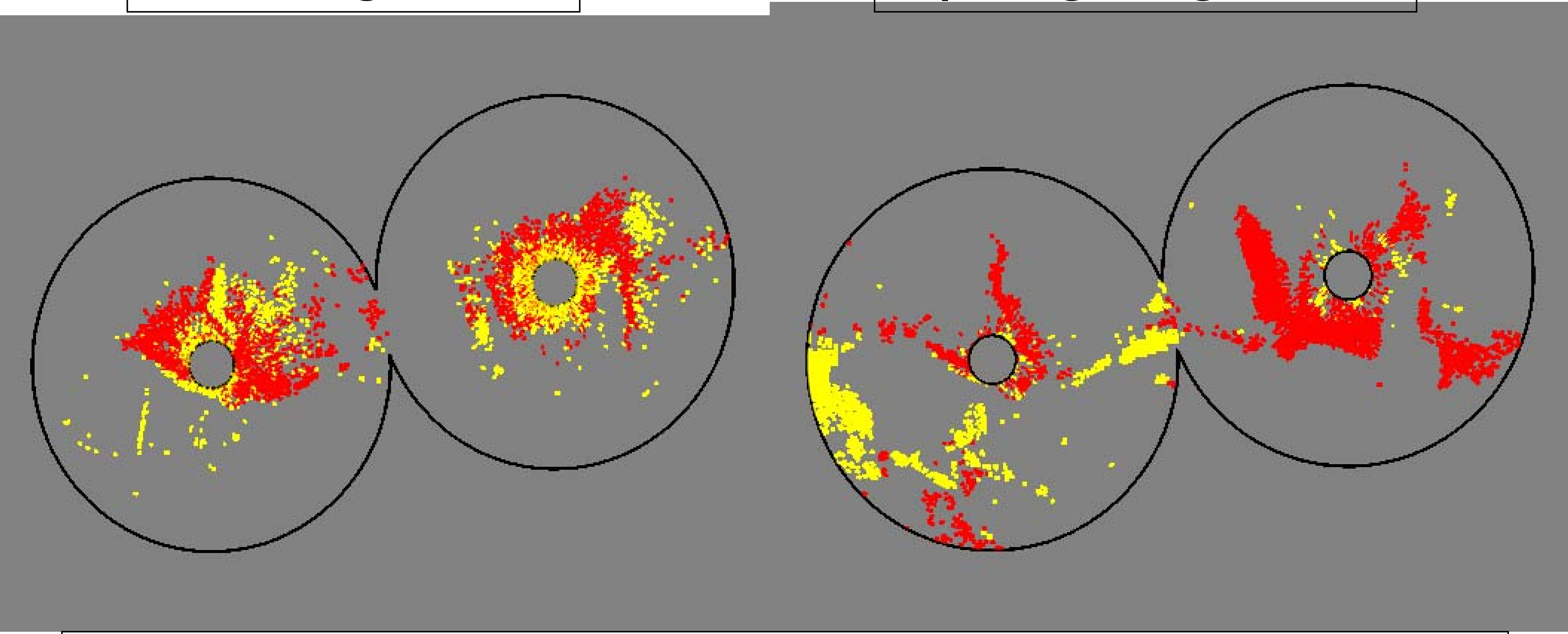
Spring Migration
Bird Density



Weather surveillance radar depicts the departure of migratory birds

Fall Migration

Spring Migration



Migratory birds concentrate before and after crossing the Gulf of Mexico

GRADUATE STUDENT COURSE

"AVIAN MOVEMENTS AND MIGRATION TECHNOLOGY"

- WHAT QUESTIONS FORM THE BASIS OF YOUR RESEARCH?
- MOVEMENT ECOLOGY: FINDING A CONCEPTUAL FRAMEWORK
- STOPOVER BIOLOGY OF MIGRATORY BIRDS: MEETING EN ROUTE CHALLENGES

MOVEMENT ECOLOGY: FINDING A CONCEPTUAL FRAMEWORK

FRANK R. MOORE

Biological Sciences
The University of Southern Mississippi

MOVEMENT ECOLOGY

- Driven by processes that act across multiple spatial and temporal scales
- Plays major role in determining the fate of individuals
- Plays a role in determining structure and dynamics of populations, communities and ecosystems
- Hence, an understanding of causes, patterns, mechanisms, and consequences of organismal movement is central.

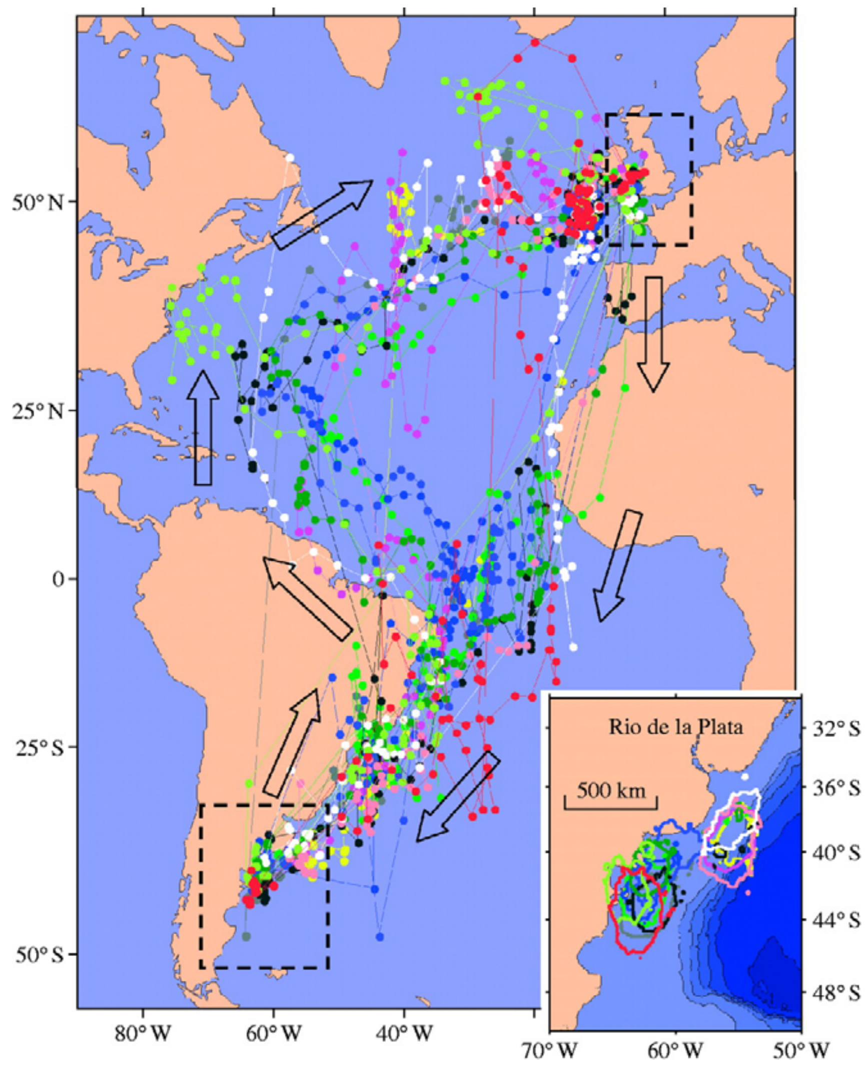
MOVEMENT ECOLOGY

Over 2,300 years ago, Aristotle argued in *De Motu Animalium* [On the Movement of Animals]:
"The movement of animals that belong to each genus, and how these are differentiated, and what the reasons are for the accidental characteristics of each – all this we have considered elsewhere. But now we must consider in general the common reason for moving with any movement whatever… ."

MOVEMENT ECOLOGY

- Movement important to all organisms
- Vast literature
- Research adheres to an idiosyncratic classification of different modes, which conflates pattern and process and cause and effect. For example:
- Same movement may be classified as foraging, within-patch movement, or station-keeping depending on whether defined by goal, landscape, or temporal dynamics.
- Migration has been applied to nearly all possible movement types.
- Idiosyncratic classification exacerbated by separation of studies by taxonomic group, geographic regions, and research approach.
- Still lack a general framework for studying why, how, where and when organisms move.

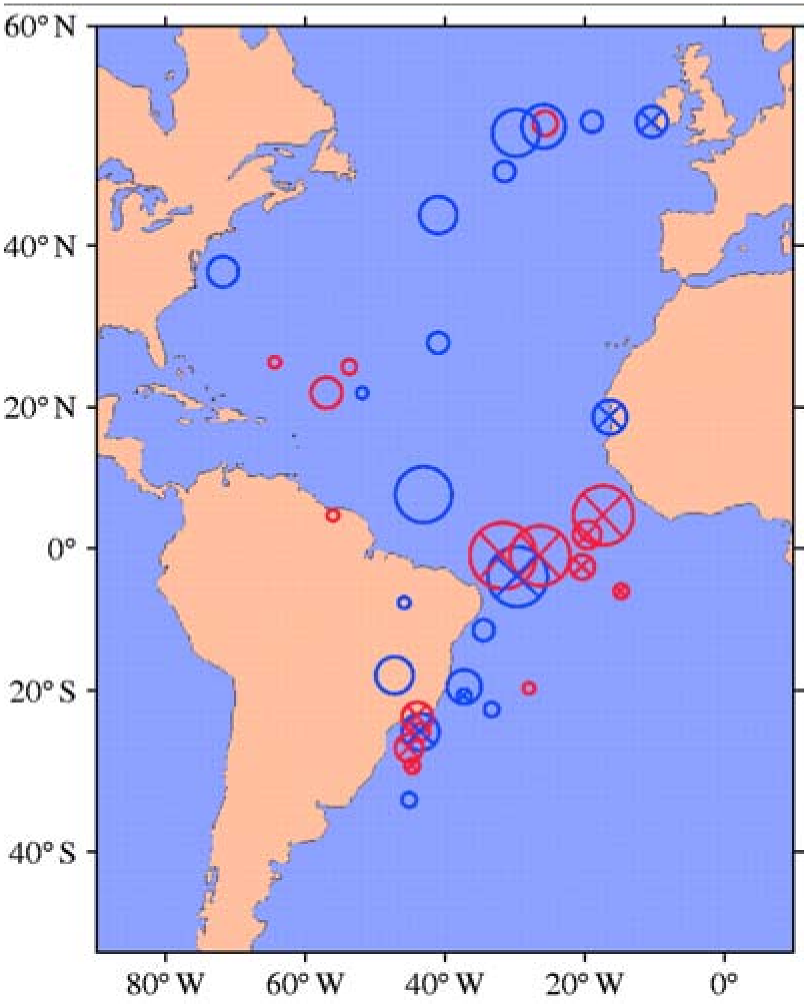
MOVEMENT ECOLOGY



- Growing capacity to quantify and analyze movement of individual at reasonably high spatiotemporal resolution and reasonably large spatiotemporal scales
- Growing capacity to collect high-resolution data requires significant improvements in data management, processing, and analytical techniques
- Development of movement ecology paradigm in connection with technological advances improves our ability to address 4 fundamental questions about movement:

- Why move?
- How to move?
- When/Where to move?
- Ecological and evolutionary consequences of movement?

MOVEMENT ECOLOGY



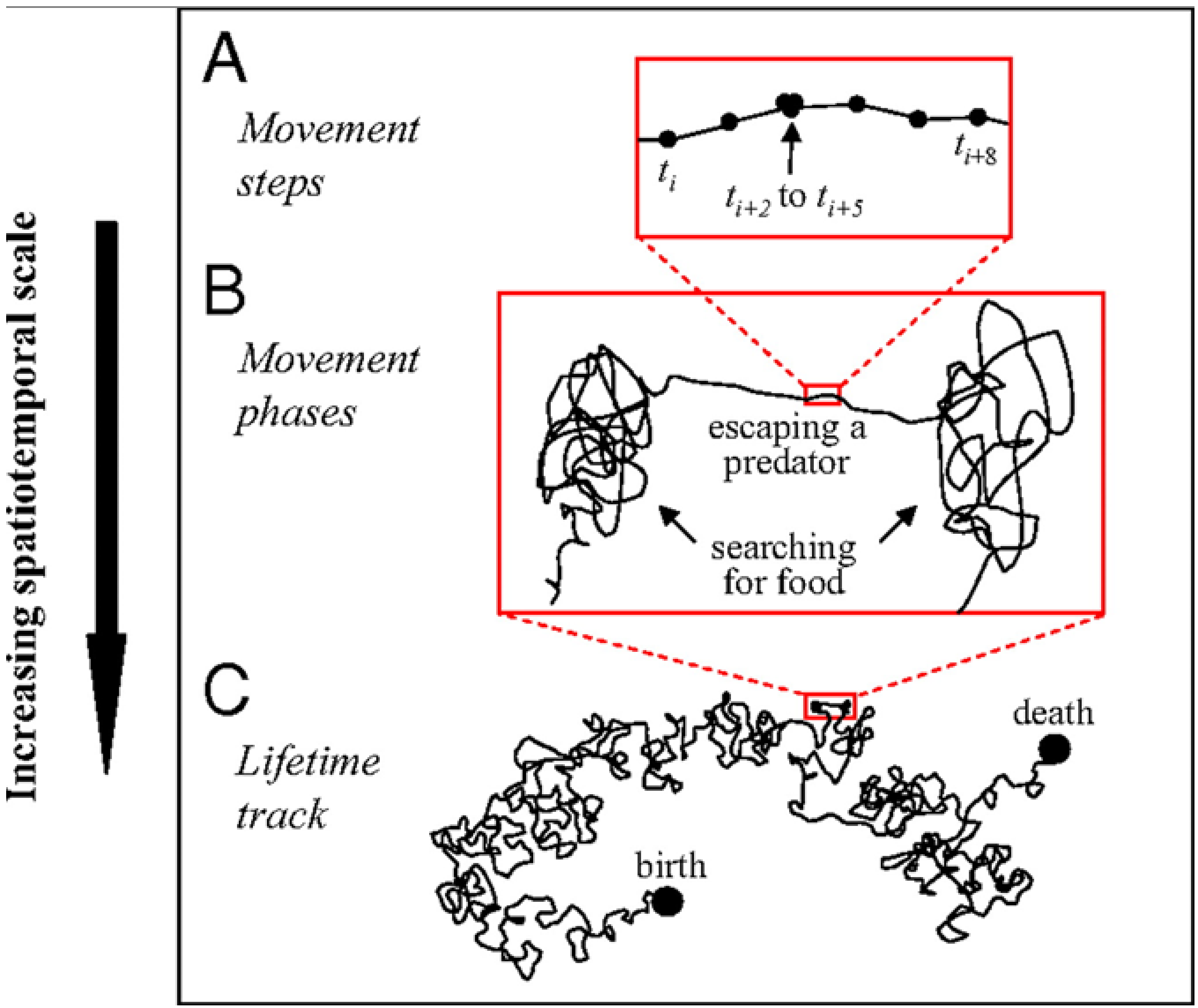
- Why move?
- How to move?
- When/Where to move?
- Ecological and evolutionary consequences of movement?

- To address must understand the proximate and ultimate causes responsible for the observed movement path.

- Desire to analyze the movement path of individuals over their lifetime track. Not without challenges:

MOVEMENT ECOLOGY

Fundamental spatiotemporal scaling of movement of an individual

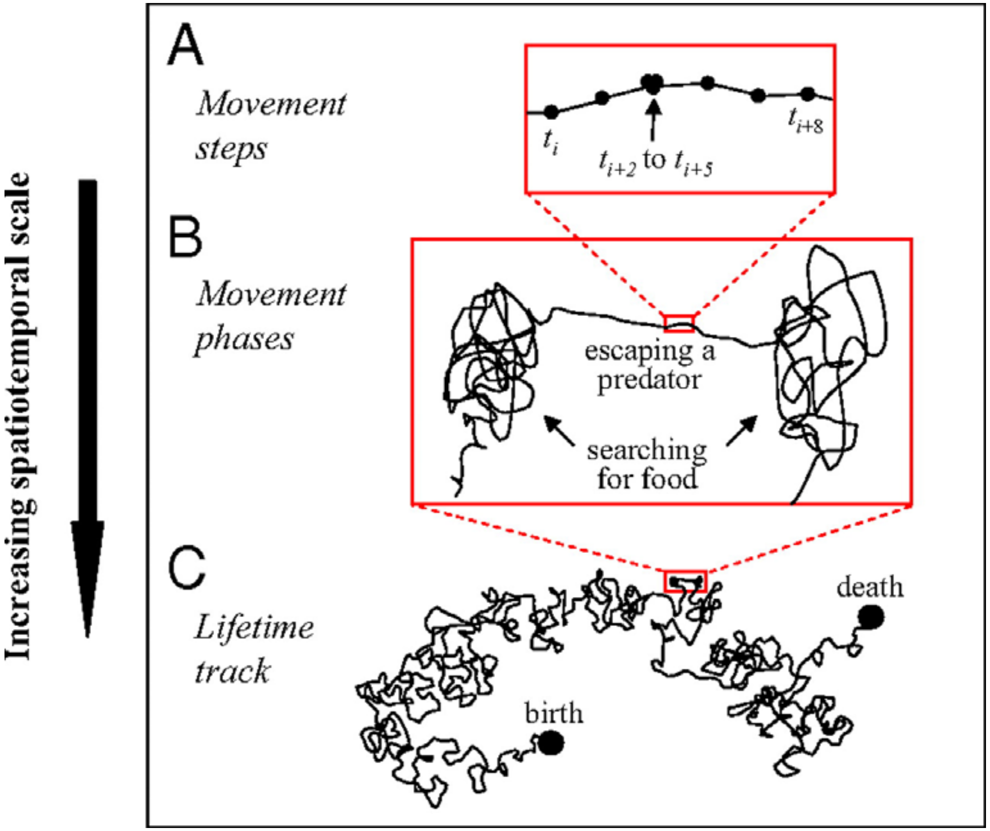


Nathan R. et.al. PNAS 2008;105:19052-19059

MOVEMENT ECOLOGY

Spatiotemporal scaling of movement: Analysis Challenges

- Parsing movement path into elemental units. Improved tracking technology makes this possible.
- Classifying path segments in terms of functional units of the lifetime track. Even with sufficient resolution, must identify proximate and ultimate drivers that break path into different movement phases.
- Functional hierarchy underlying a lifetime track necessitates study of movement mechanisms and patterns across multiple spatiotemporal scales
- Placing movement data in proper environmental context.

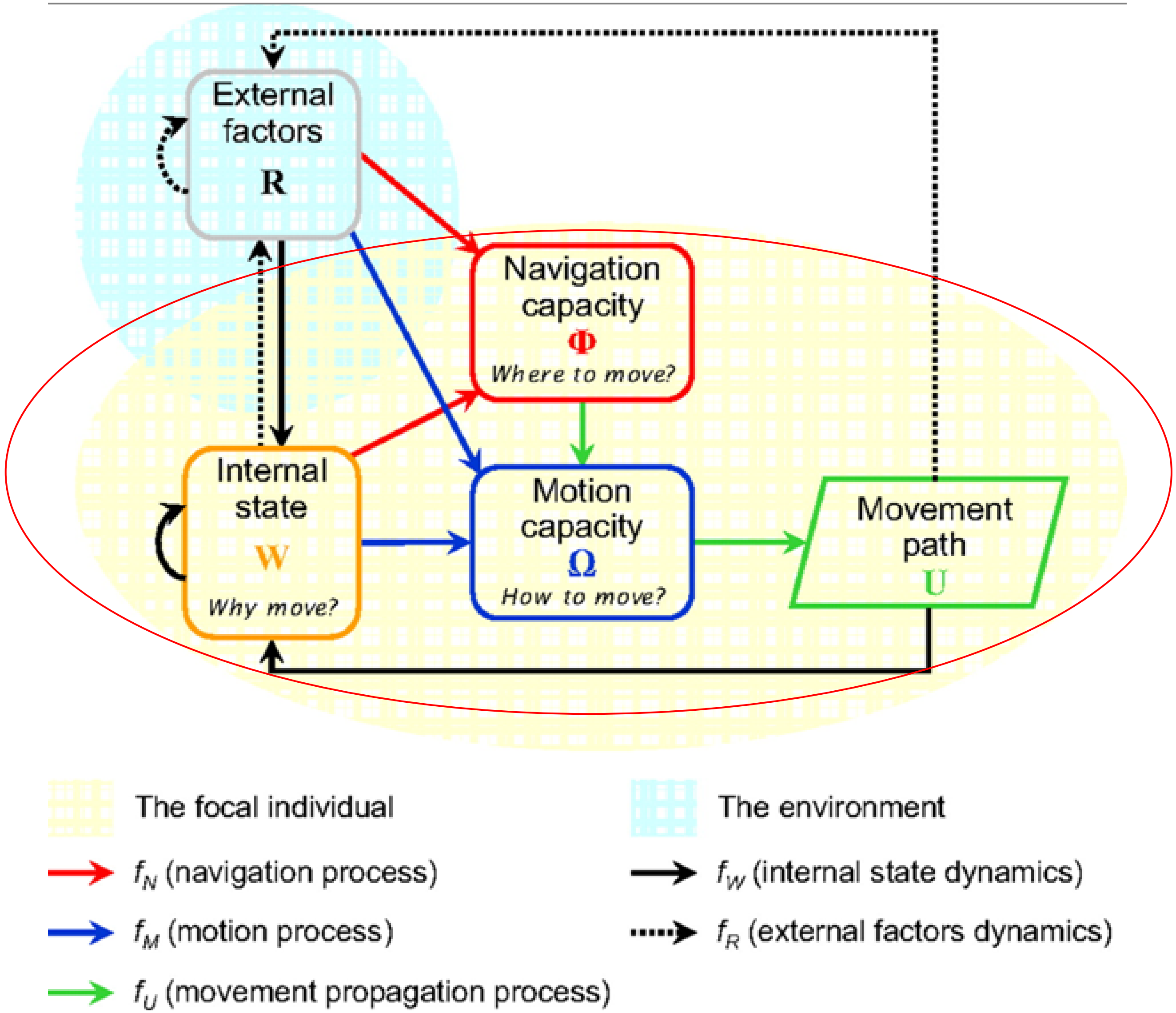


MOVEMENT ECOLOGY: A CONCEPTUAL FRAMEWORK

- Should be conceptualized from standpoint of movement itself
- Should allow exploration of causes, mechanisms, and patterns of movement
- Should facilitate understanding of the consequences of movement for ecology of individuals, populations, and communities
- Should encompass range of spatiotemporal scales over which movement is understood

MOVEMENT ECOLOGY

General Conceptual Framework



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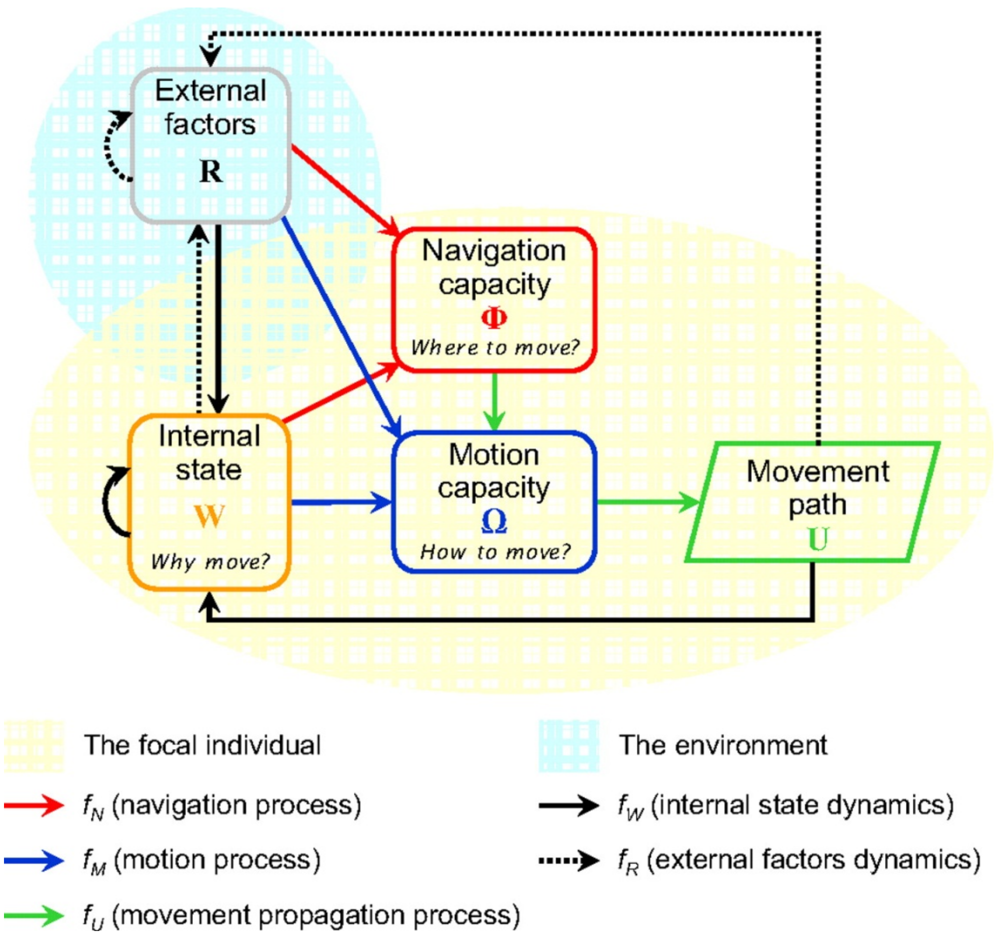
MOVEMENT ECOLOGY

General Conceptual Framework

Internal State: Why Move?

- Physiological (and psychological state) driving animal to fulfill goal
- For example: Mechanisms mediating fat deposition in migratory birds



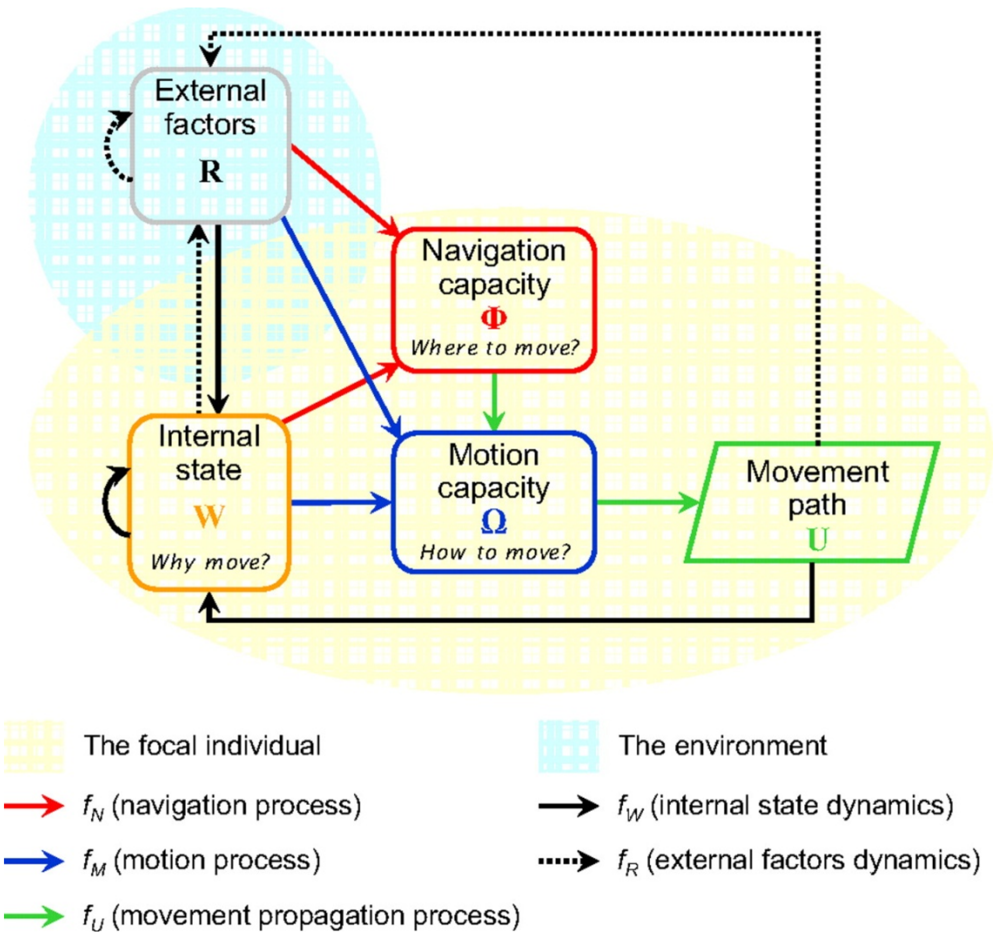
MOVEMENT ECOLOGY

General Conceptual Framework

Motion Capacity:

How to move?

- Ability to move in various ways/modes
- For example: Biomechanics of flight in migratory birds

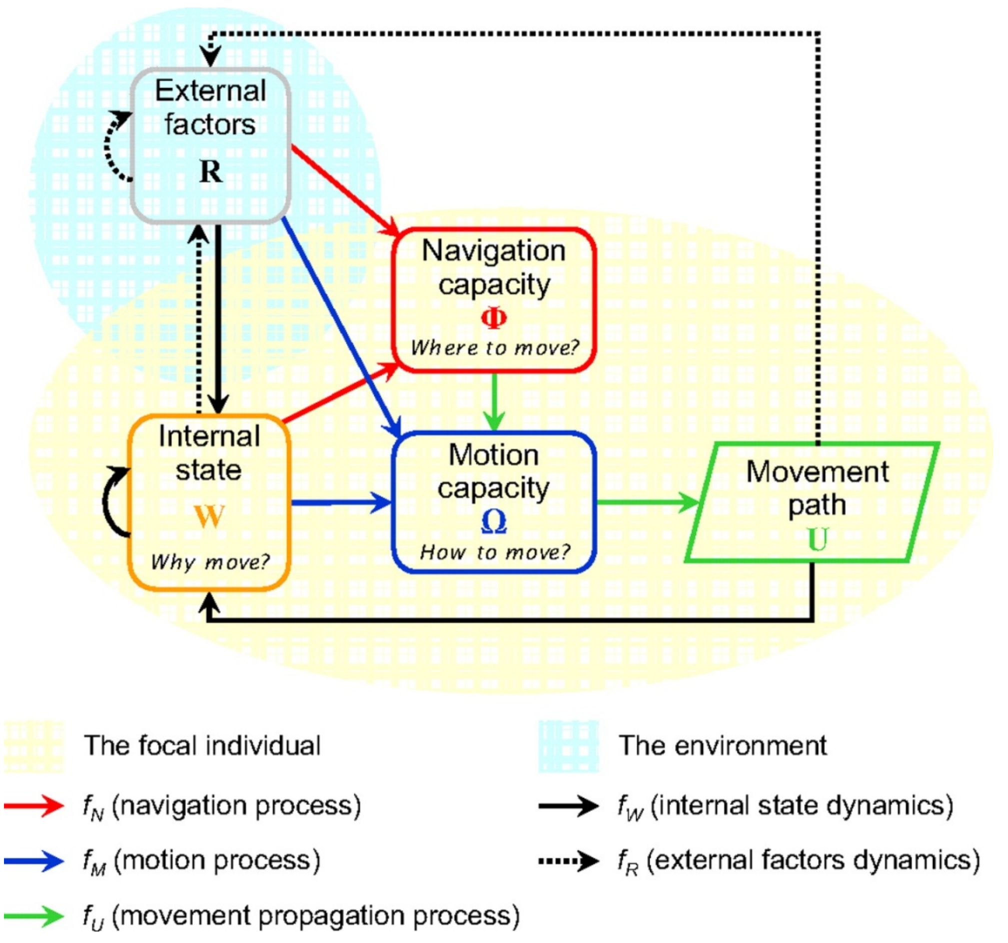


MOVEMENT ECOLOGY
General Conceptual Framework

Navigation Capacity:

When/Where to Move

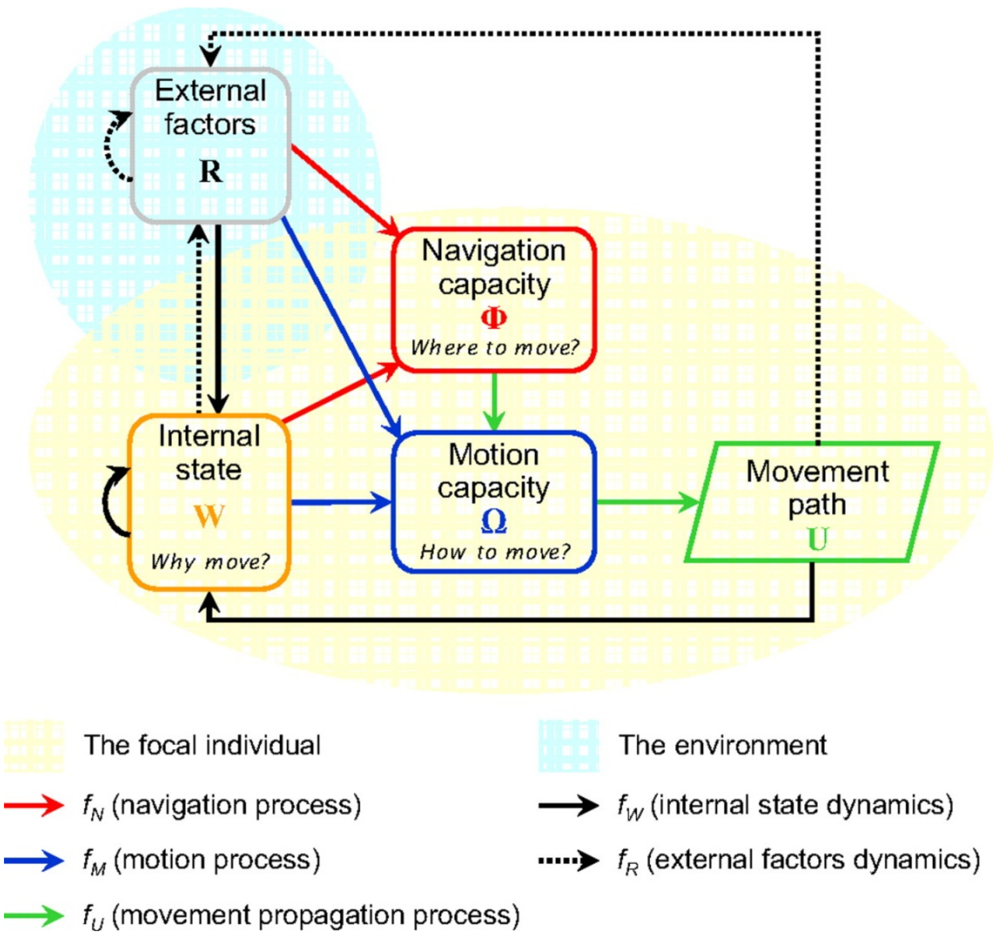
- Orientation in space and time, selecting where and when to move
- For example: Time – direction programs of migratory birds



MOVEMENT ECOLOGY

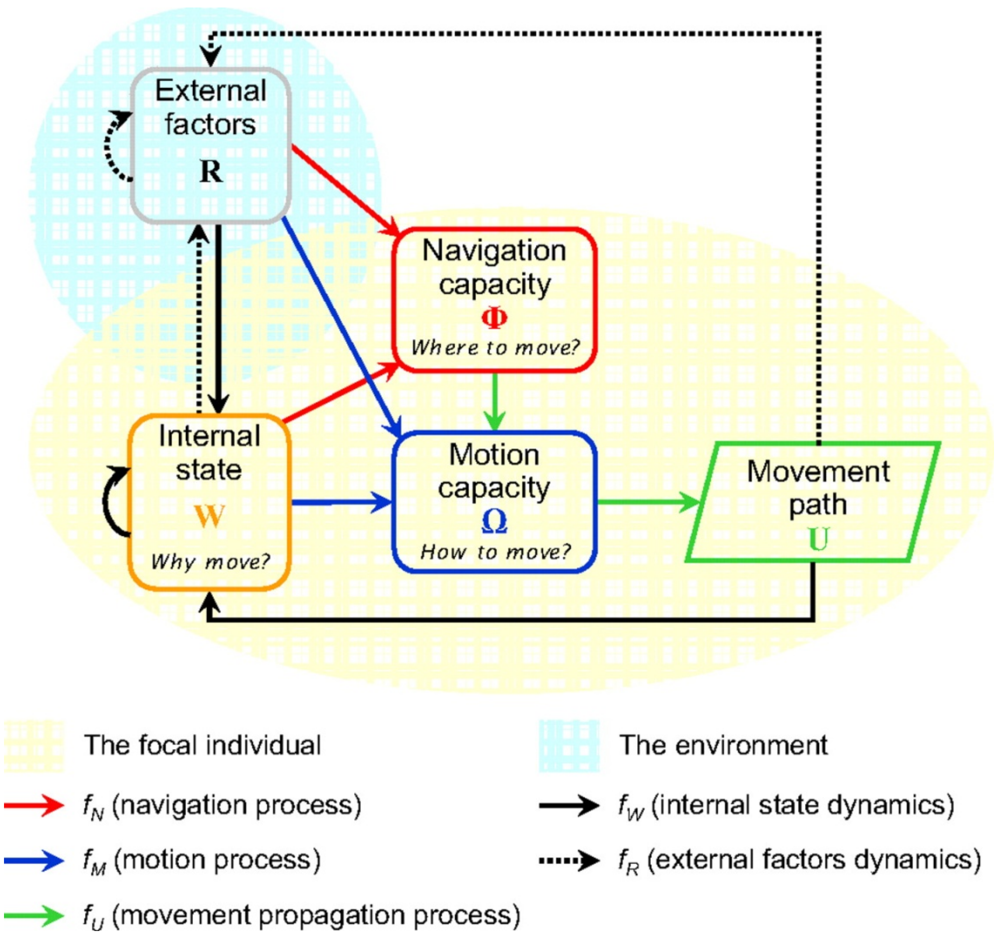
General Conceptual Framework

- Integrates basic components and processes involved in movement in a mechanistic way to understand movement:
- What are internal goals/what motivates movement?
- How is movement performed?
- When and toward what "target" is movement performed?
- How do components interact to produce movement?



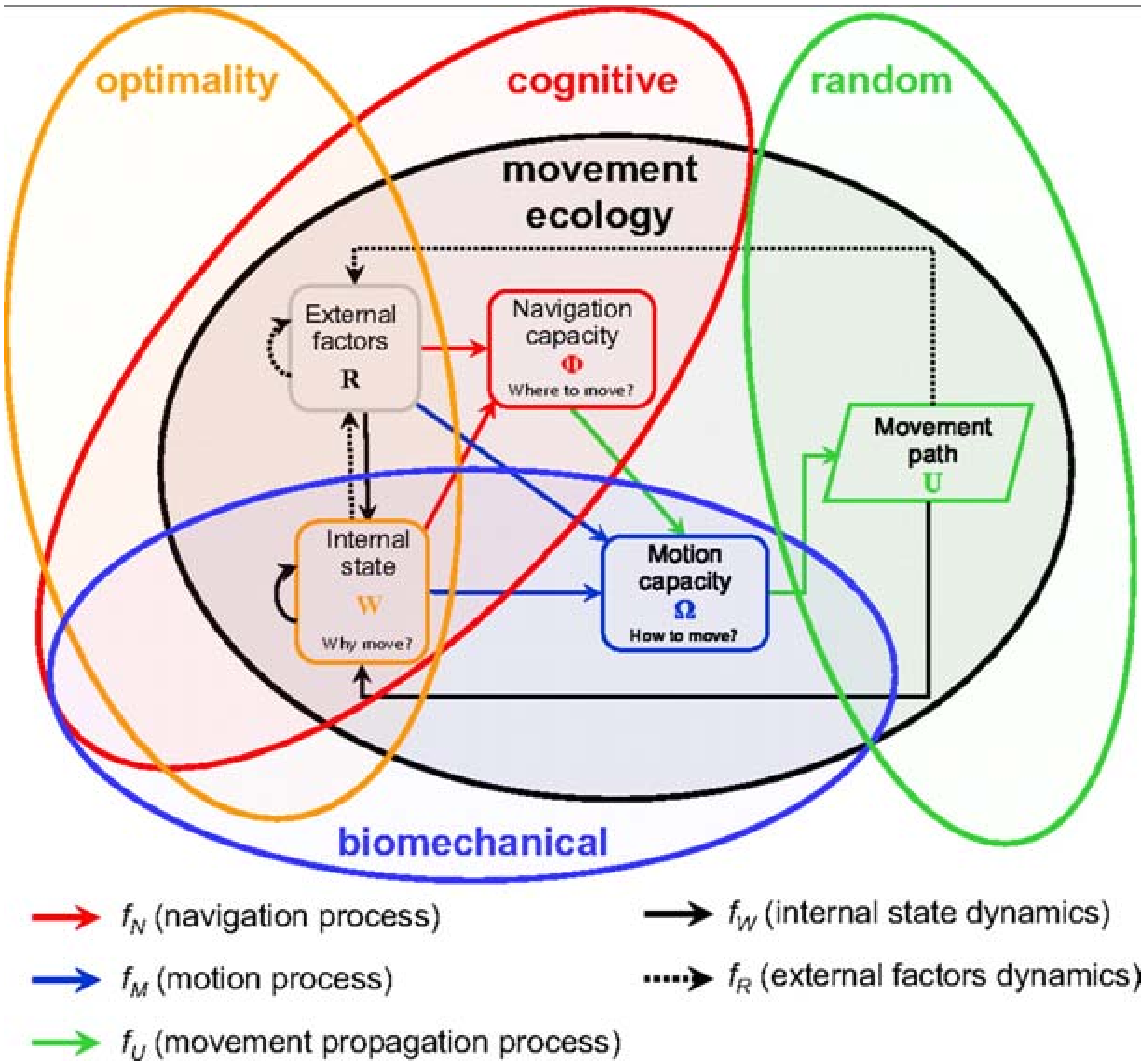
MOVEMENT ECOLOGY
General Conceptual Framework

- Primary challenge in application of framework is to identify key external factors, internal states, and motion and navigational capacities influencing movement.
- Overcome practical difficulties in quantifying the movement of individuals: See MIGRATE
- Not the only movement research paradigm, so informative to consider relationship to other paradigms



MOVEMENT ECOLOGY

Movement Ecology Paradigm and Existing Paradigms

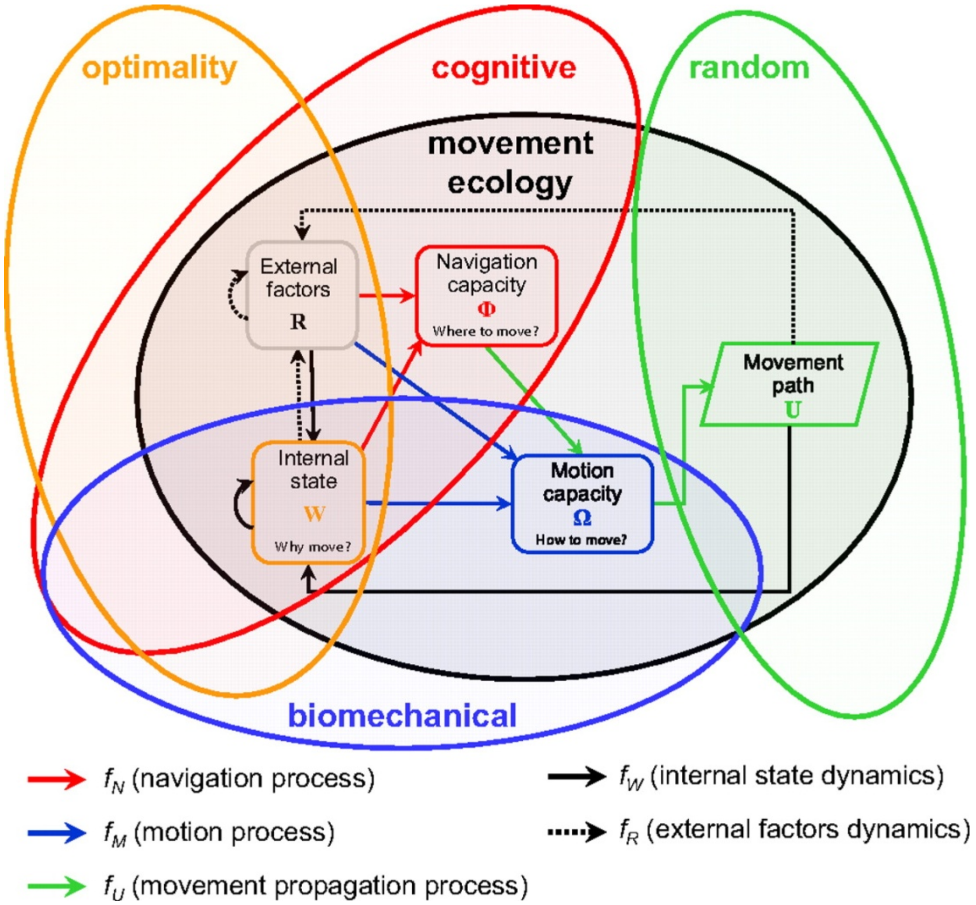


Nathan R. et.al. PNAS 2008;105:19052-19059

MOVEMENT ECOLOGY

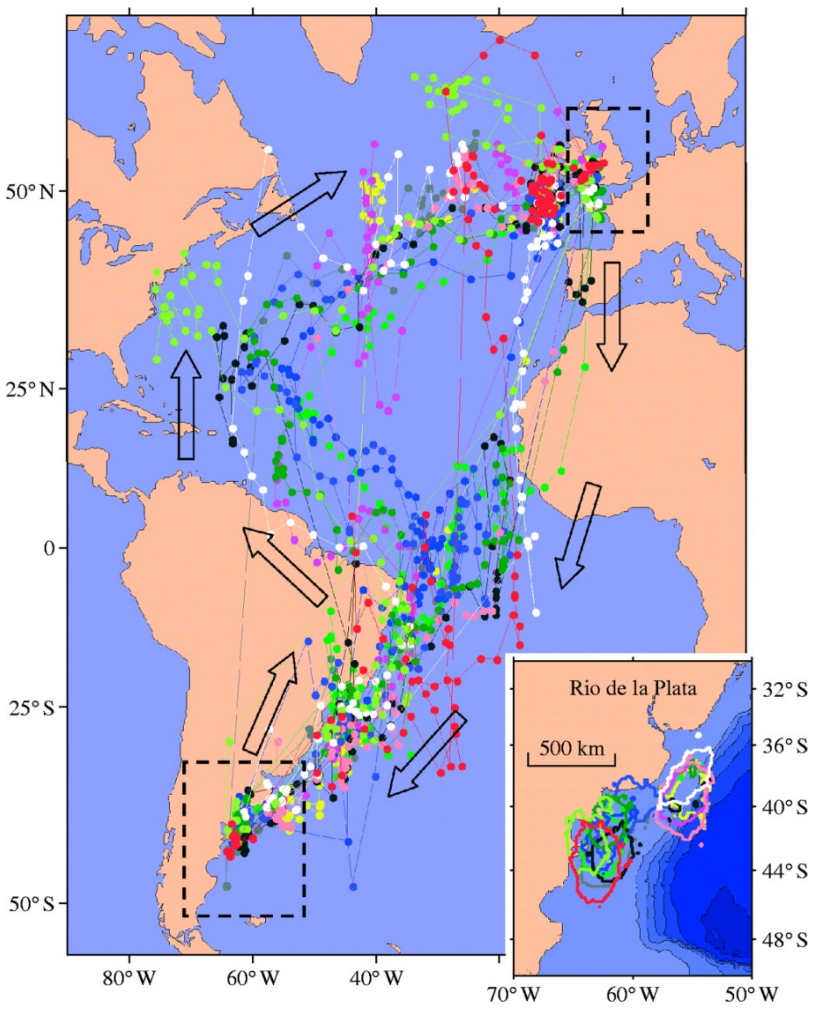
Movement Ecology Paradigm and Existing Paradigms

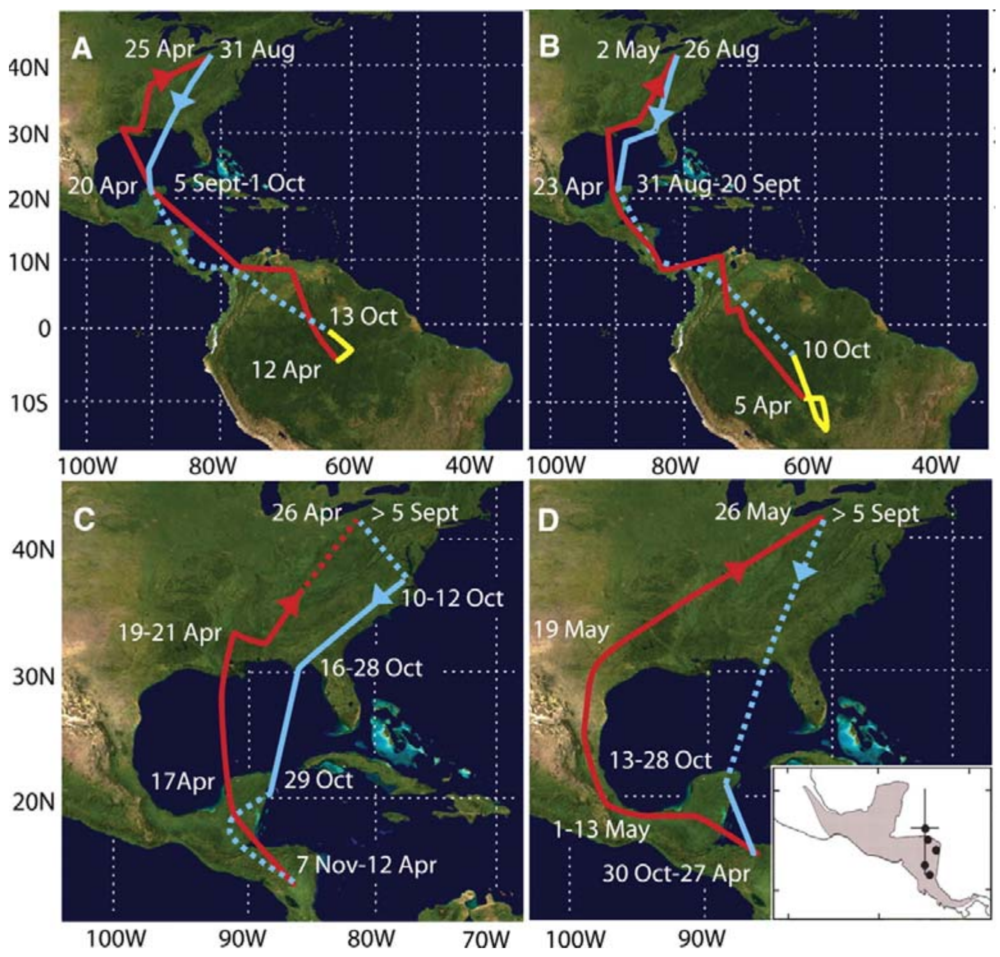
- Biomechanical paradigm: Good description of motion capacity, but little on why, where, and when organisms move. See Pennycuick's flight performance modeling.
- Cognitive paradigm: how organisms make movement-related decisions. See sensory basis of magnetoreception.
- Random paradigm: phenomenological description of movement paths; often start with null models .See large-scale movement across landscapes
- Optimality paradigm: explores efficacy of different strategies in optimizing some fitness currency (e.g., fuel deposition rate). See Lindstrom and Alerstam.



MOVEMENT ECOLOGY

General Conceptual Framework:
How Far Are We?





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Positions of 12 shearwaters tracked with geolocators. Each bird is represented by a different colour. Coloured lines serve to connect the positions in series providing approximate trajectories. However, where erroneous locations have been excluded, lines may sometimes connect neighbouring positions that are many days apart and hence are not indicative of actual routes travelled (e.g. over land). For clarity around the breeding colony and the main over-wintering area (inside the dashed boxes) where there is a high density of points, plots are of mean positions over two-week periods. The inset shows the 50% occupancy contours within the southern dashed box around the over-wintering area for all daily positions within that box, using the same colour scheme as the tracks. Bathymetry contours at 1000 m intervals indicate the edge of the Patagonian Shelf.

The relationships among the proposed movement ecology paradigm (Fig. 2) and four existing paradigms representing different scientific disciplines in which the movement of organism is being studied. Elements in the gray background are components of the movement ecology framework.

Stopovers, sized in proportion to the length of the stop, are shown at mean location of positions. Blue, male; red, female (small circles, duration 5 days; big circles, duration 10 days). Outward-bound stops from colony towards winter feeding ground are indicated with a cross. Locations apparently over land almost certainly do not indicate that birds were stopping inland, but serve to emphasize that position estimates may be subject to considerable error.

Fundamental spatiotemporal scaling of movement of an individual organism. A short movement path representing five steps and one stop (A); a longer path representing three movement phases (B); a lifetime track (C). The concept of movement phase, as defined here, provides the essential link between movement patterns and their underlying processes. Glossary: Movement, a change in the spatial location of the whole individual over time; Movement step (or simply "step"), a displacement between two successive positional records of the organism; Movement phase, a sequence of steps and stops associated with the fulfillment of a particular goal or a set of goals; Goal, a proximate cause of movement, combining ultimate internal drivers (e.g., to gain energy, seek safety, learn, or reproduce) and external stimuli; Lifetime track, the complete sequence of steps and stops of an individual from birth to death; Movement path, a general term for a sequential collection of steps and stops, applied flexibly to various step/stop definitions and overall length or duration.

A general conceptual framework for movement ecology, composed of three basic components (yellow background) related to the focal individual (internal state, motion capacity, and navigation capacity) and a fourth basic component (turquoise background) referring to external factors affecting its movement. Relationships among components related to the processes by which they affect each other, with arrows indicating the direction of impact. The resulting movement path (defined in Fig. 1) feeds back to the internal and external components. Glossary: Internal state, the multidimensional state (e.g., physiological and neurological) of the focal individual that affects its motivation and readiness to move; Motion capacity, the set of traits (e.g., biomechanical or morphological machineries) that enables the focal individual to execute or facilitate movement; Navigation capacity, the set of traits (e.g., cognitive or sensory machineries to obtain and use information) that enables the focal individual to orient its movement in space and/or time; External factors, the set of biotic and abiotic environmental factors that affect the movement of the focal individual; Motion process, the realized motion capacity given the impact of the current location, internal state, and external factors on the fundamental motion capacity of the focal individual; Navigation process, the realized navigation capacity given the impact of the current location, internal state, and external factors on the fundamental navigation capacity of the focal individual; Movement propagation process, the realized movement produced by the motion process and (optionally affected by the navigation process).