RangeShifter & RangeShiftR Workshop

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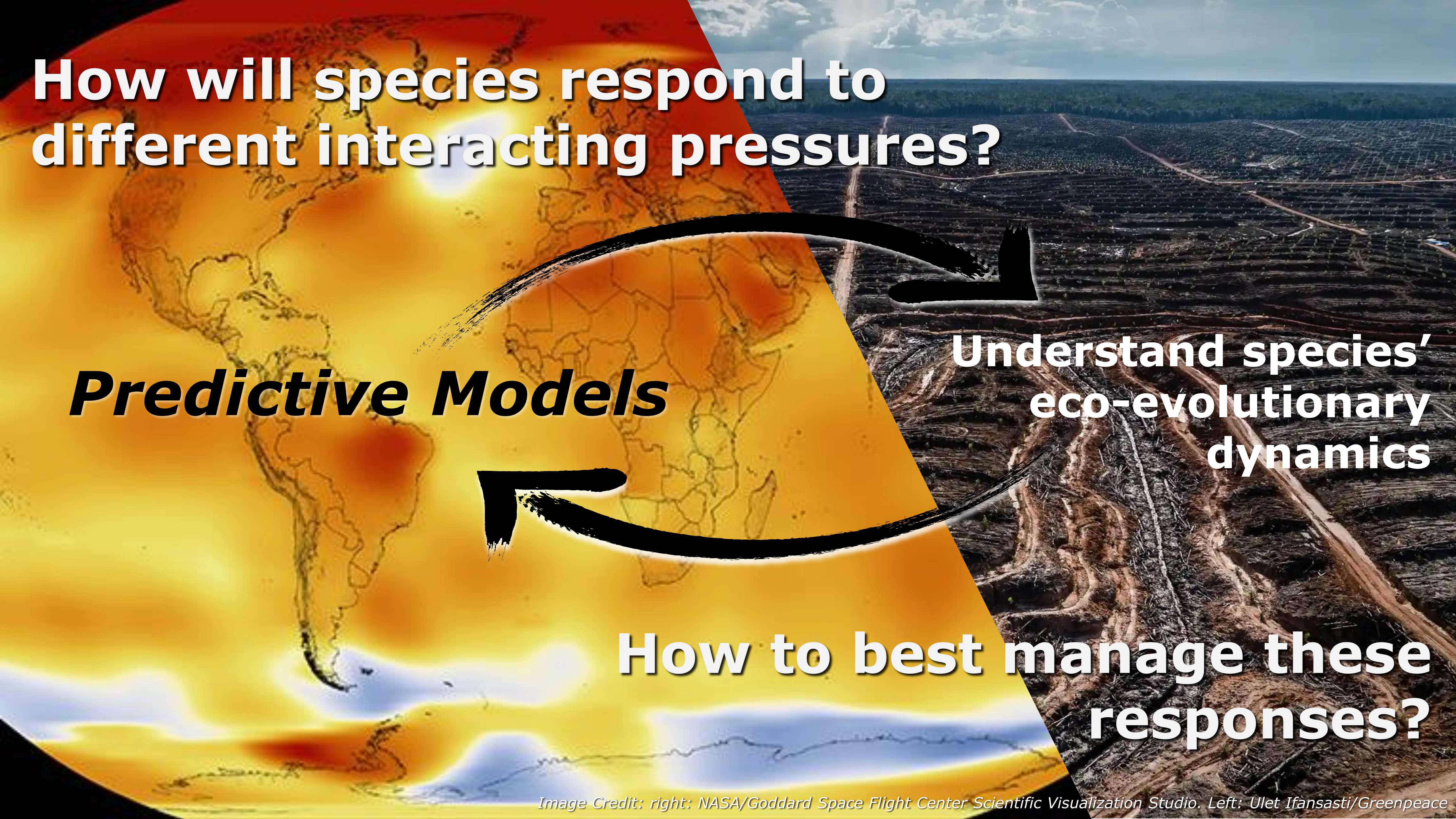
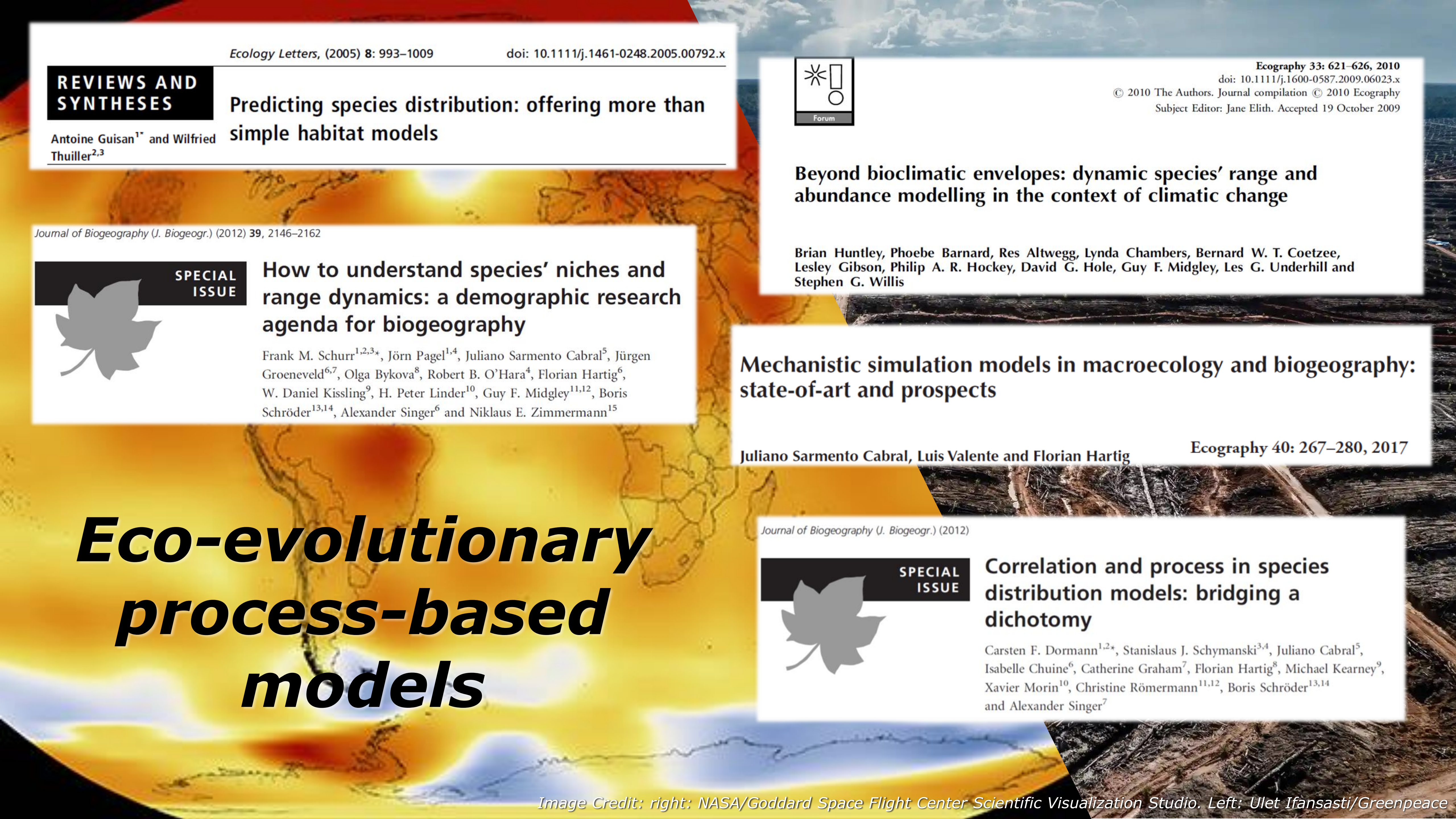
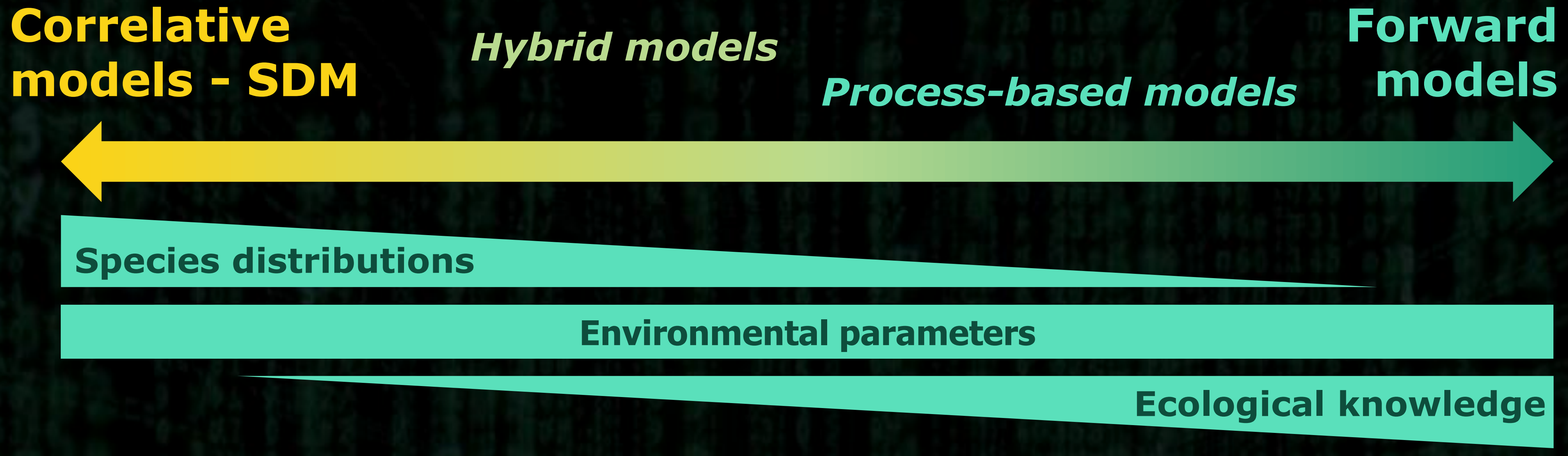
ATBC 2022
CARTAGENA - COLOMBIA

THE ROYAL SOCIETY

UNIVERSITY OF ABERDEEN


How will species respond to different interacting pressures?
Predictive Models
Understand species' eco-evolutionary dynamics
How to best manage these responses?
Image Credit: right: NASA/Goddard Space Flight Center Scientific Visualization Studio. Left: Ulet Ifansasti/Greenpeace


Ecology Letters, (2005) 8: 993–1009
doi: 10.1111/j.1461-0248.2005.00792.x
REVIEWS AND SYNTHESES
Predicting species distribution: offering more than simple habitat models
Antoine Guisan[1*] and Wilfried Thuiller[2,3]
Ecography 33: 621–626, 2010
doi: 10.1111/j.1600-0587.2009.06023.x
© 2010 The Authors. Journal compilation © 2010 Ecography
Subject Editor: Jane Elith. Accepted 19 October 2009
Forum
Beyond bioclimatic envelopes: dynamic species' range and abundance modelling in the context of climatic change
Brian Huntley, Phoebe Barnard, Res Altwegg, Lynda Chambers, Bernard W. T. Coetzee, Lesley Gibson, Philip A. R. Hockey, David G. Hole, Guy F. Midgley, Les G. Underhill and Stephen G. Willis
Journal of Biogeography (J. Biogeogr.) (2012) 39, 2146–2162
SPECIAL ISSUE
How to understand species' niches and range dynamics: a demographic research agenda for biogeography
Frank M. Schurr[1,2,3*], Jörn Pagel[1,4], Juliano Sarmento Cabral[5], Jürgen Groeneveld[6,7], Olga Bykova[8], Robert B. O'Hara[4], Florian Hartig[6], W. Daniel Kissling[9], H. Peter Linder[10], Guy F. Midgley[11,12], Boris Schröder[13,14], Alexander Singer[6] and Niklaus E. Zimmermann[15]
Mechanistic simulation models in macroecology and biogeography: state-of-art and prospects
Juliano Sarmento Cabral, Luis Valente and Florian Hartig
Ecography 40: 267–280, 2017
Eco-evolutionary process-based models
Journal of Biogeography (J. Biogeogr.) (2012)
SPECIAL ISSUE
Correlation and process in species distribution models: bridging a dichotomy
Carsten F. Dormann[1,2*], Stanislaus J. Schymanski[3,4], Juliano Cabral[5], Isabelle Chuine[6], Catherine Graham[7], Florian Hartig[8], Michael Kearney[9], Xavier Morin[10], Christine Römermann[11,12], Boris Schröder[13,14] and Alexander Singer[7]
Image Credit: right: NASA/Goddard Space Flight Center Scientific Visualization Studio. Left: Ulet Ifansasti/Greenpeace



Correlative SDMs statistically relate environmental variables directly to species ***occurrence or abundance***

- × *Parameters have no a priori defined ecological meaning*
- × *Processes are implicit*

Process-based models formulate the ecology of a species as mathematical functions defining ***causality***

- ✓ *Built around explicitly stated mechanisms*
- ✓ *Parameters have a clear ecological interpretation defined a priori*

Reproduced from: Dormann et al. 2012, J.Biogeogr. 39:2119-2131

Process-based models

Advantages…

- ✓ Rooted in ecological and evolutionary theory
- ✓ Not based on correlations but on processes:
  - Causal links
  - Predictive power
  - Extrapolation
- ✓ Generate new hypotheses

Uncertainty

… and challenges

- x Complexity – How much is too much?

  … which processes?
- x Data availability
- x Upscaling

Journal of Biogeography (J. Biogeogr.) (2012)

SPECIAL ISSUE

Correlation and process in species distribution models: bridging a dichotomy

Carsten F. Dormann[1,2*], Stanislaus J. Schymanski[3,4], Juliano Cabral[5], Isabelle Chuine[6], Catherine Graham[7], Florian Hartig[8], Michael Kearney[9], Xavier Morin[10], Christine Römermann[11,12], Boris Schröder[13,14] and Alexander Singer[7]

Ecology Letters, (2019) **22**: 1940–1956 doi: 10.1111/ele.13348

Forecasting species range dynamics with process-explicit models: matching methods to applications

Briscoe et al. 2019

Global Change Biology (2016) 22, 2651–2664, doi: 10.1111/gcb.13251

Benchmarking novel approaches for modelling species range dynamics

Zurell et al. 2016

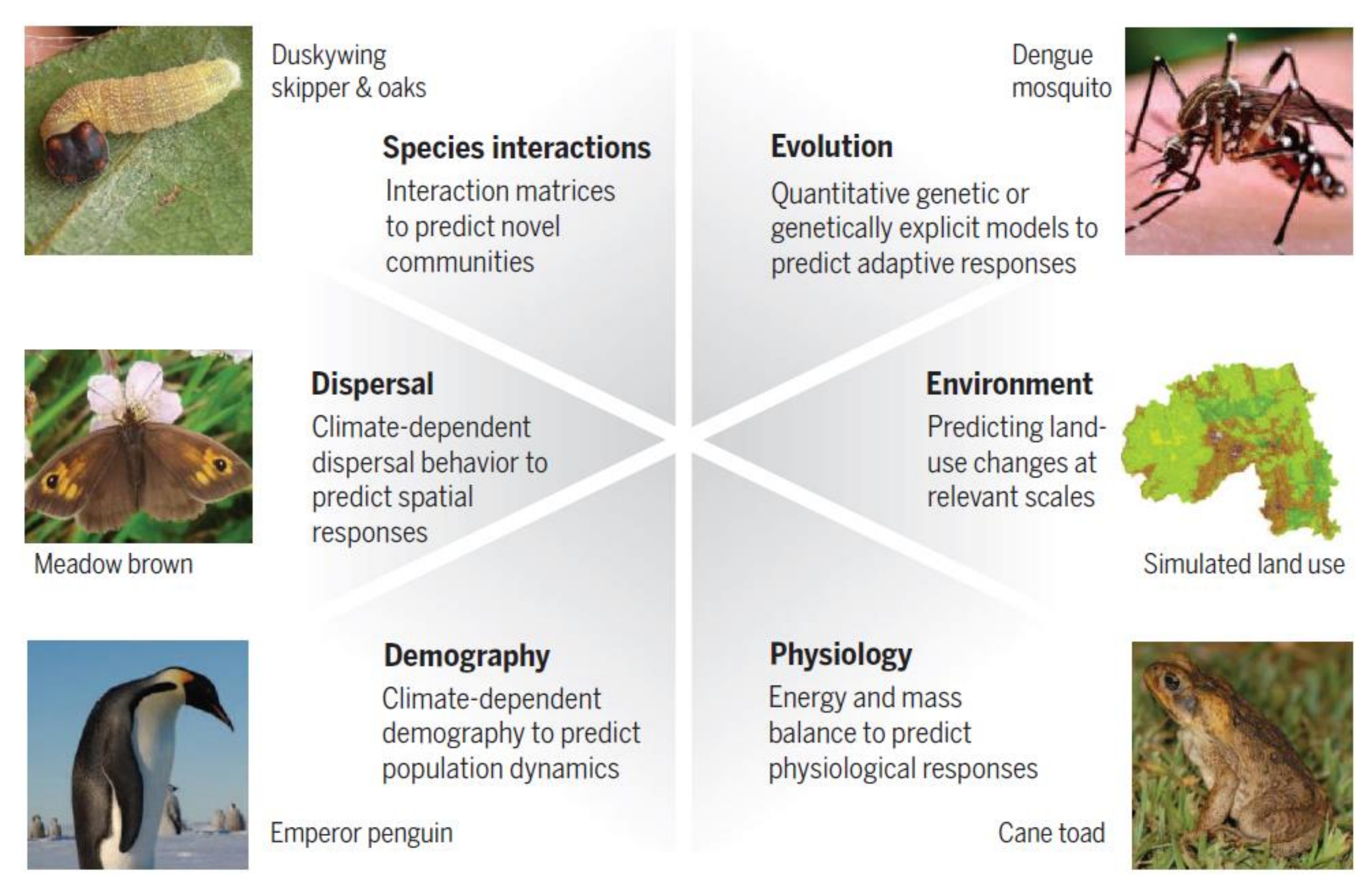
Review & synthesis

Ecography 40: 267–280, 2017
doi: 10.1111/ecog.02480
© 2016 The Authors. Ecography © 2016 Nordic Society Oikos
Subject Editor: Catherine Graham. Editor-in-Chief: Miguel Araújo. Accepted 11 November 2016

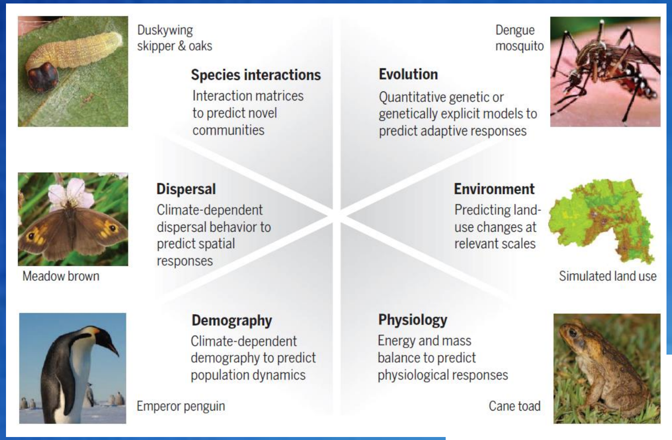
Mechanistic simulation models in macroecology and biogeography: state-of-art and prospects

Juliano Sarmento Cabral, Luis Valente and Florian Hartig

Which processes?

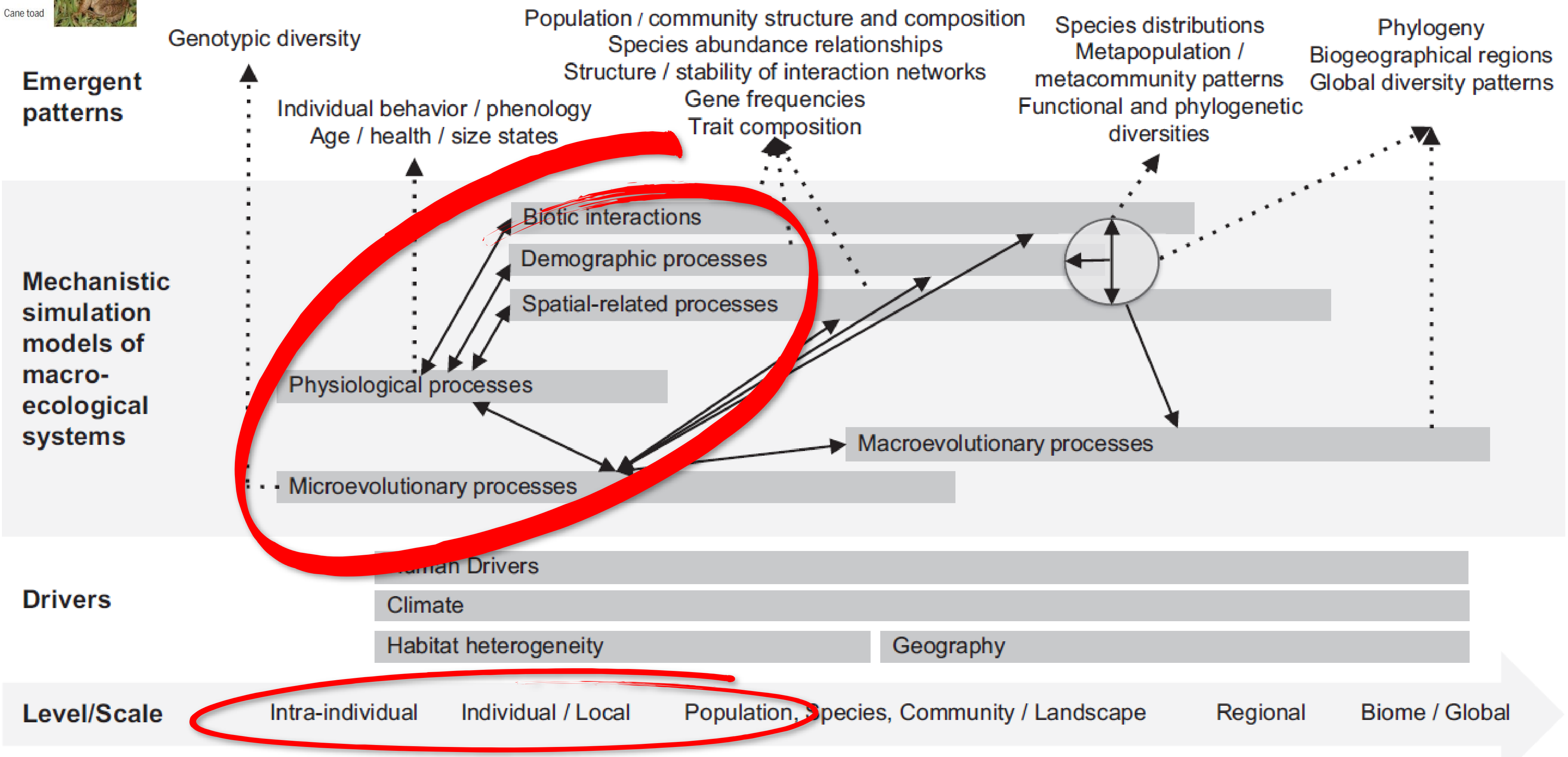


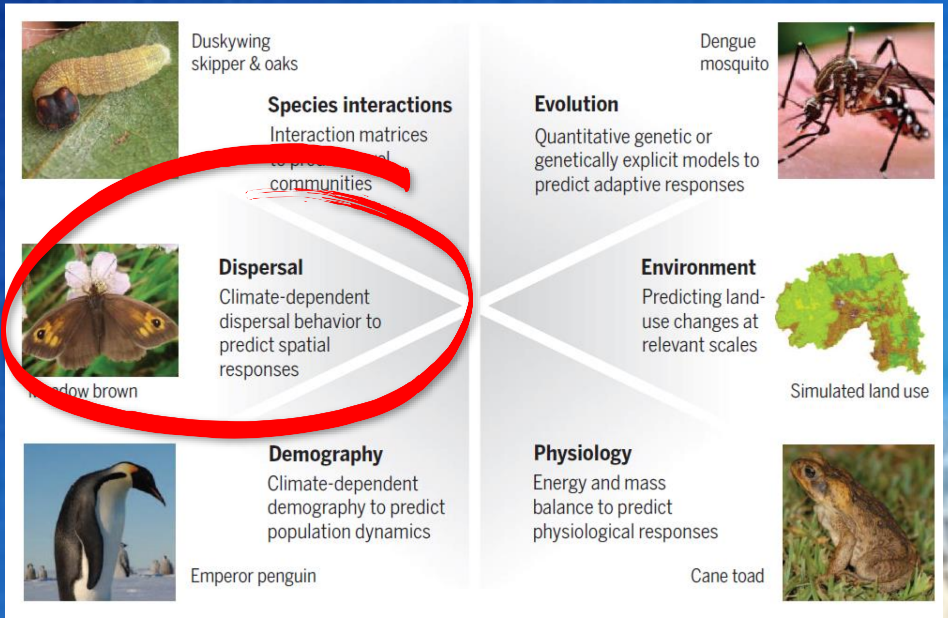
Urban, Bocedi et al. 2016, Science



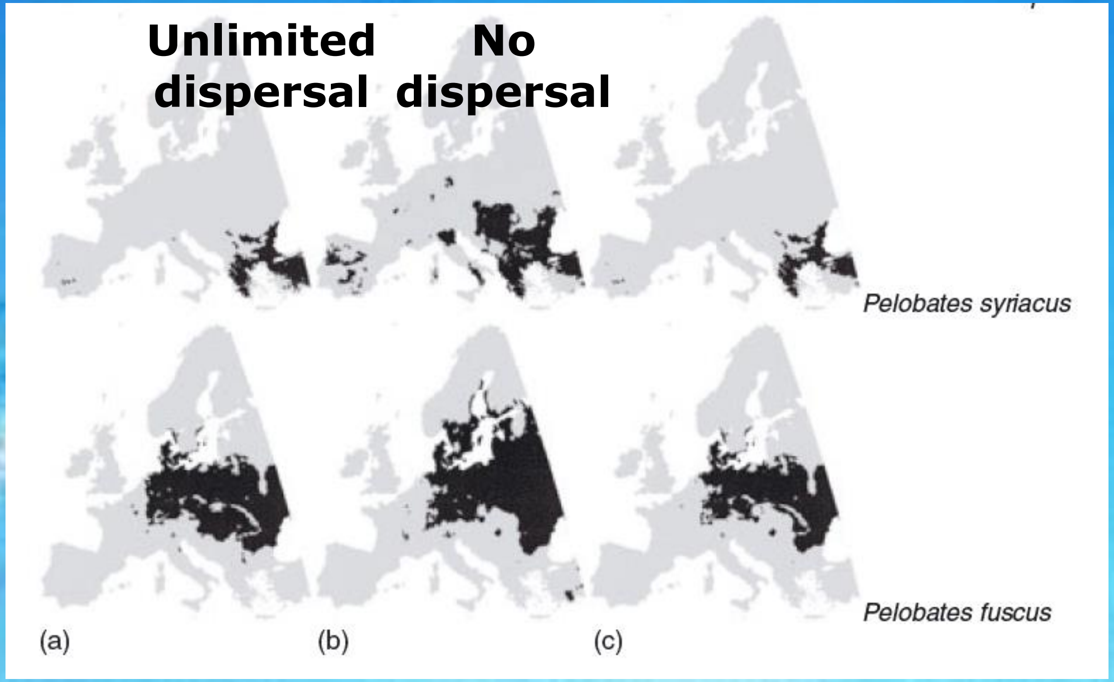
Which processes?

Cabral et al. 2017, Ecography





No dispersal vs. unlimited dispersal



Araújo et al. 2006, J. Biogeogr.

Dispersal kernels – "one fits all"

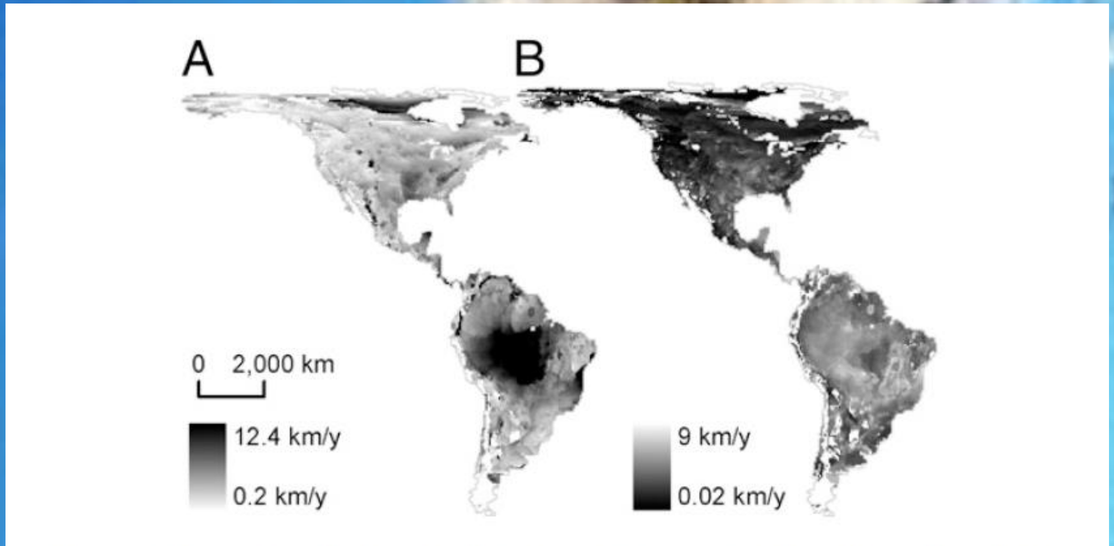
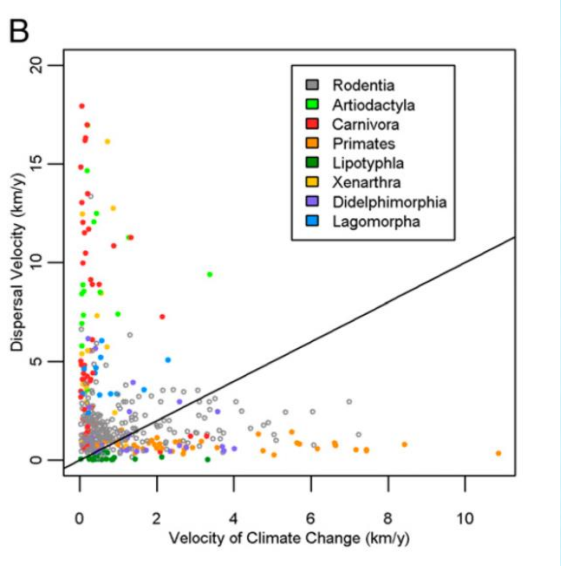
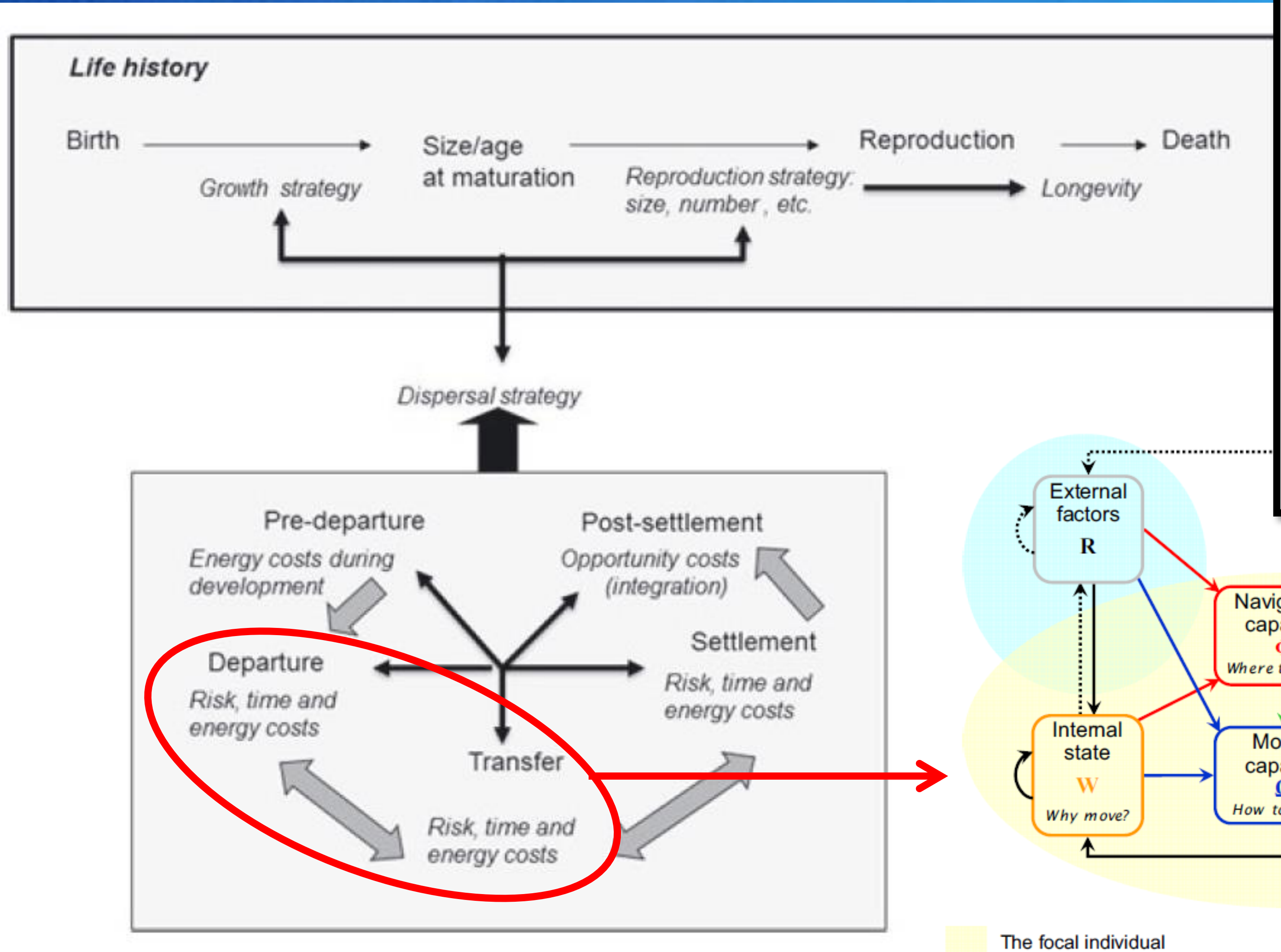


Fig. 2. Average velocity of climate change as projected by 10 climate models (*A*) and average dispersal velocity (*B*) of all mammals that are projected to be unable to keep pace with climate change.

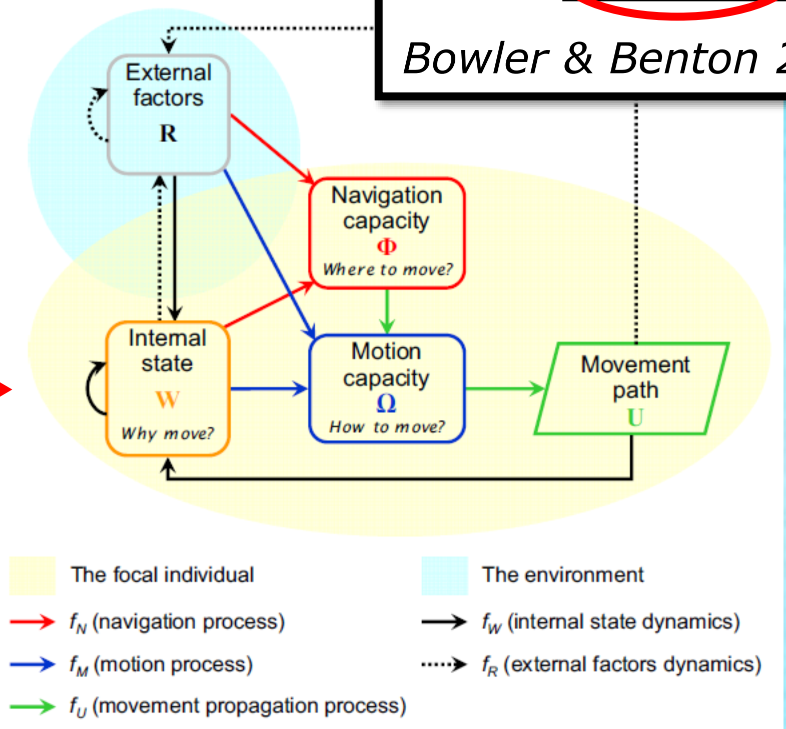


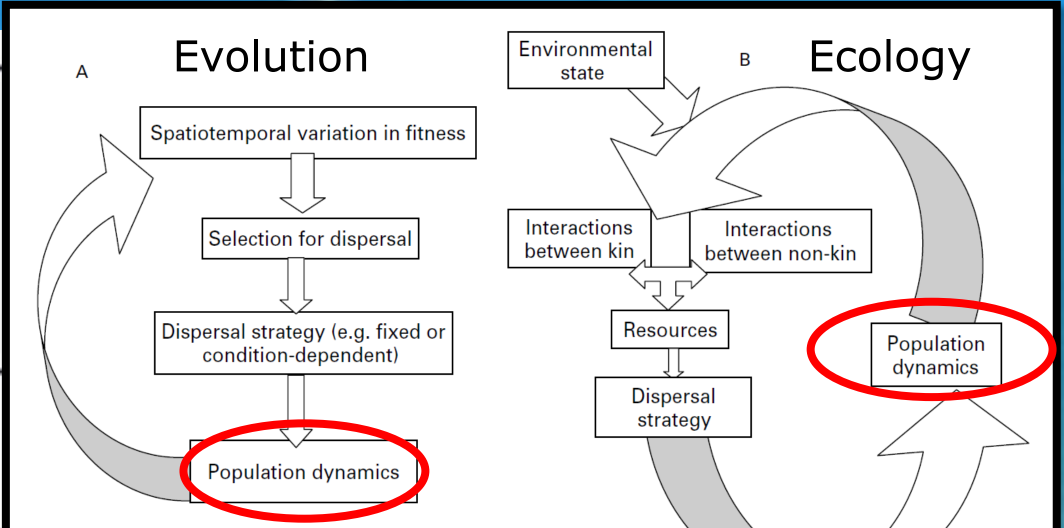
Schloss et al. 2012, PNAS

Dispersal is a complex process



Bonte et al. 2012, Biol. Rev.





Bowler & Benton 2005, Biol. Rev.

Nathan et al. 2008, PNAS

Do process-based model perform better than correlative ones?

Global Change Biology

Global Change Biology (2016) 22, 2651–2664, doi: 10.1111/gcb.13251

Benchmarking novel approaches for modelling species range dynamics

DAMARIS ZURELL[1], WILFRIED THUILLER[2,3], JÖRN PAGEL[4], JULIANO S. CABRAL[5,6], TAMARA MÜNKEMÜLLER[2,3], DOMINIQUE GRAVEL[7], STEFAN DULLINGER[8], SIGNE NORMAND[9], KATJA H. SCHIFFERS[2,3,10], KARA A. MOORE[11] and NIKLAUS E. ZIMMERMANN[1,12]

Received: 27 May 2016 | Accepted: 14 September 2017

DOI: 10.1111/gcb.13935

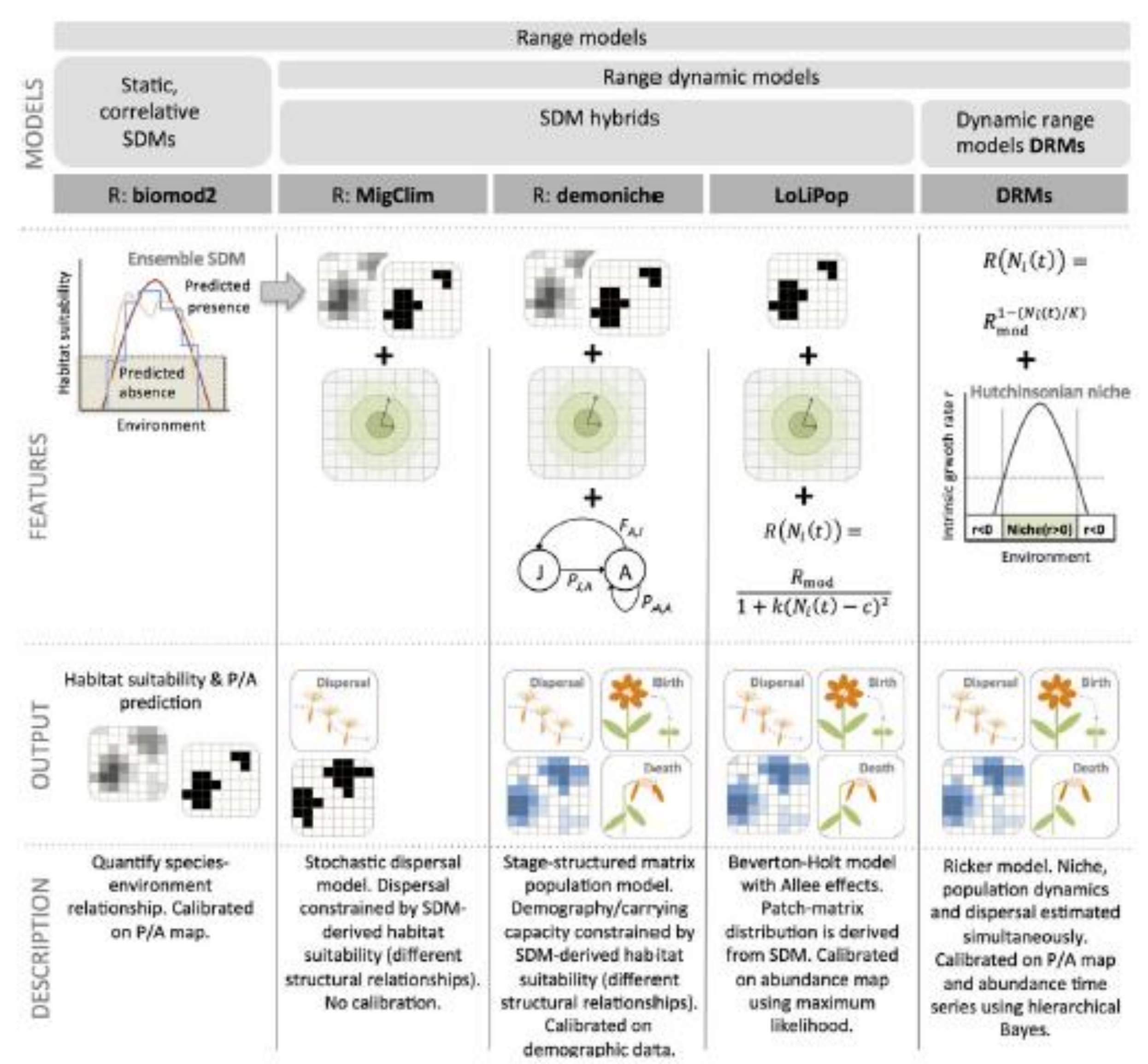
PRIMARY RESEARCH ARTICLE

WILEY Global Change Biology

How complex should models be? Comparing correlative and mechanistic range dynamics models

Damien A. Fordham[1] | Cleo Bertelsmeier[1,2] | Barry W. Brook[3] | Regan Early[4] | Dora Neto[5] | Stuart C. Brown[1] | Sébastien Ollier[6] | Miguel B. Araújo[5,7,8]

Do process-based model perform better than correlative ones?

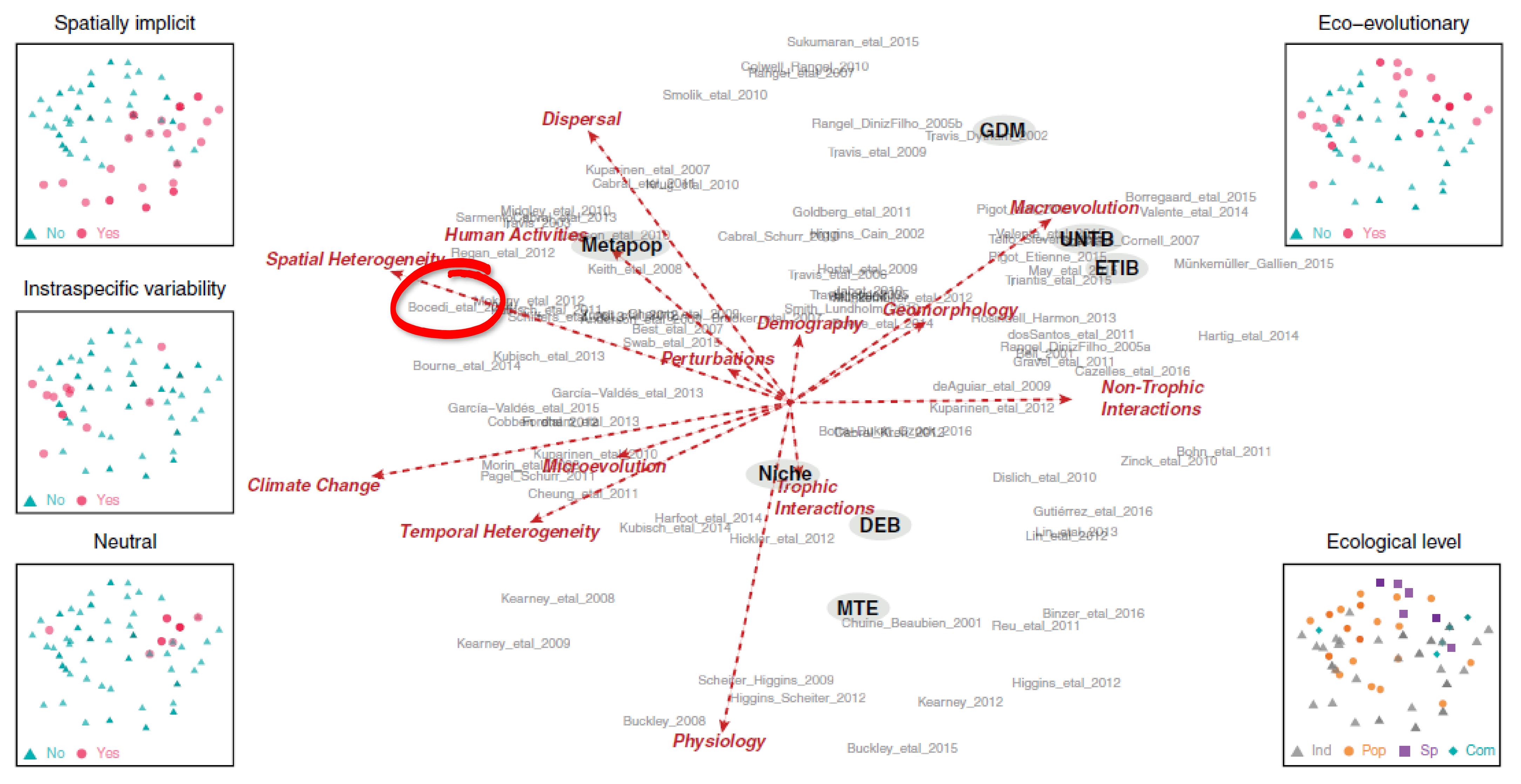


... it depends....

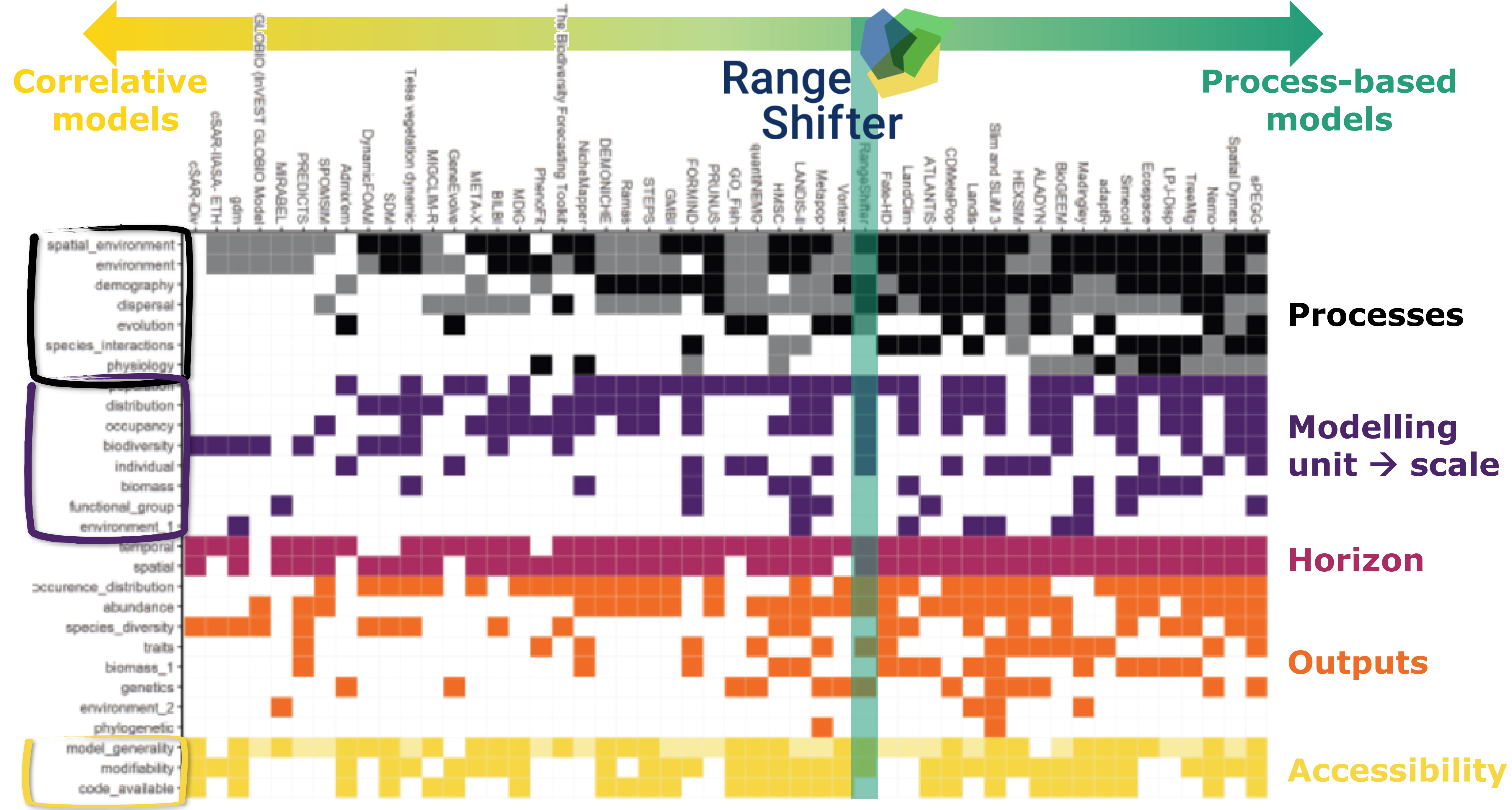
- ✓ Substantially improve predictions under climate change compared to purely correlative SDMs
- ✓ Also predict reasonable extinction risks
- ✗ More data required
- ✗ SDMs may perform even better under current conditions

Zurell et al. 2016, Global Change Biology

Process-based model: where are we at?



Cabral et al. 2017, Ecography



Urban et al. 2021, BioScience

Range Shifter

https://rangeshifter.github.io

Methods in Ecology and Evolution
British Ecological Society

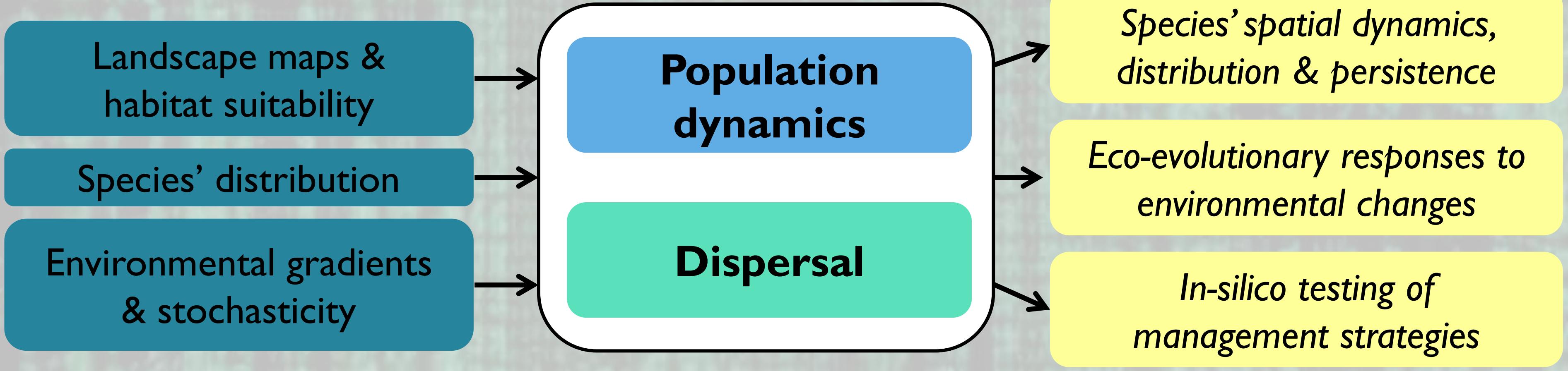
Methods in Ecology and Evolution 2014, 5, 388–396 doi: 10.1111/2041-210X.12162

APPLICATION

RangeShifter: a platform for modelling spatial eco-evolutionary dynamics and species' responses to environmental changes

Greta Bocedi[1]*, Stephen C.F. Palmer[1], Guy Pe'er[2], Risto K. Heikkinen[3], Yiannis G. Matsinos[4], Kevin Watts[5] and Justin M.J. Travis[1]

Individual-based, spatially explicit, stochastic model



https://rangeshifter.github.io

Range Shifter

Methods in Ecology and Evolution

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Methods in Ecology and Evolution 2014, 5, 388–396 doi: 10.1111/2041-210X.12162

APPLICATION

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ECOGRAPHY

Software notes

2021

RangeShifter 2.0: an extended and enhanced platform for modelling spatial eco-evolutionary dynamics and species' responses to environmental changes

Greta Bocedi, Stephen C. F. Palmer, Anne-Kathleen Malchow, Damaris Zurell, Kevin Watts and Justin M. J. Travis

RangeShiftR

ECOGRAPHY

Software notes

2021

RangeShiftR: an R package for individual-based simulation of spatial eco-evolutionary dynamics and species' responses to environmental changes

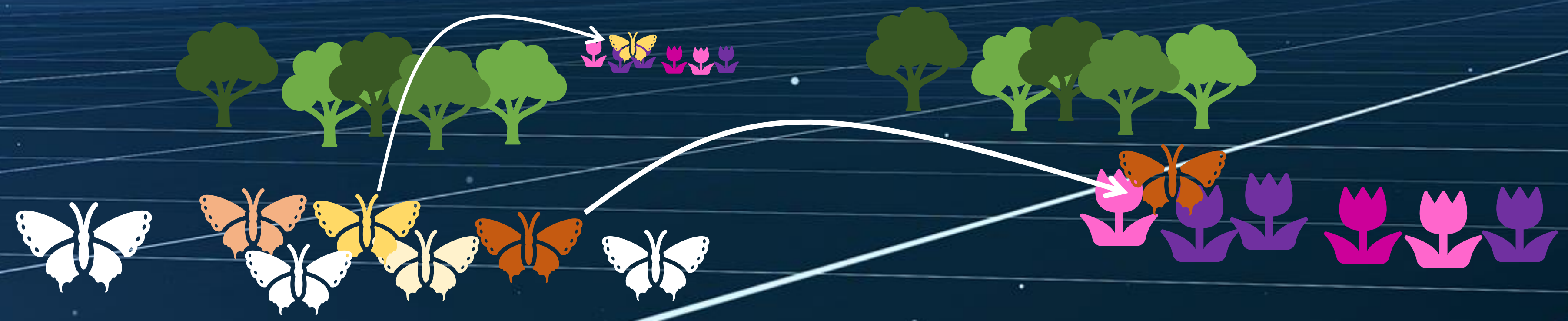
Anne-Kathleen Malchow, Greta Bocedi, Stephen C. F. Palmer, Justin M. J. Travis and Damaris Zurell

INDIVIDUAL-BASED MODELS

Individuals and their interactions are the units of the simulation

INDIVIDUAL VARIABILITY

ECOLOGY



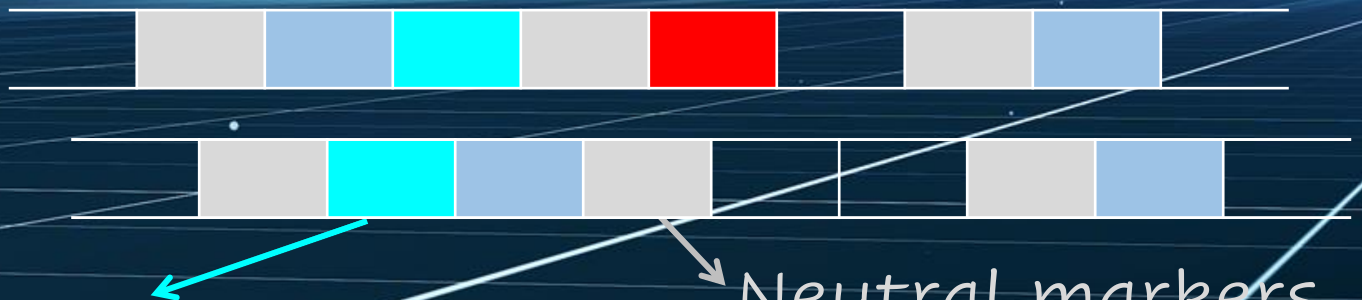
INDIVIDUAL-BASED MODELS

Individuals and their interactions are the units of the simulation

INDIVIDUAL VARIABILITY

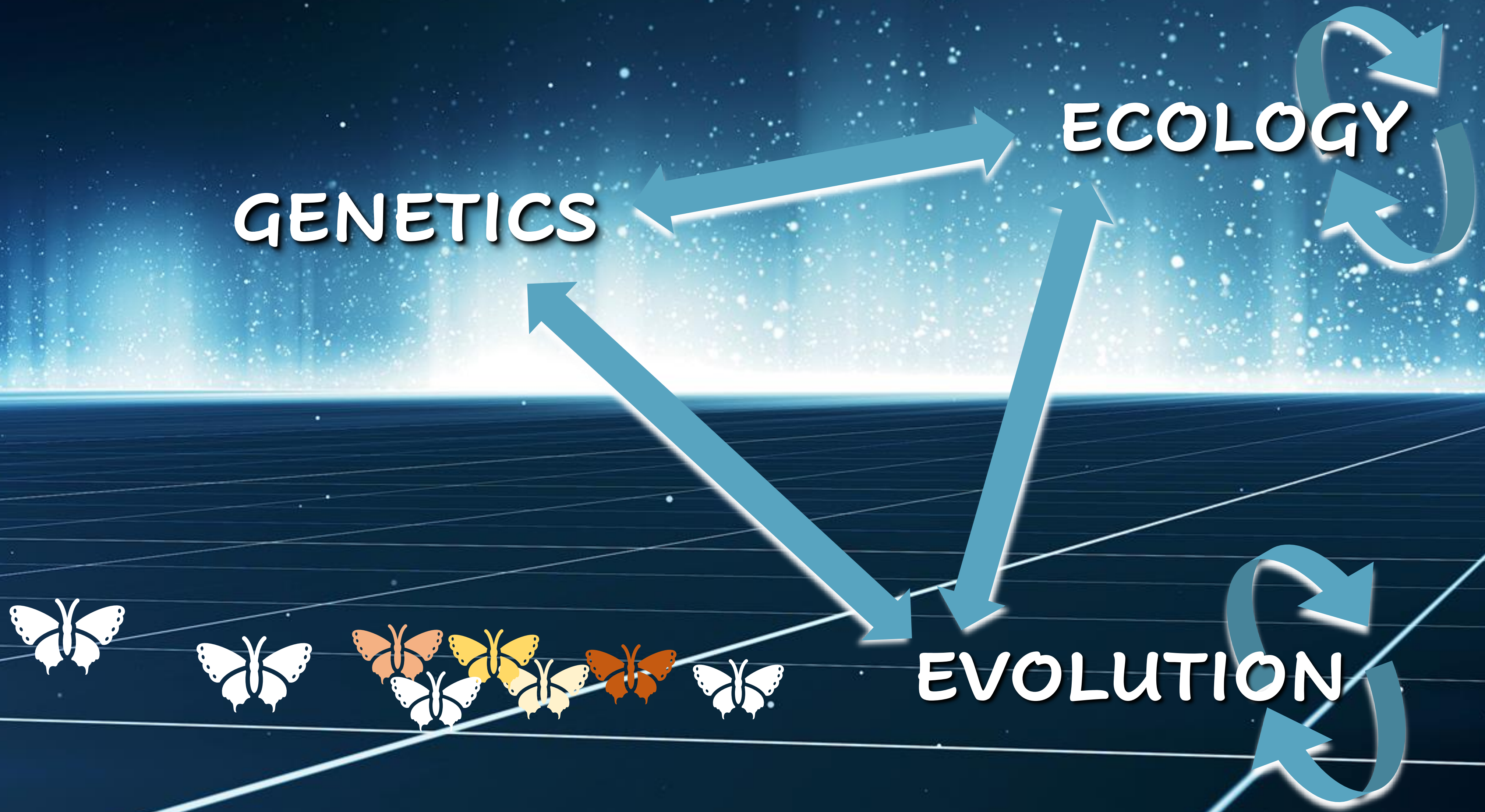
GENETICS

ECOLOGY



EVOLUTION

INDIVIDUAL-BASED MODELS

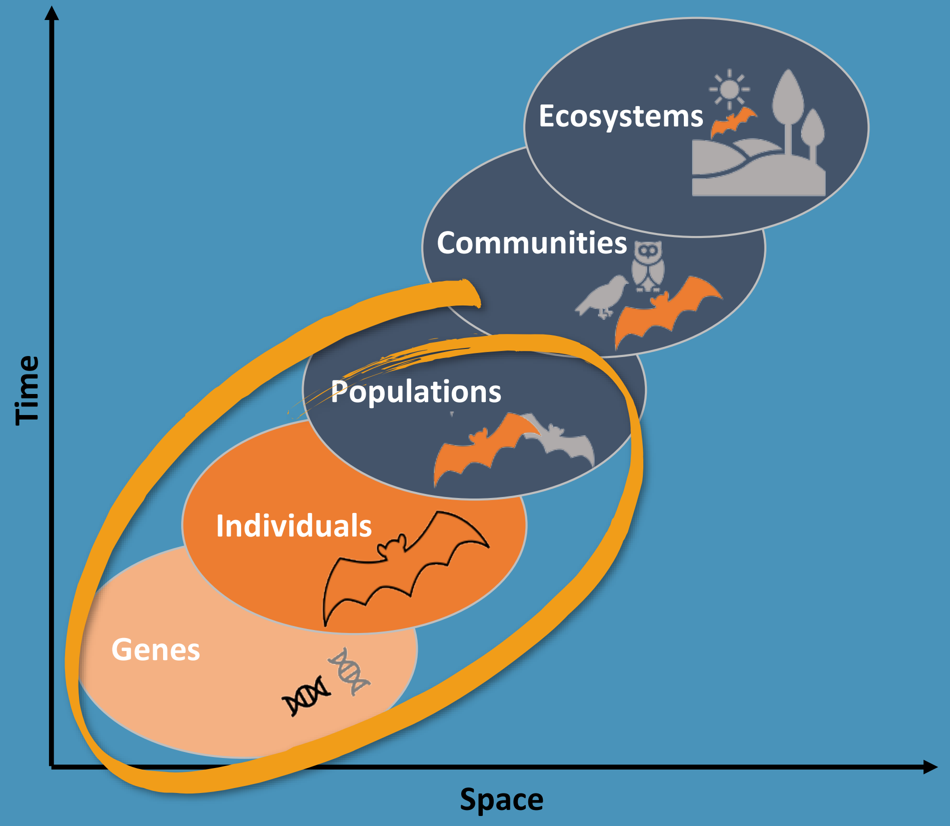


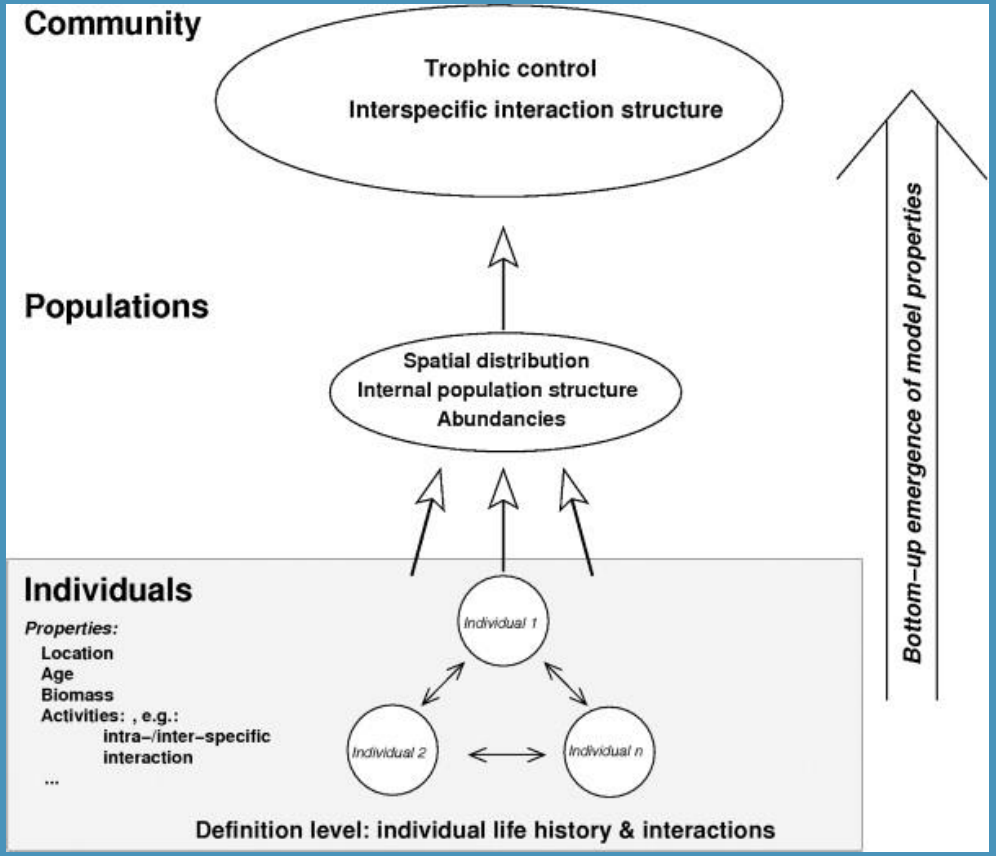
Emerging population dynamics

"The whole is more than the sum of its parts" – Aristotle

Bottom-up approach

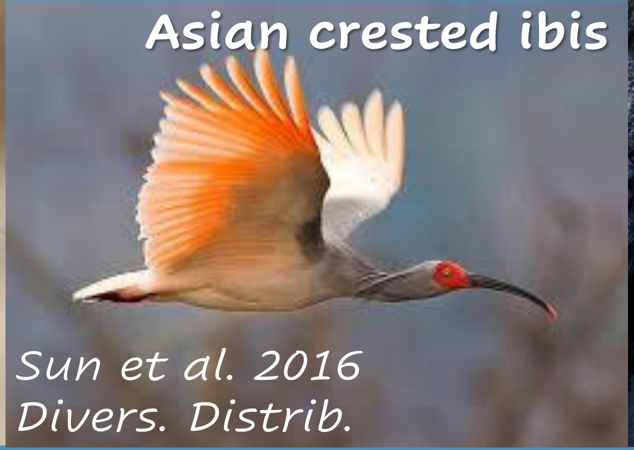
use knowledge about behaviour of single individuals to infer properties of the larger population or community





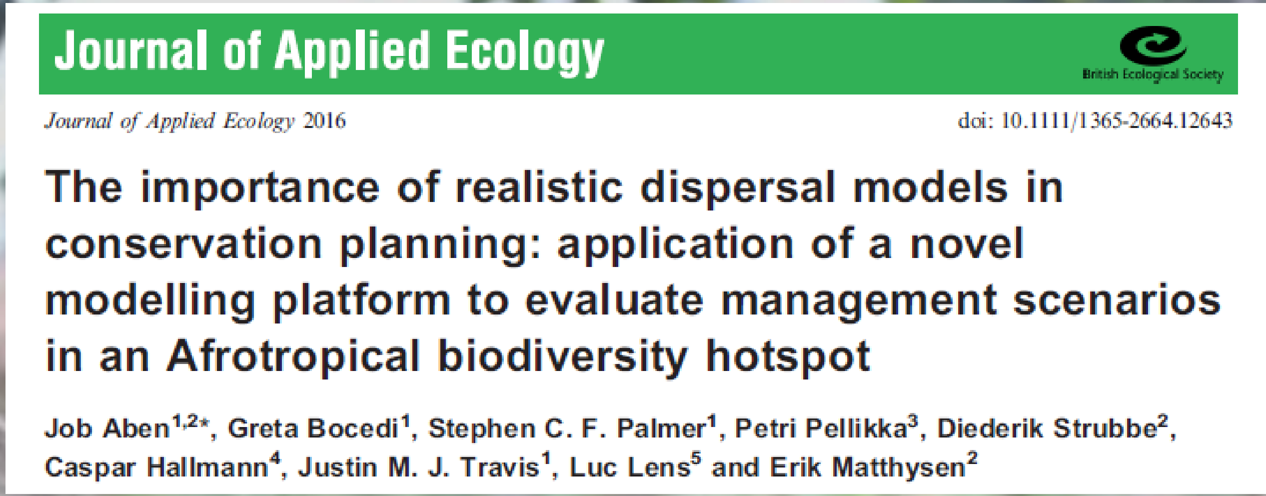
Reuter, et al. (2010) Basic Appl Ecol 11: 572-581.

Range Shifter



- ✓ Investigate species' eco-evolutionary responses to environmental changes across their ranges
- ✓ Develop new theory to increase understanding
- ✓ Tool for exploring relative effectiveness of alternative management interventions

Application to conservation management


Journal of Applied Ecology

Journal of Applied Ecology 2016 doi: 10.1111/1365-2664.12643

The importance of realistic dispersal models in conservation planning: application of a novel modelling platform to evaluate management scenarios in an Afrotropical biodiversity hotspot

Job Aben[1,2*], Greta Bocedi[1], Stephen C. F. Palmer[1], Petri Pellikka[3], Diederik Strubbe[2], Caspar Hallmann[4], Justin M. J. Travis[1], Luc Lens[5] and Erik Matthysen[2]

Aims:

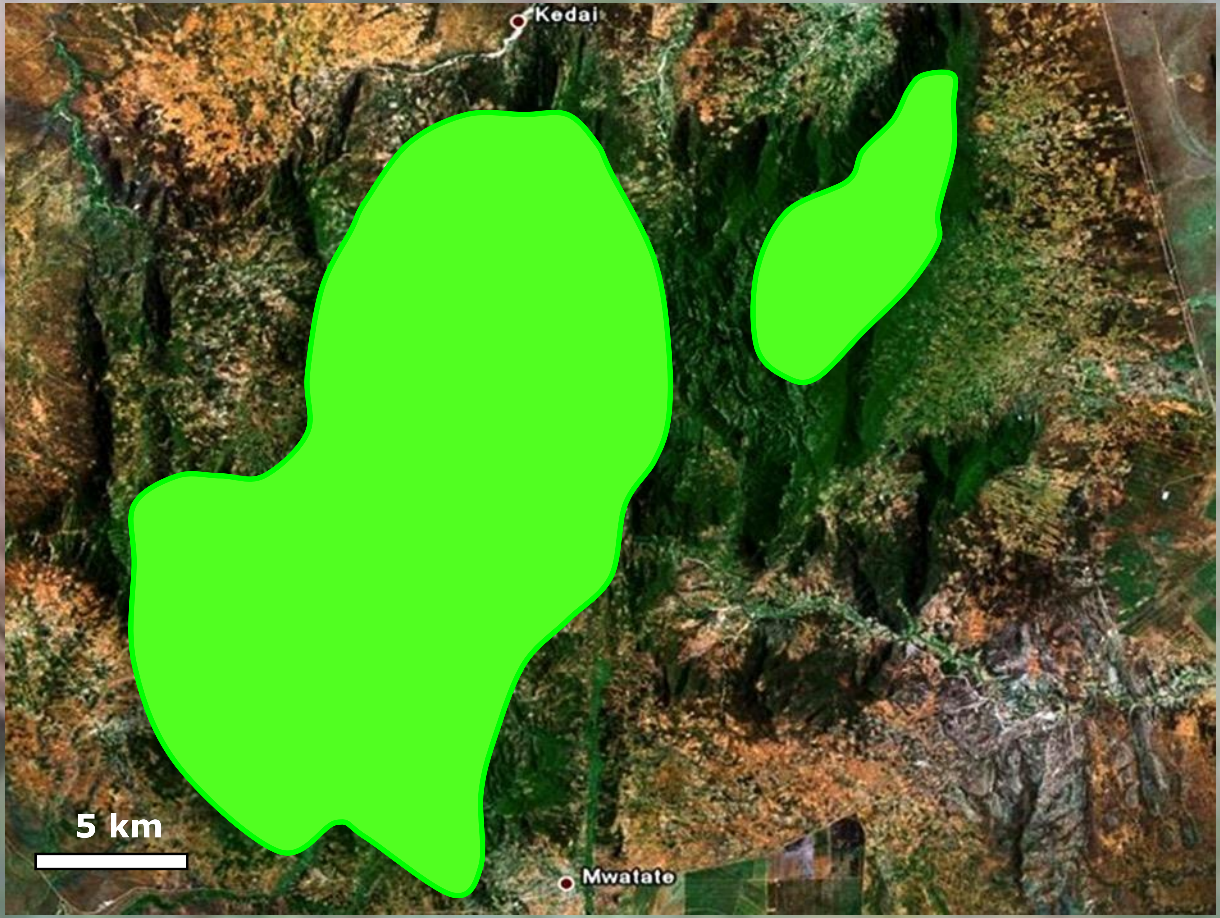
1. Quantifying movement behaviour in relation to the landscape

2. Validating a connectivity model using empirical data on:
   - animal movement
   - gene flow

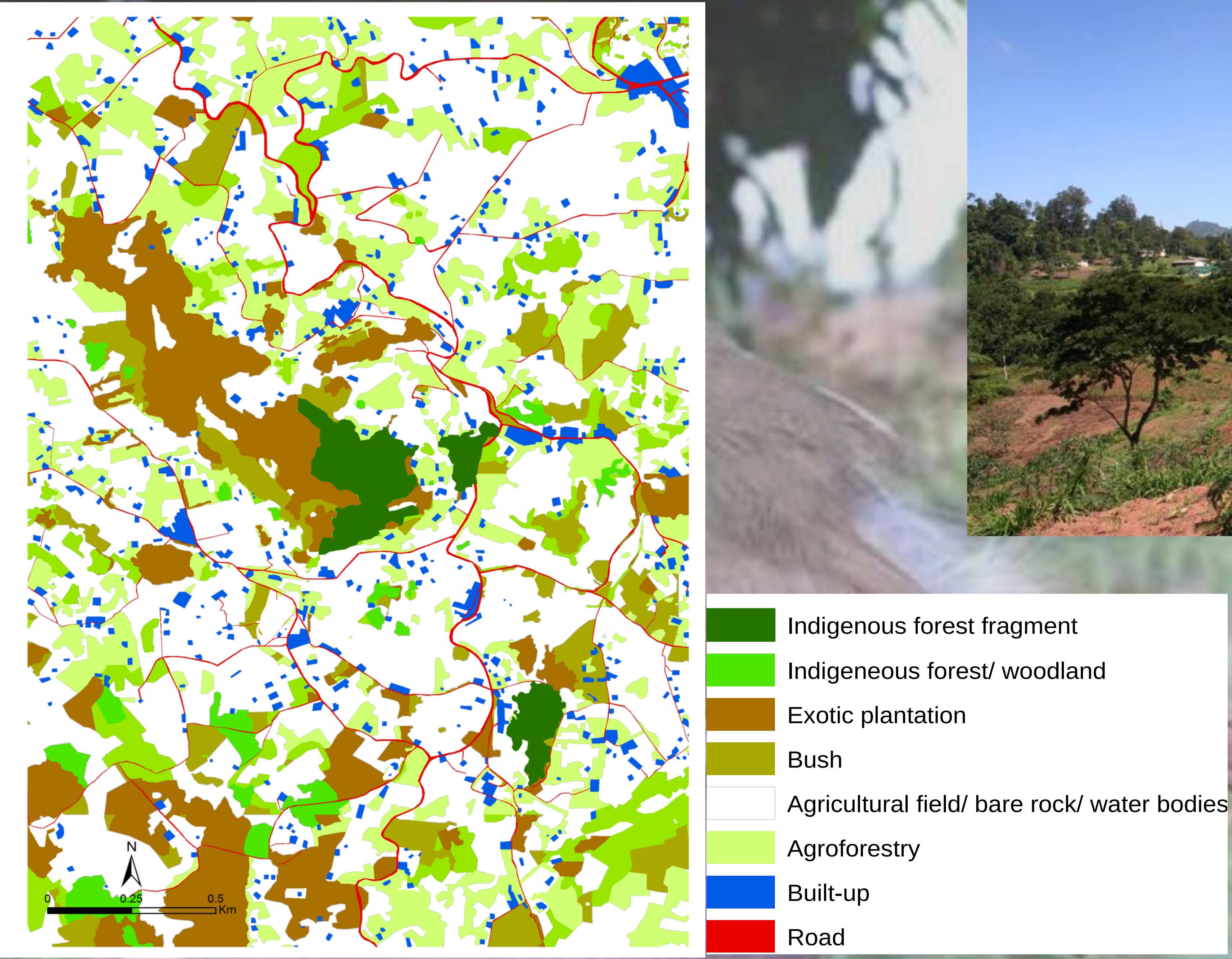
3. Applying spatially explicit population models for conservation planning

the Taita Hills

Severe deforestation



Aben, Bocedi *et al.* 2016, *J. Appl. Ecol.*



Aben, Bocedi *et al.* 2016, *J. Appl. Ecol.*

Cabanis's greenbul *Phyllastrephus cabanisi*

- Forest-dependent insectivore - arboreal forager
- Sensitive to fragmentation
- Only occurring in a subset of patches

Aims:

1. Quantifying movement behaviour in relation to the landscape

- Translocation experiments
  28 greenbuls
- Radio tracking
  1123 point-fixes of locations

Movement paths

Aben, Bocedi *et al.* 2016, *J. Appl. Ecol.*

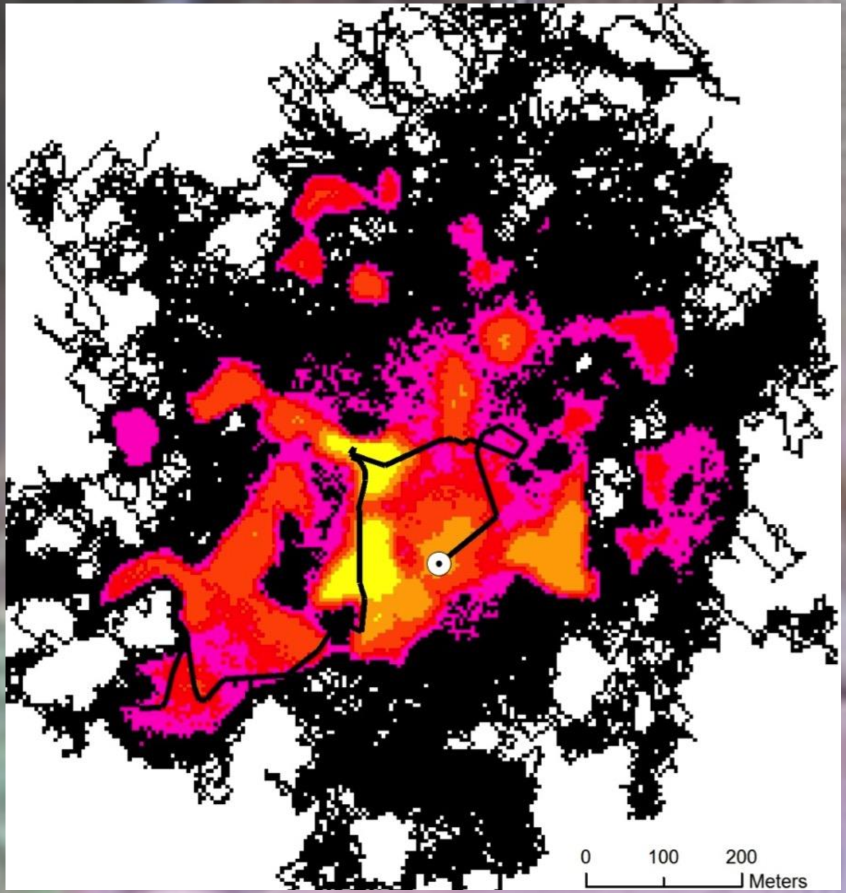
2. Validating connectivity model using empirical data on:

- animal movement
- gene flow

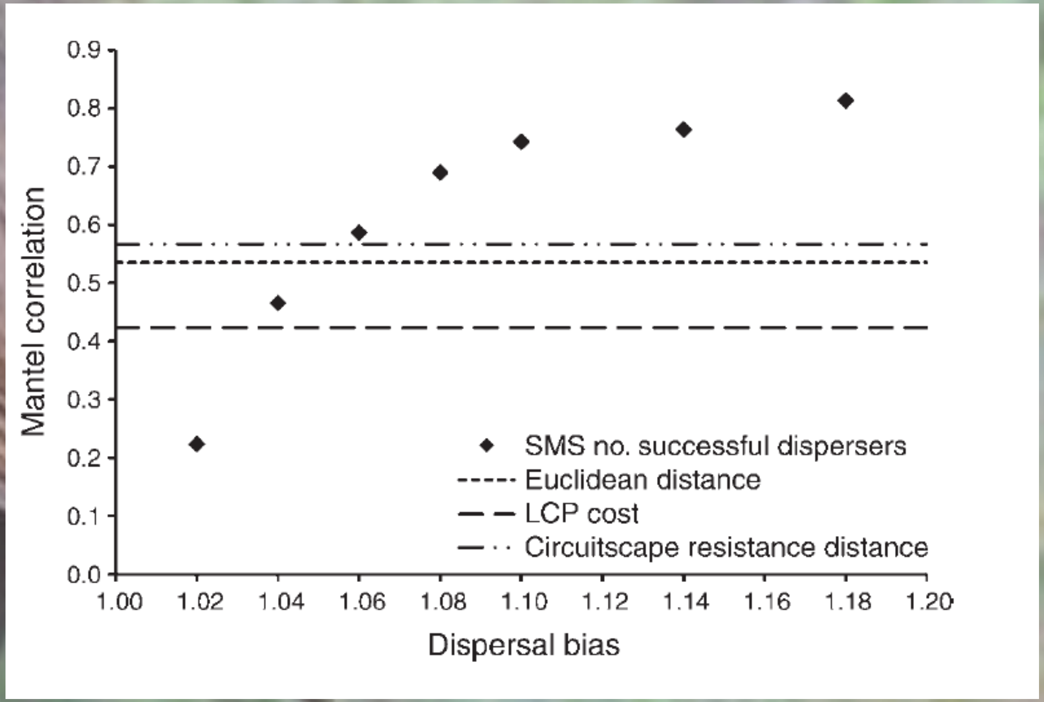
Methods in Ecology and Evolution
British Ecological Society
Methods in Ecology & Evolution doi: 10.1111/j.2041-210X.2010.00073.x

Introducing a 'stochastic movement simulator' for estimating habitat connectivity

Stephen C. F. Palmer[1]*, Aurélie Coulon[2] and Justin M. J. Travis[1]

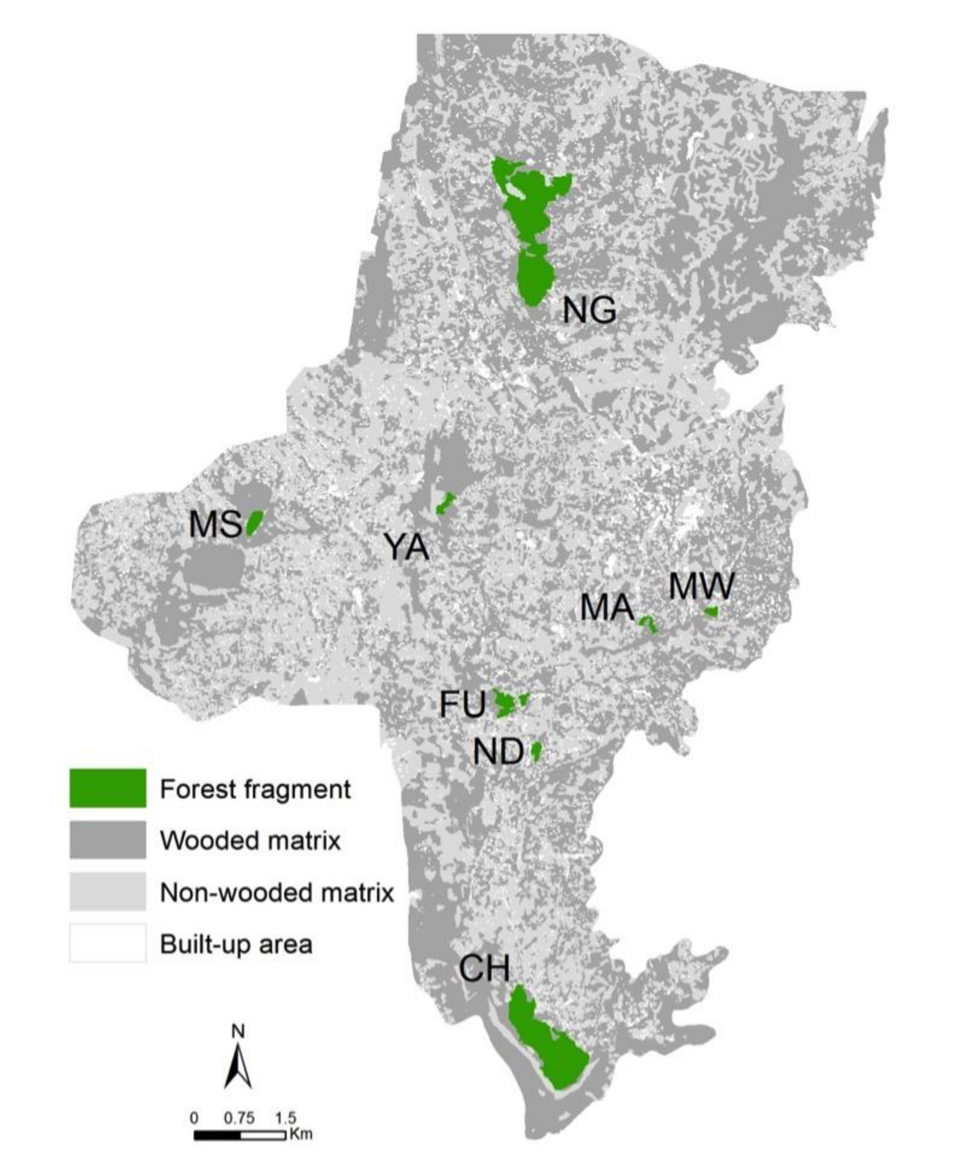


Aben et al. 2014, J. Appl. Ecol.



Coulon et al. 2015, Ecology

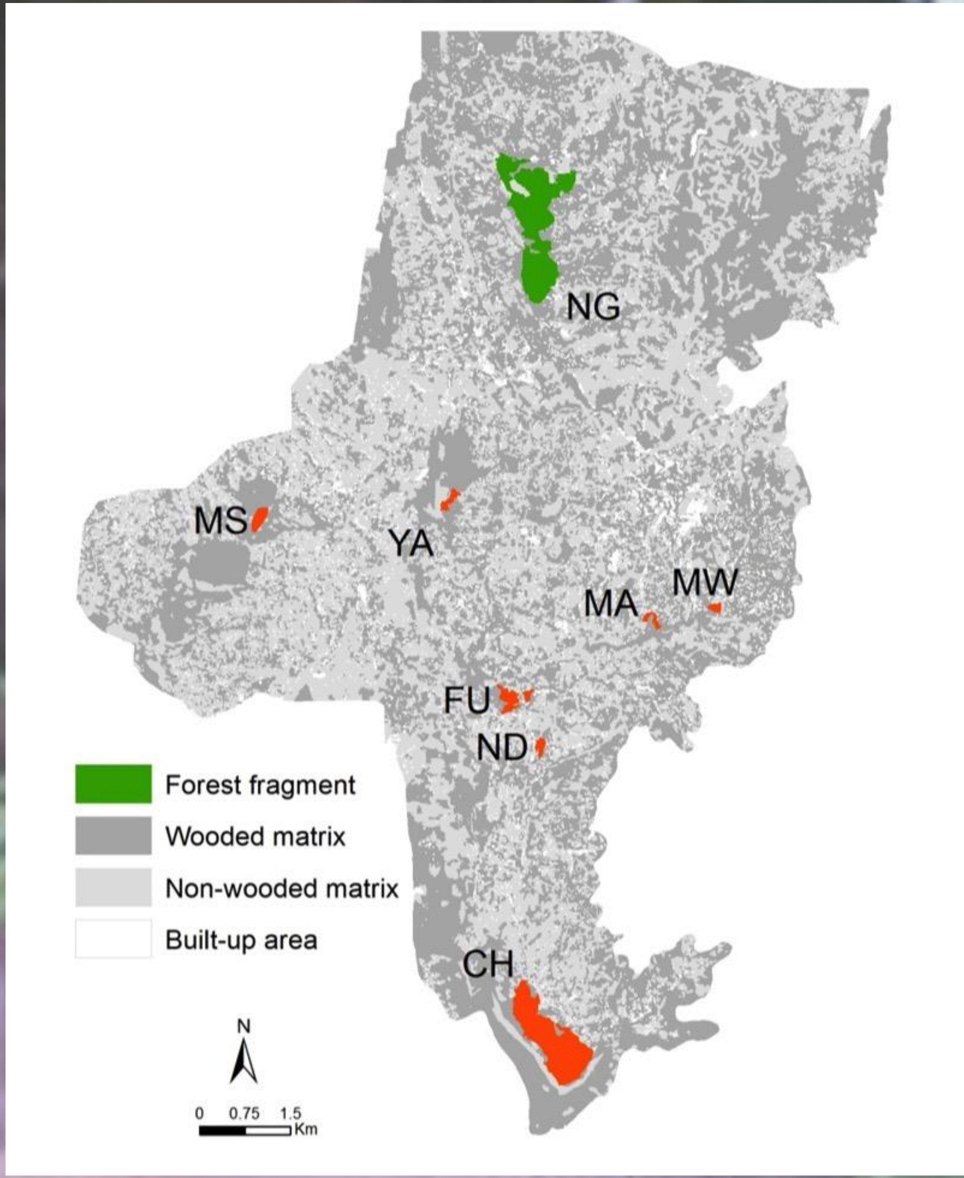
3. Applying spatially explicit population models for conservation planning



Conservation planning in the Taita Hills

- Stakeholder workshops
- Realistic options to increase species persistence (<u>management scenarios</u>):

3. Applying spatially explicit population models for conservation planning

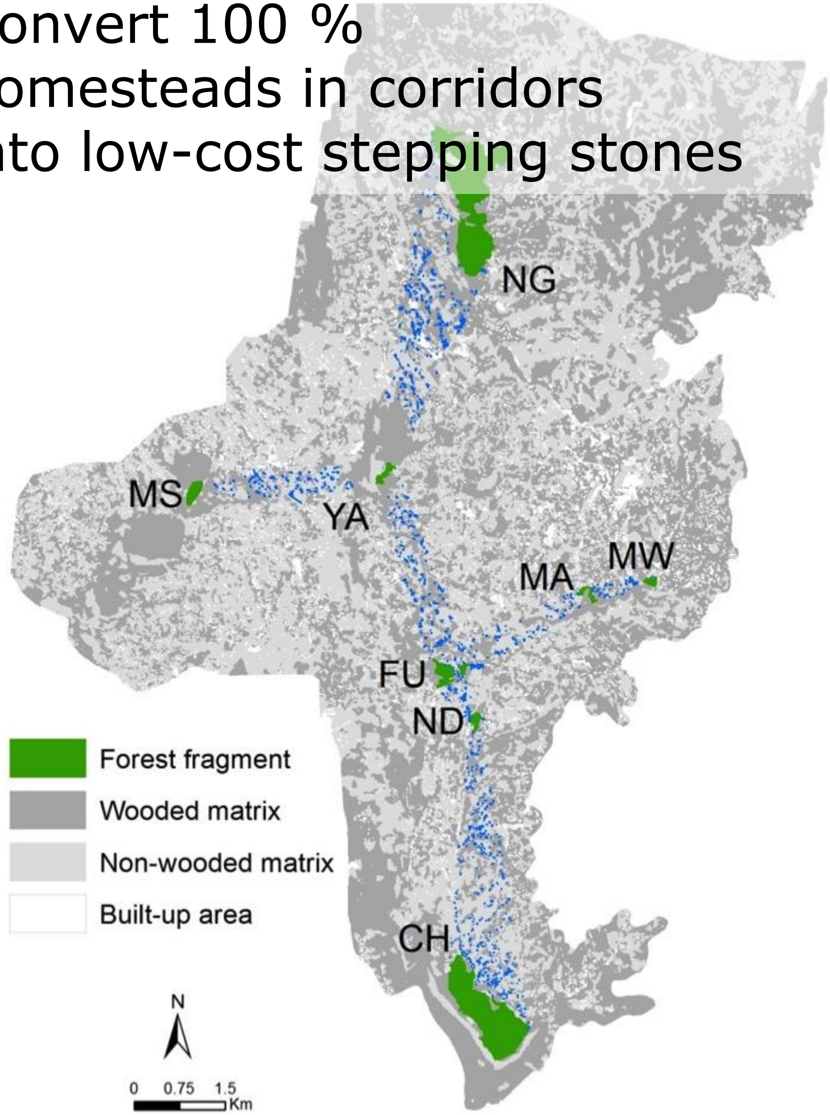


Conservation planning in the Taita Hills

- Stakeholder workshops
- Realistic options to increase species persistence (management scenarios):
  1. Habitat restoration

3. Applying spatially explicit population models for conservation planning

Convert 100 % homesteads in corridors into low-cost stepping stones

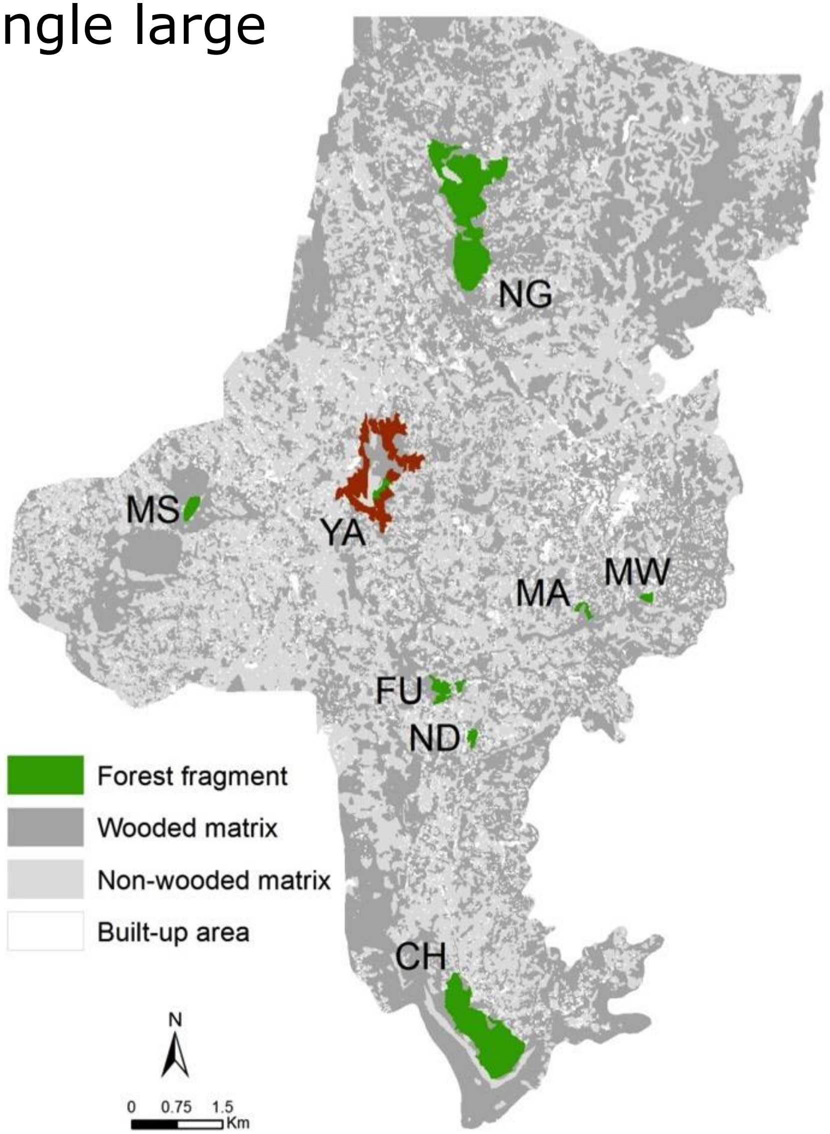


Conservation planning in the Taita Hills

- Stakeholder workshops
- Realistic options to increase species persistence (<u>management scenarios</u>):
  1. Habitat restoration
  2. Matrix enrichment by planting indigenous trees at people homesteads

3. Applying spatially explicit population models for conservation planning

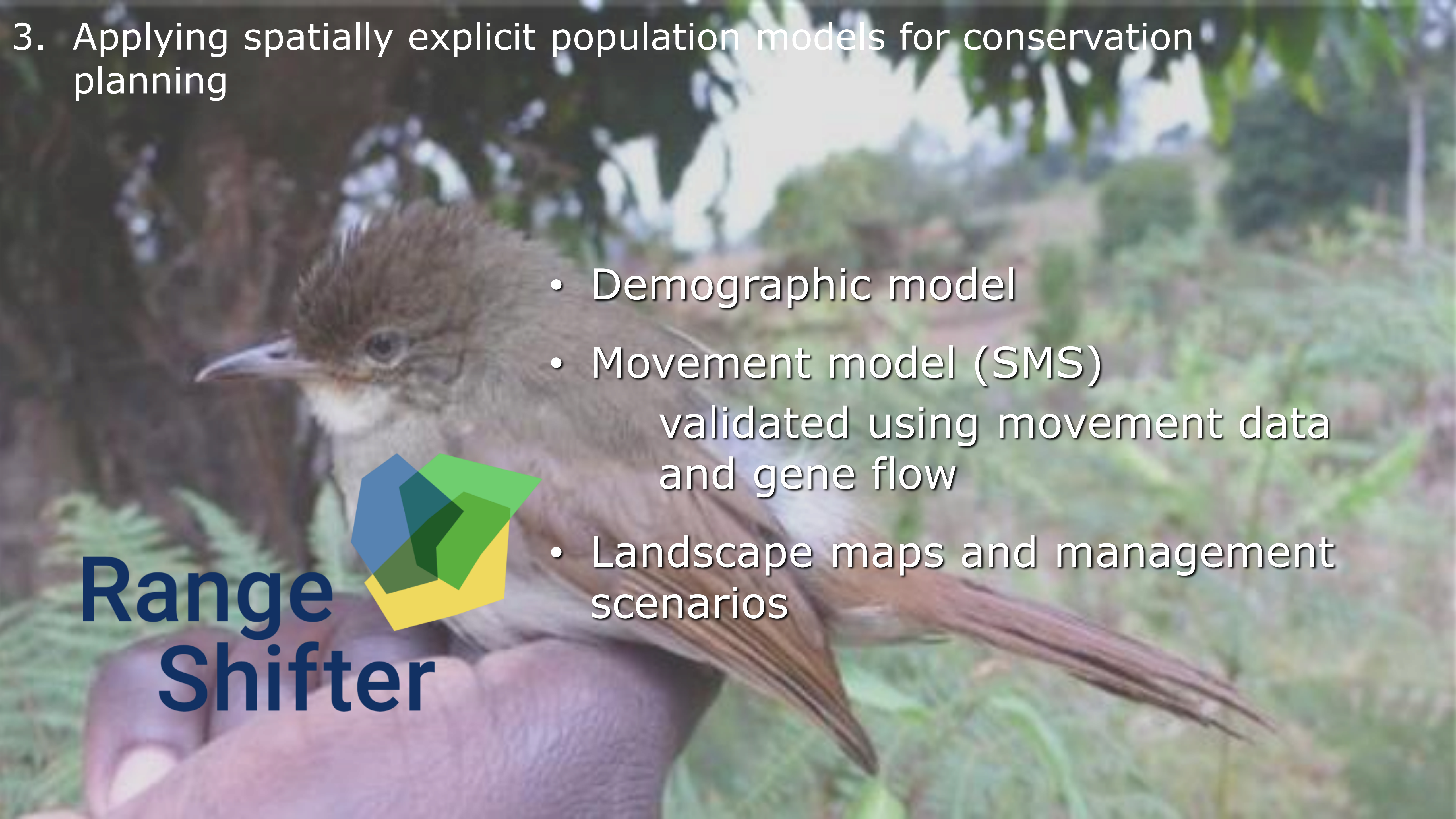
Single large



Conservation planning in the Taita Hills

- Stakeholder workshops
- Realistic options to increase species persistence (management scenarios):
  1. Habitat restoration
  2. Matrix enrichment by planting indigenous trees at people homesteads
  3. Conversion of exotic plantations into indigenous forest

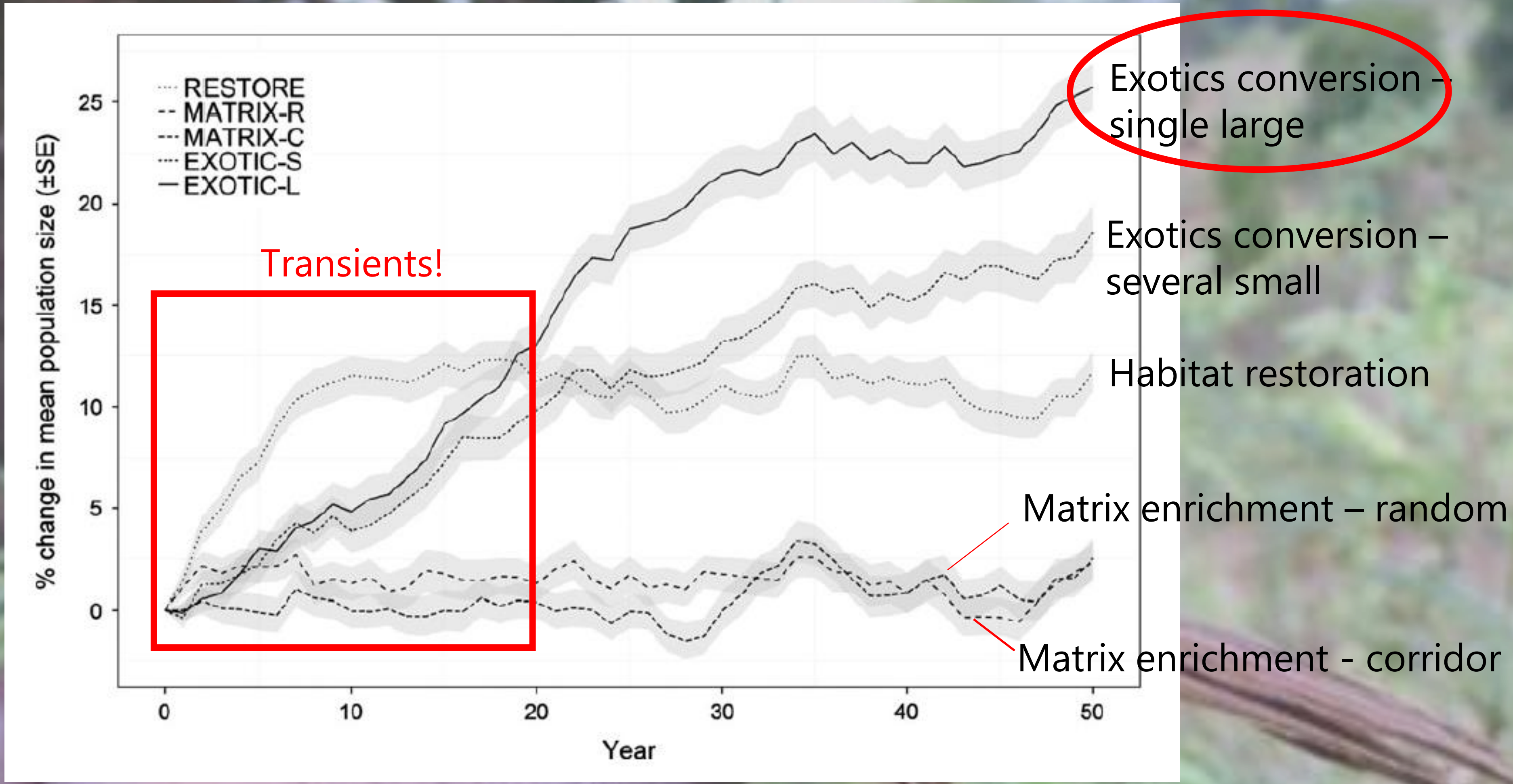
3. Applying spatially explicit population models for conservation planning



- Demographic model
- Movement model (SMS)

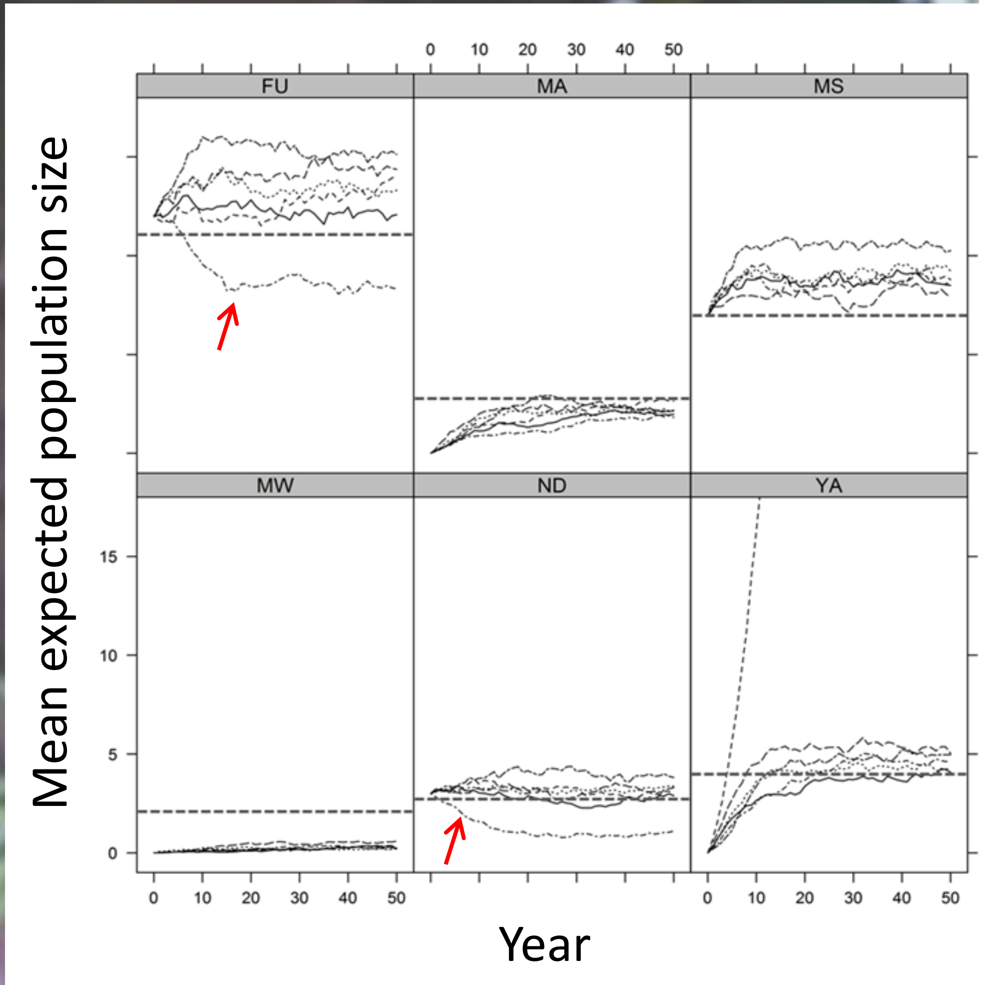
  validated using movement data and gene flow
- Landscape maps and management scenarios

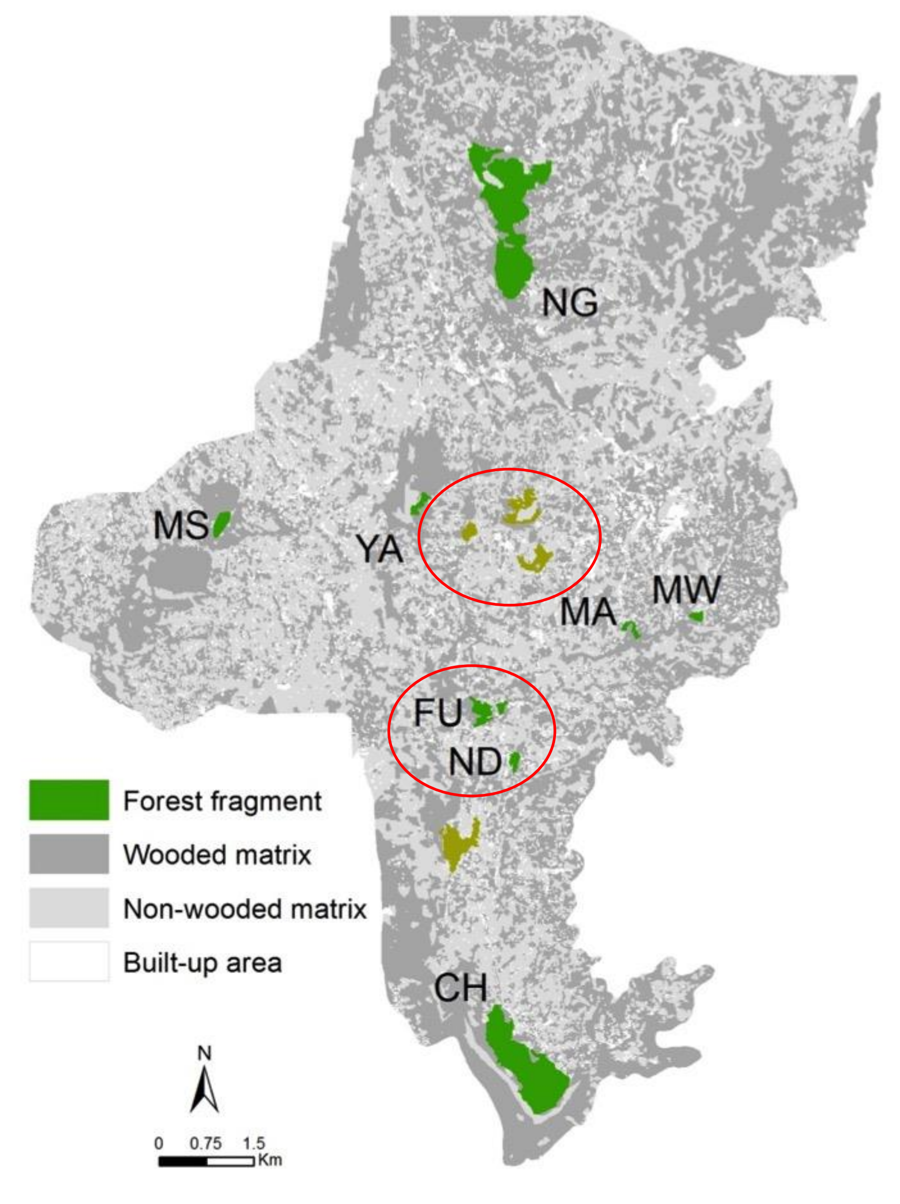
Range Shifter



RESTORE
MATRIX-R
MATRIX-C
EXOTIC-S
EXOTIC-L
Transients!
% change in mean population size (±SE)
25
20
15
10
5
0
0
10
20
30
40
50
Year
Exotics conversion – single large
Exotics conversion – several small
Habitat restoration
Matrix enrichment – random
Matrix enrichment - corridor

Shading effects of new patches





Ecological Applications, 0(0), 2021, e02338

Reducing persecution is more effective for restoring large carnivores than restoring their prey

Benjamin Bleyhl,[1,2,15] Arash Ghoddousi,[1] Elshad Askerov,[3,4,5] Greta Bocedi,[6] Urs Breitenmoser,[7,8] Karen Manvelyan,[9] Stephen C. F. Palmer,[6] Mahmood Soofi,[6,10] Paul Weinberg,[1] Nugzar Zazanashvili,[5,12] Valerii Shmunk,[13] Damaris Zurell,[1,14] and Tobias Kuemmerle[1,2]

x Persecution

x Prey depletion

- What is the potential spatial structure and size of a future Persian leopard metapopulation in the Caucasus?
- How do <u>persecution reduction</u> & <u>prey restoration</u> affect metapopulation viability?

- Habitat suitability model

(validated with camera traps, scrapes and scats from WWF's Caucasus Programme Office)

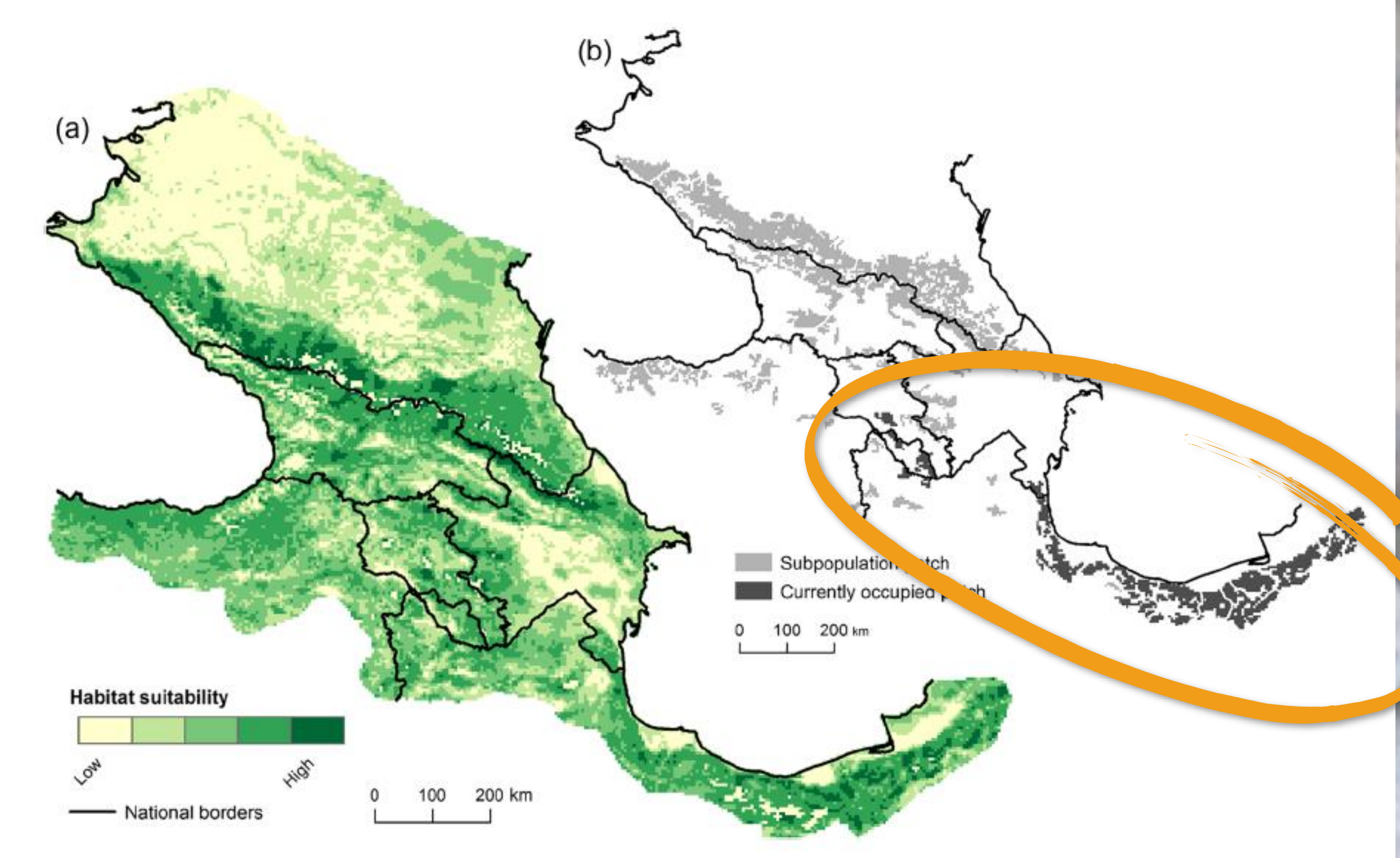


Photo credit: WWF-Caucasus

Bleyhl et al. 2021, Ecol. Appl.

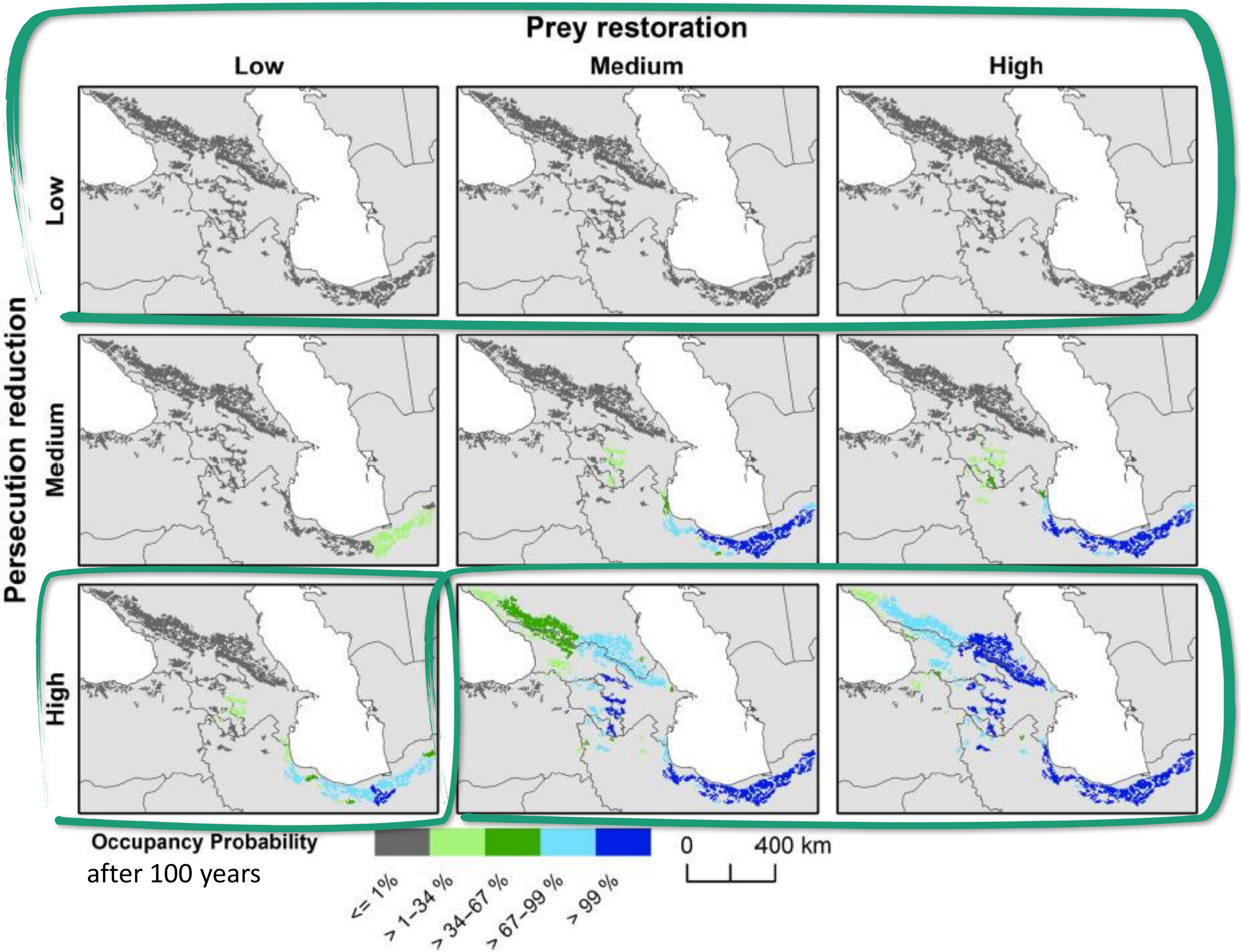
- Habitat suitability model

(validated with camera traps, scrapes and scats from WWF's Caucasus Programme Office)

- Parameterize a spatially-explicit population model
  - ✓ Prey restoration scenarios
  - ✓ Persecution reduction scenarios

Range Shifter

Bleyhl et al. 2021, Ecol. Appl.



Range Shifter

Bleyhl et al. 2021, Ecol. Appl.

Range Shifter

✓ **The Caucasus has the potential to host a viable leopard metapopulation**

if the appropriate conservation measures are implemented

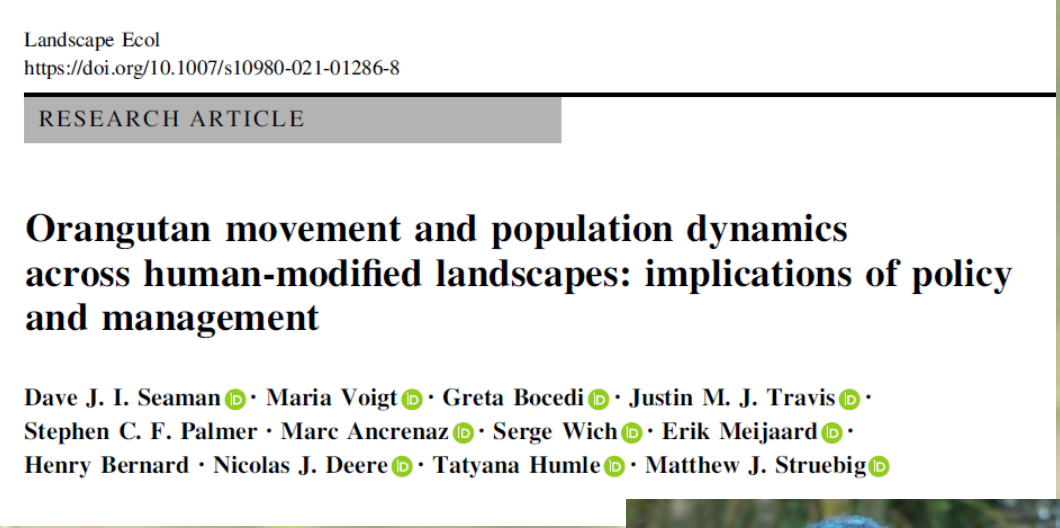
✓ **High mortality is the main constraints to population growth in the region**

- Strict low enforcement against poaching
- Carnivore-adapted live stock husbandry

✓ **Prey restoration is also needed**

Bleyhl et al. 2021, Ecol. Appl.

Range Shifter


Landscape Ecol
https://doi.org/10.1007/s10980-021-01286-8

RESEARCH ARTICLE

Orangutan movement and population dynamics across human-modified landscapes: implications of policy and management

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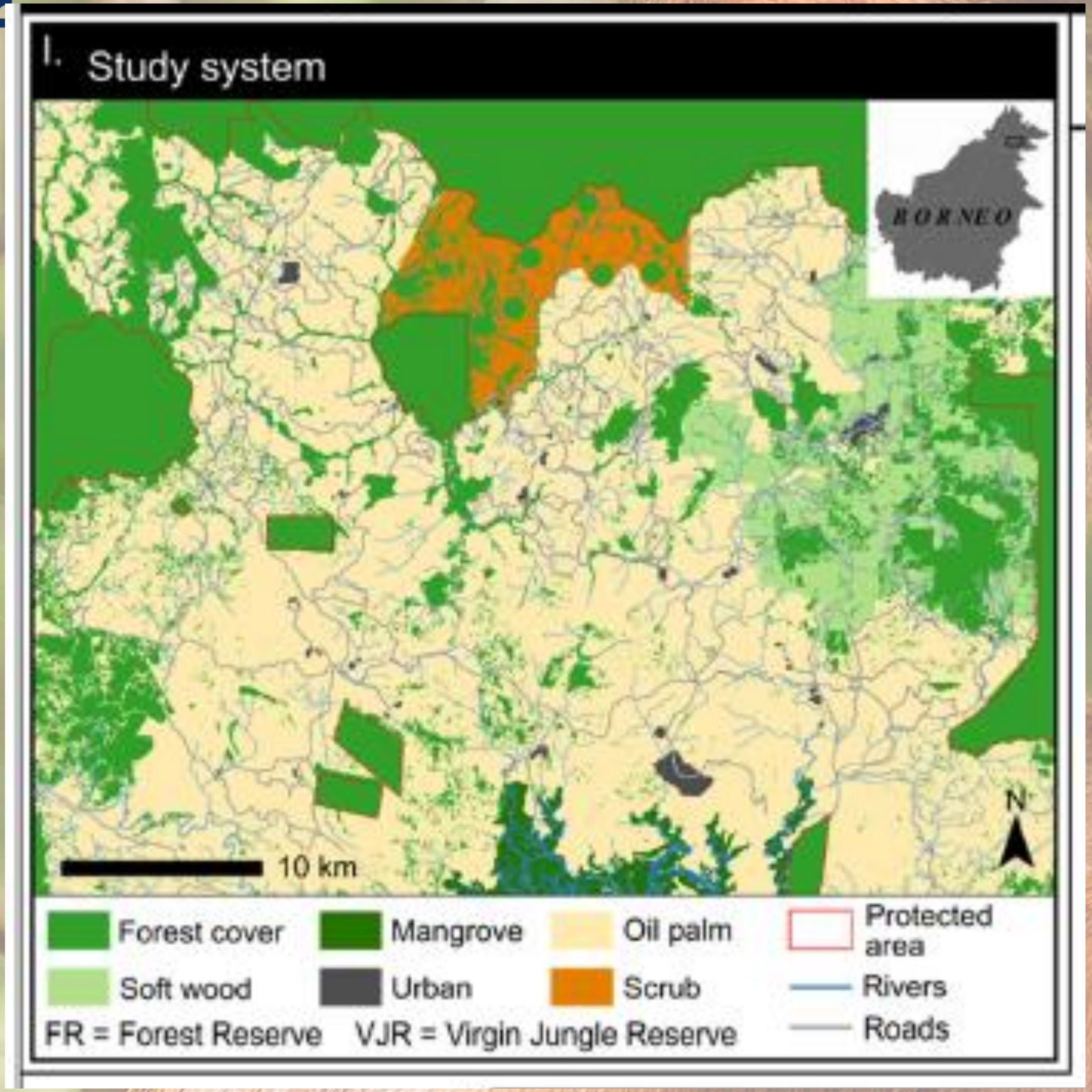
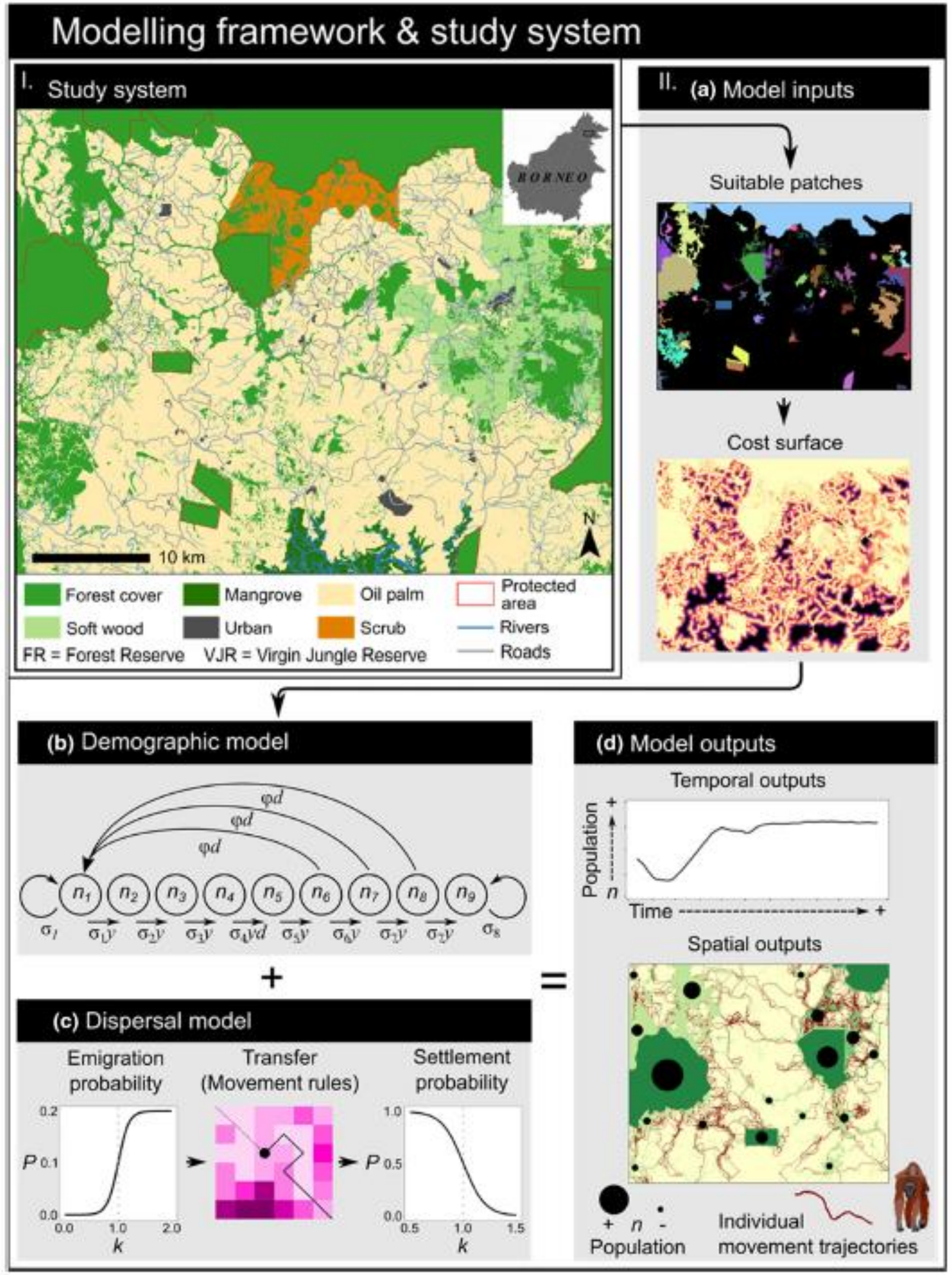
What is the impact of potential management scenarios for a highly modified oil-palm dominated landscape in Sabah, Malaysian Borneo, on the Orangutan populations?

Range
Shif





Seaman et al. 2021, Landscape Ecol.

Seaman et al. 2021, Landscape Ecol.

Landscape scenarios

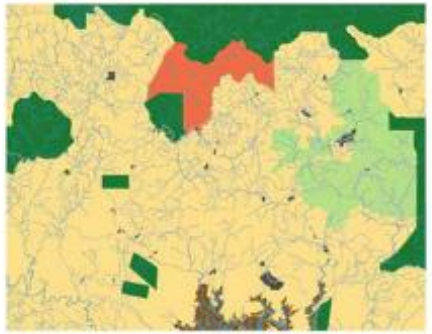
Forest cover
Soft wood
Mangrove
Shrub
Oil palm
Urban
Water
Roads

Land Sparing

The only forest remaining in the landscapeis within strictly protected areas

- Class I Forest Reserve
- Class VI Virgin Jungle Reserve

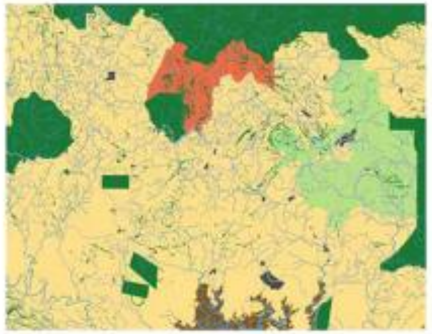
(Sabah Forest Policy (2018), Sabah Forestry Department)



Uncertified

As 'Land Sparing' but with the addtion of minimum environmental regulations for Sabah at the time of study

- 20 m buffers retained each side of permanent rivers (*Section 40 of Sabah Water Resources Enactment (1998), Malaysian Department of Irrigation and Drainage)*
- Forest retained on areas with ≥25° of slope *(Conservation of Environment Enactment (1996) and Conservation of Environment Order (1999), Environmental Protection Department, Sabah)*



Certified

As above, with the inclusion of the Roundtable on Sustainable Palm Oil (RSPO) certification standards, following High Carbon Stock (HCS) Toolkit. HCS forest patches identified as forest ≥35 C t/ha & prioritised by core area >100 ha High, 10-100 ha Medium, ≤10 ha Low

Patches retained in landscape if:
- High priority or within 200 m of a High priority patch,
- at low risk (>2 km settlement, >1 km from other anthropogenic activities
- or likely act as corridors/stepping stones between protected areas < 5km apart

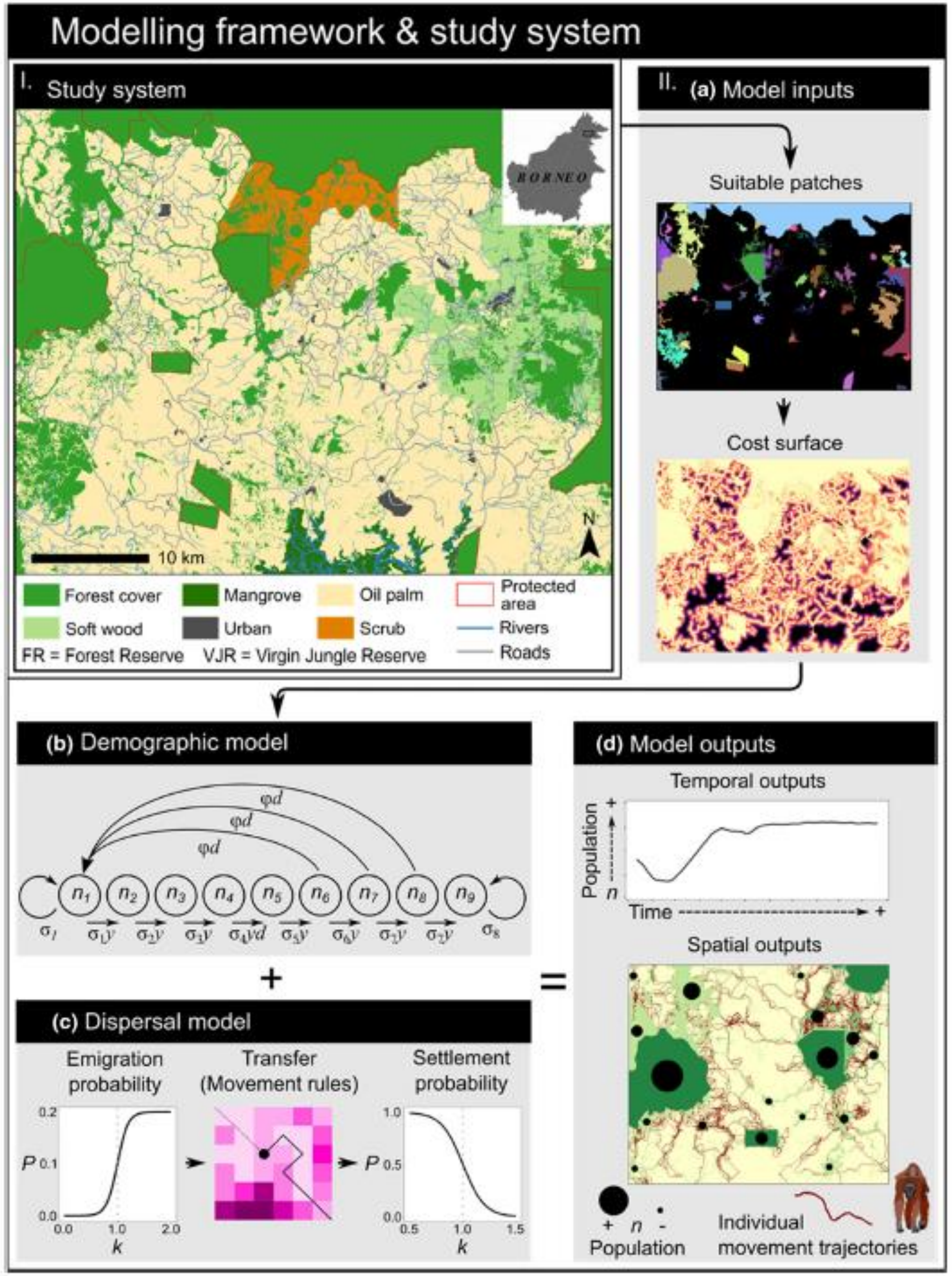
Conservation Enhanced

Includes best practice standards promoted by RSPO+ in addition to those implemented under the 'Certified' scenario (*https://rspo.org/news-and-events/news/rspo-voluntary-addendum-to-strengthen-the-standard-on-peat-deforestation-and-social-requirements*), by:

- Increasing riparian buffer width from 20m to 45m each side of permanent rivers
- Increasing core areas of Medium Priority patches to 100 ha and remove Low Priority patches <200 m of a High priority patch '*give and take development*'

Range Shifter

Seaman et al. 2021, Landscape Ecol.



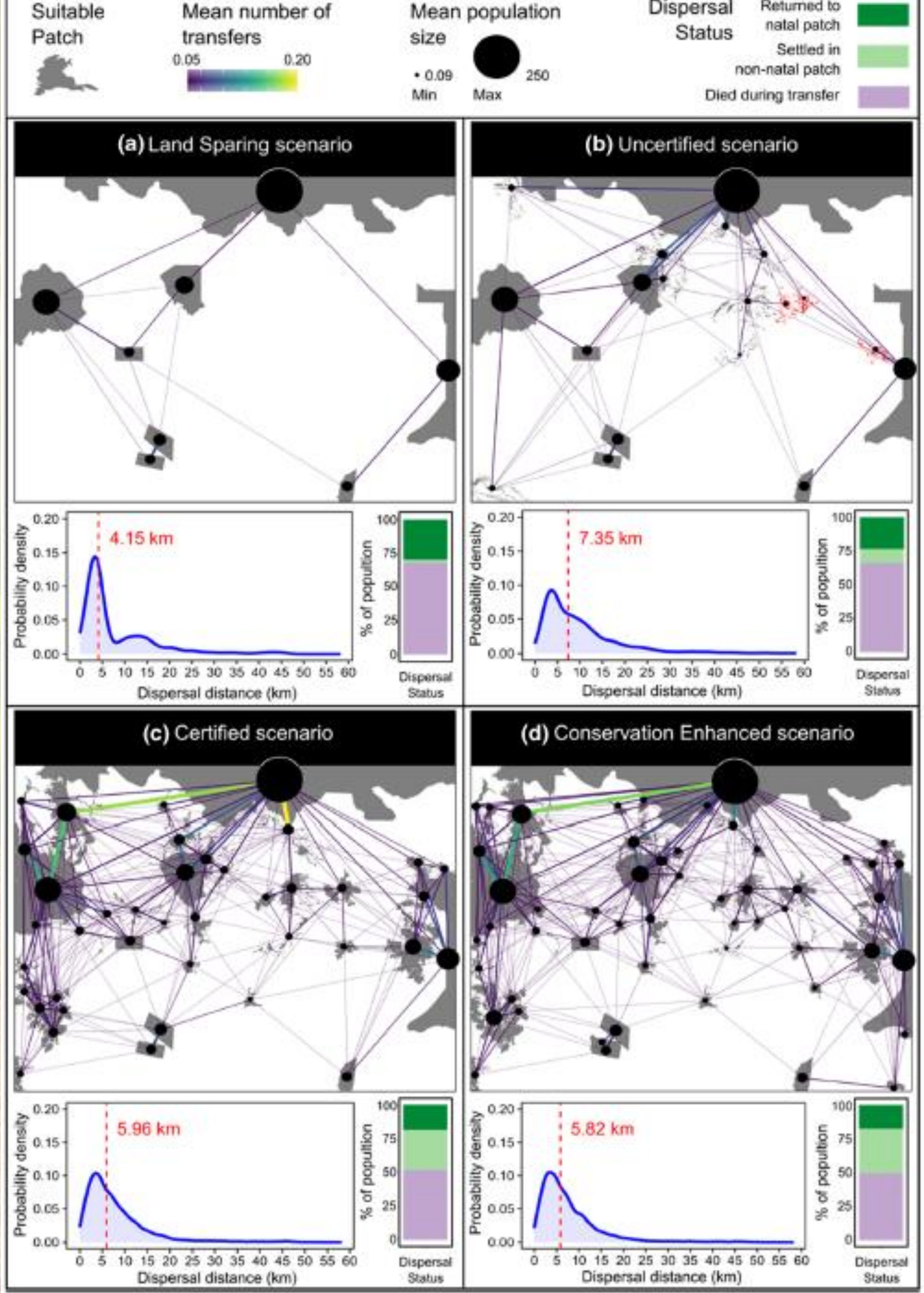
Range Shifter

(a) Limited connectivity – individuals confined in protected areas

(b) Increased connectivity but not population size

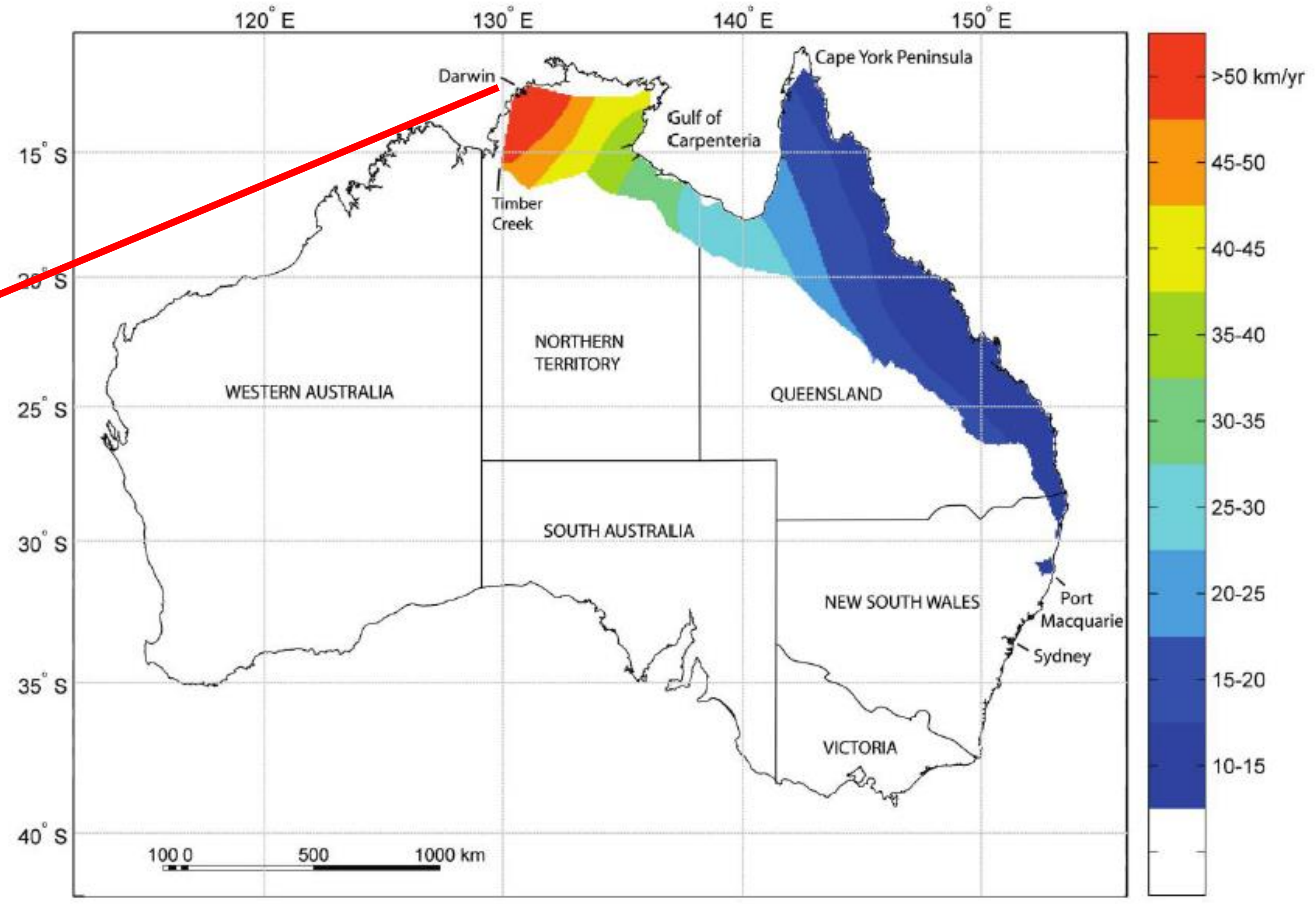
(c) Much increased connectivity and increased population size

Potential of human-modified landscapes to support orangutan populations



Seaman et al. 2021, Landscape Ecol.

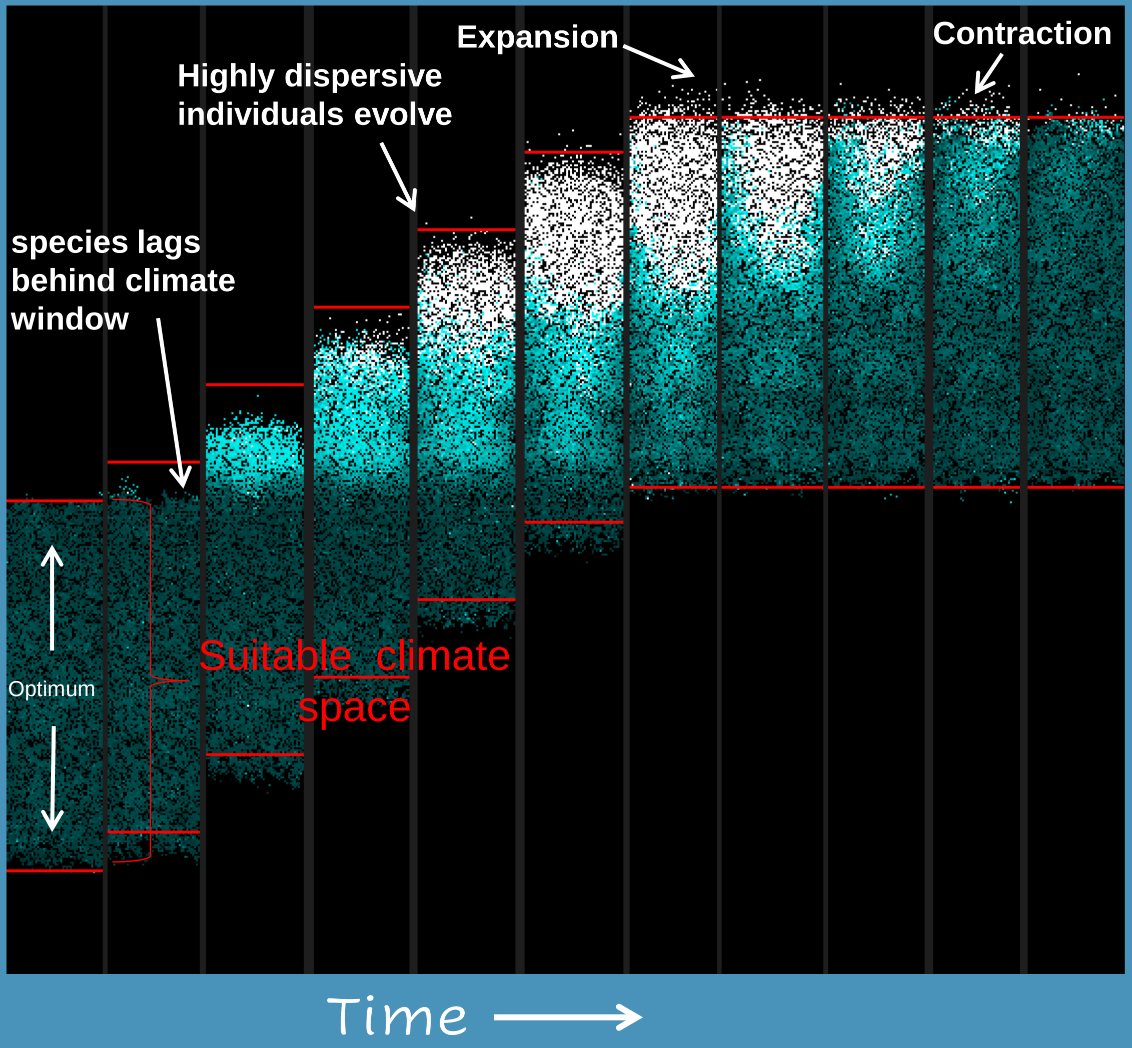
Eco-evolutionary dynamics during species' range shifting: EVOLUTION of DISPERSAL



21 years before 1985 forecast that assumed constant expansion rates!

Phillips et al. 2008, Am.Nat.; Urban et al. 2008, Am.Nat.; Phillips et al. 2006, Nature

Eco-evolutionary dynamics during species' range shifting: Evolution of dispersal

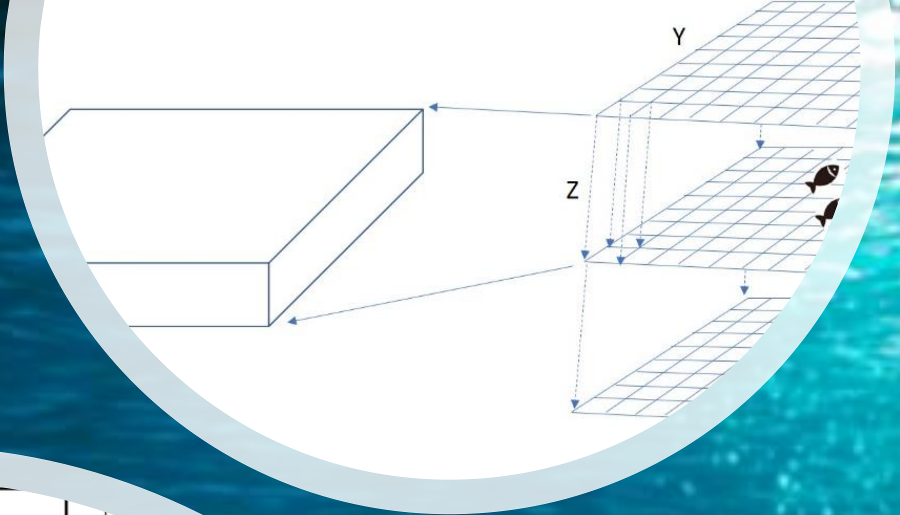


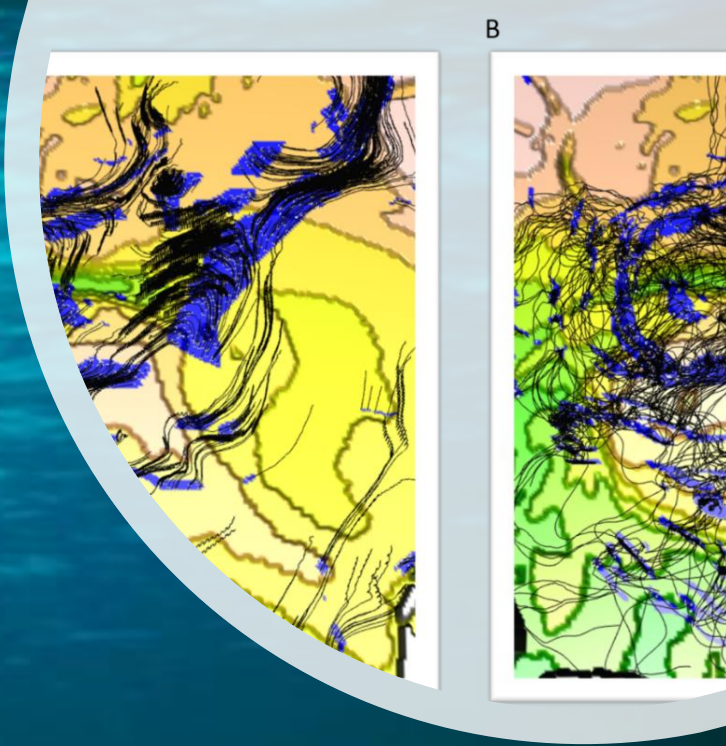
- At the start of climate change the species lags behind the climate window
- Higher dispersal distances evolve (light blue/white)

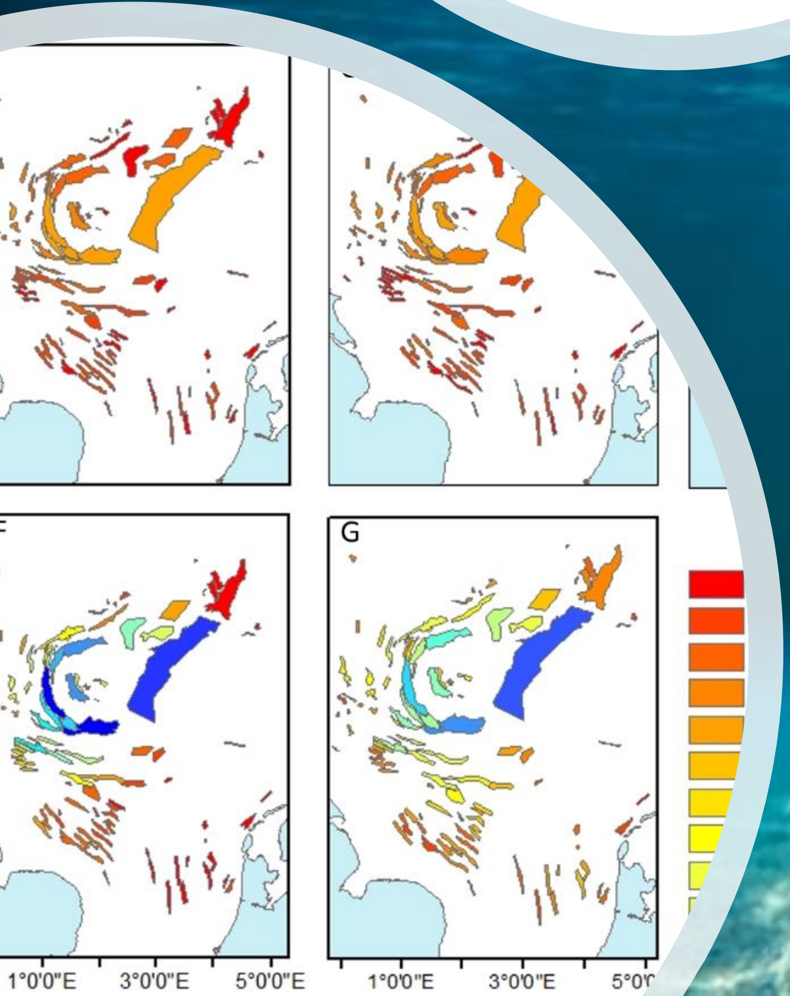
  ↓

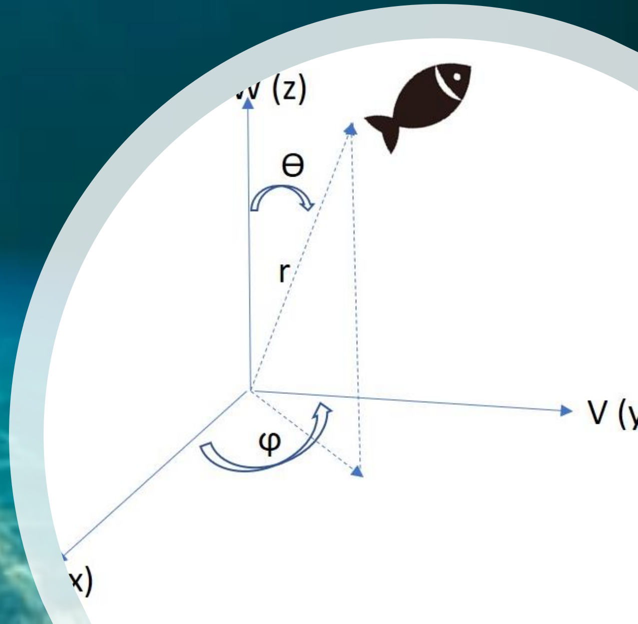
  Range catches up with climate
- At the end of climate change, dispersal evolves back → range contracts, '**elastic margin**'

Henry, Bocedi & Travis 2013, Journal of Theoretical Biology









Coming very soon:

MerMADE

(RangeShifter for Marine environments)