Process-based models for predicting species' responses to environmental changes

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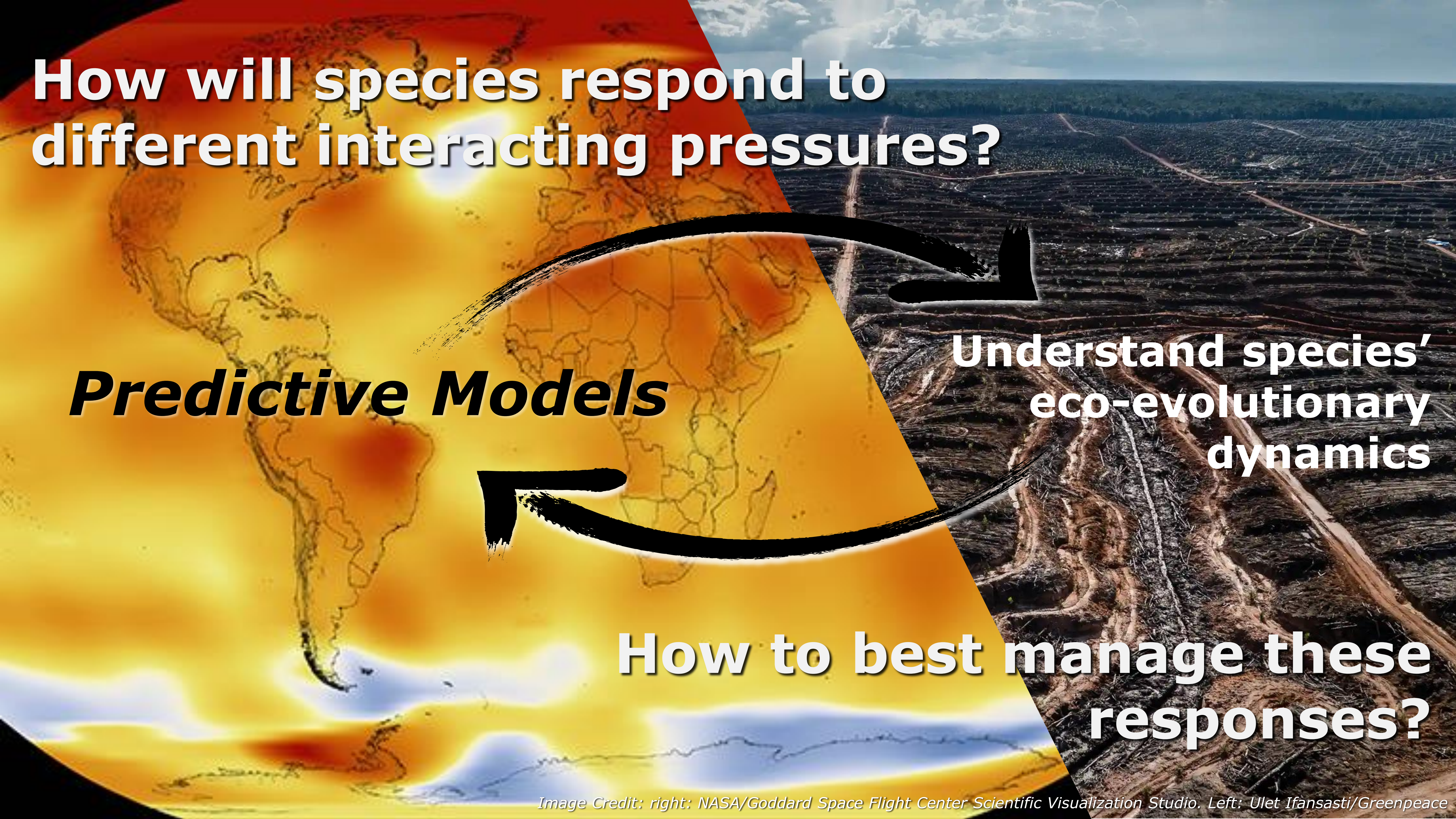
1495 UNIVERSITY OF ABERDEEN

THE ROYAL SOCIETY

NERC SCIENCE OF THE ENVIRONMENT


How will species respond to different interacting pressures?
Understand species' eco-evolutionary dynamics
Predictive Models
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

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

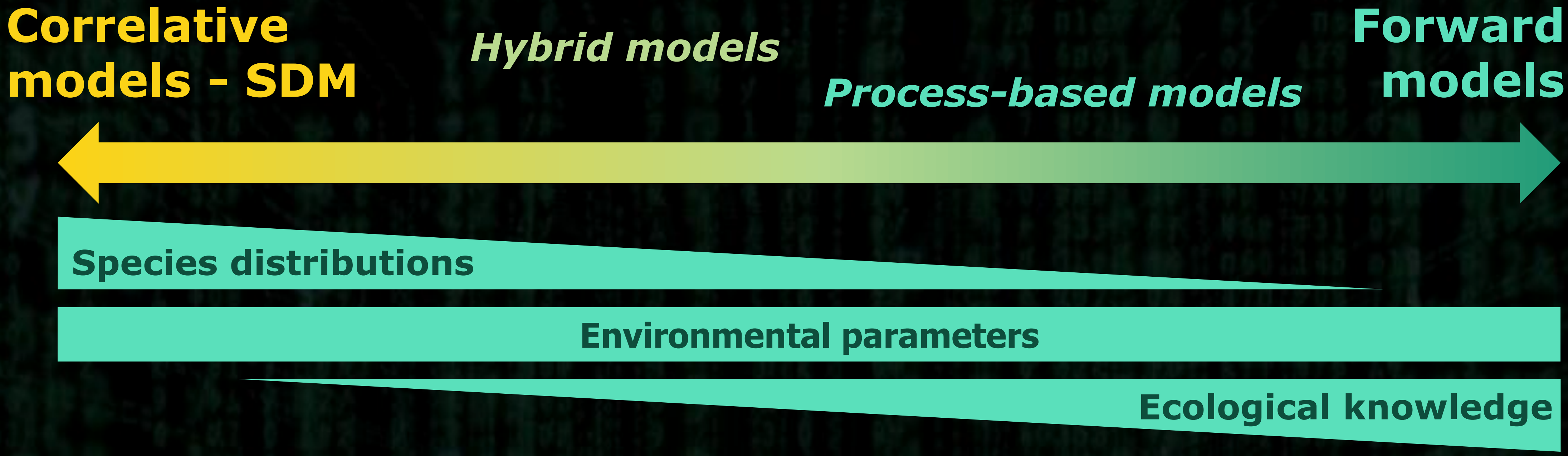
Journal of Biogeography (*J. Biogeogr.*) (2012)

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 ***<u>occurrence or abundance</u>***

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

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

- ✓ *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

- × Complexity – How much is too much?

  … which processes?
- × Data availability
- × Upscaling

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

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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

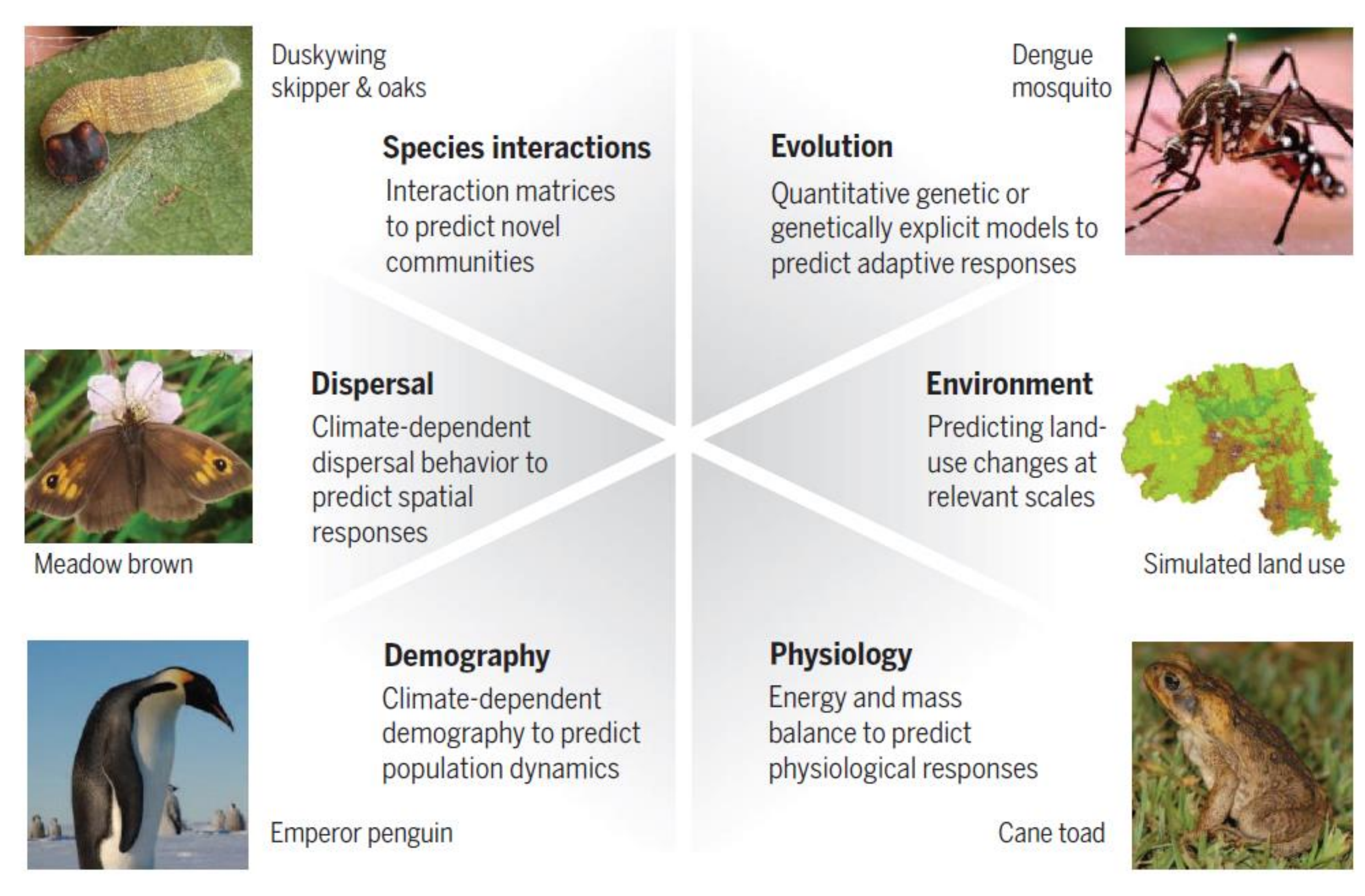
Ecography 40: 267–280, 2017
doi: 10.1111/ecog.02480

Subject Editor: Catherine Graham. Editor-in-Chief: Miguel Araújo. Accepted 11 November 2016

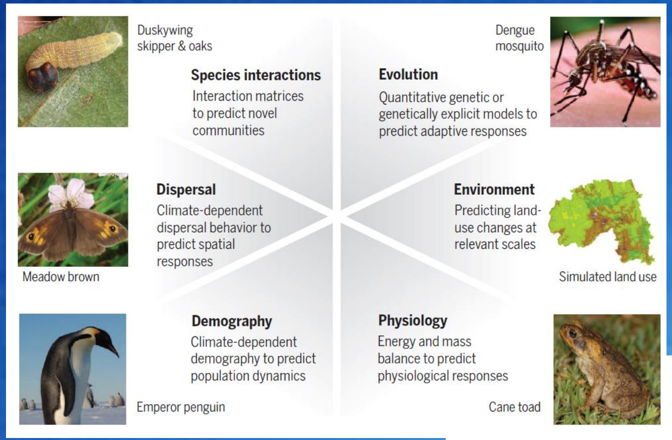
Mechanistic simulation models in macroecology and biogeography: state-of-art and prospects

Juliano Sarmento Cabral, Luis Valente and Florian Hartig

Which processes?

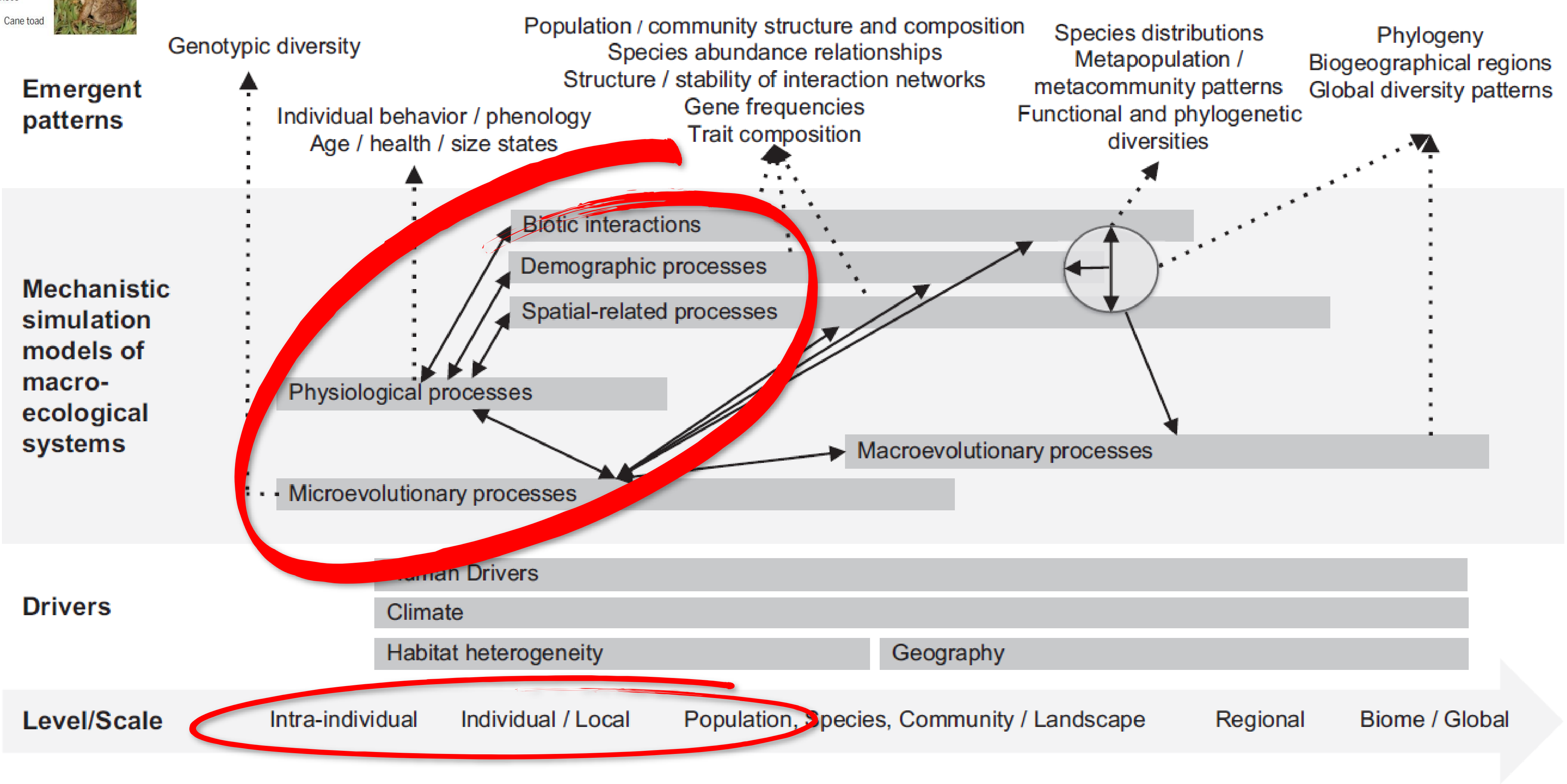


Urban, Bocedi et al. 2016, Science



Which processes?

Cabral et al. 2017, Ecography



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

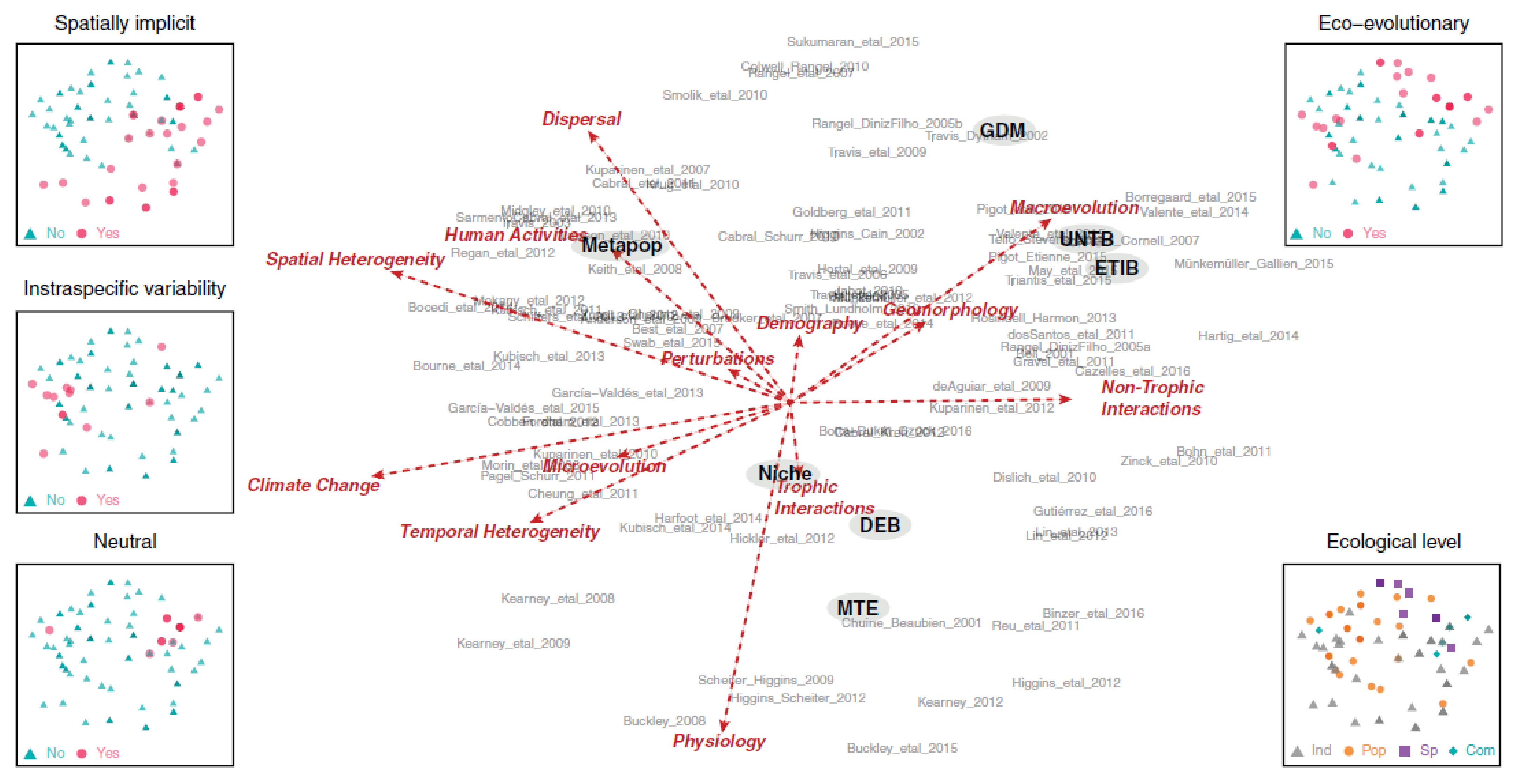
How complex should models be? Comparing correlative and mechanistic range dynamics models

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]

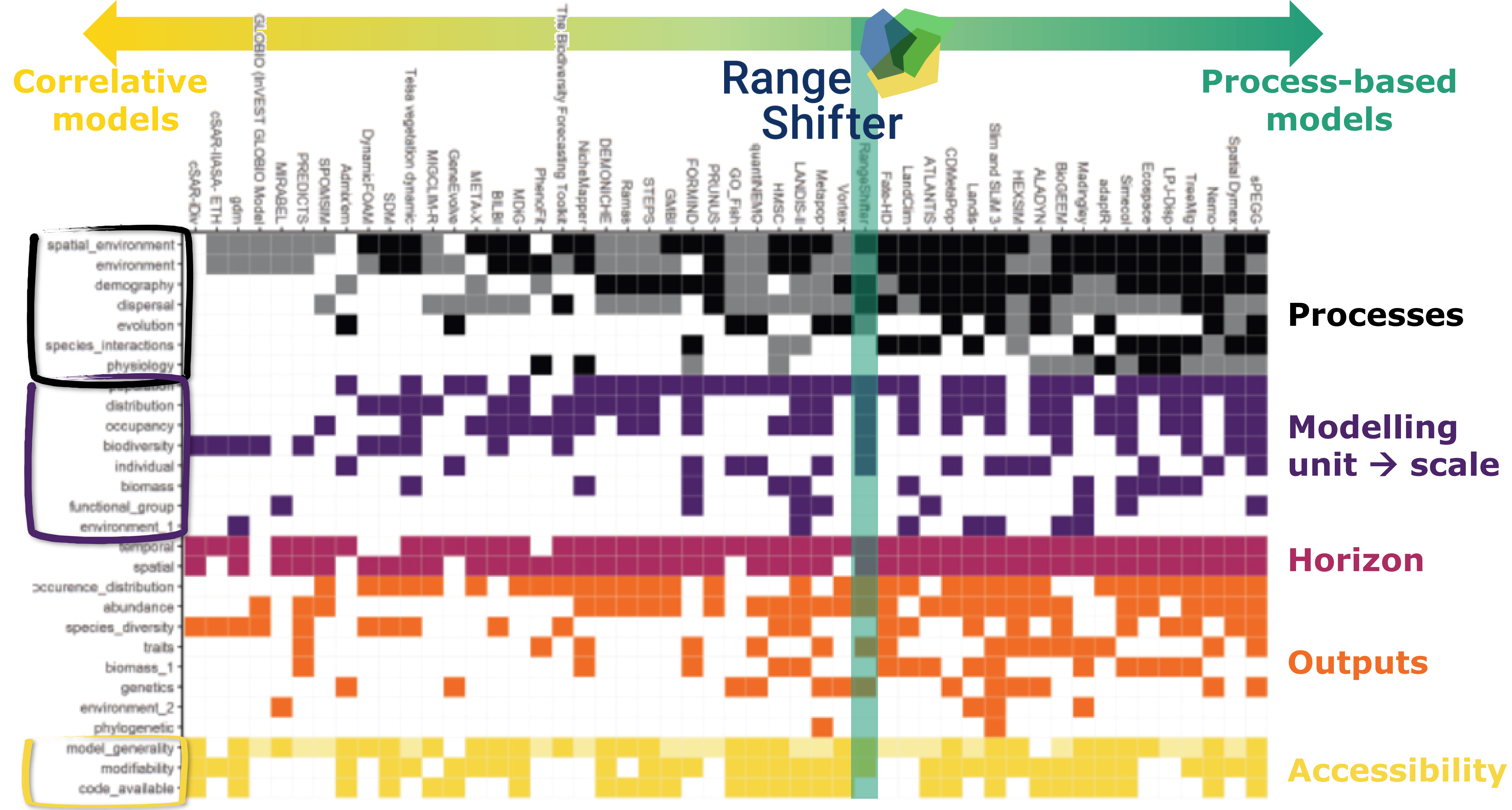
… it depends….

- ✓ 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

Process-based model: where are we at?



Cabral et al. 2017, Ecography



Urban et al. 2021, BioScience

https://rangeshifter.github.io

Range Shifter

Methods in Ecology and Evolution

British Ecological Society

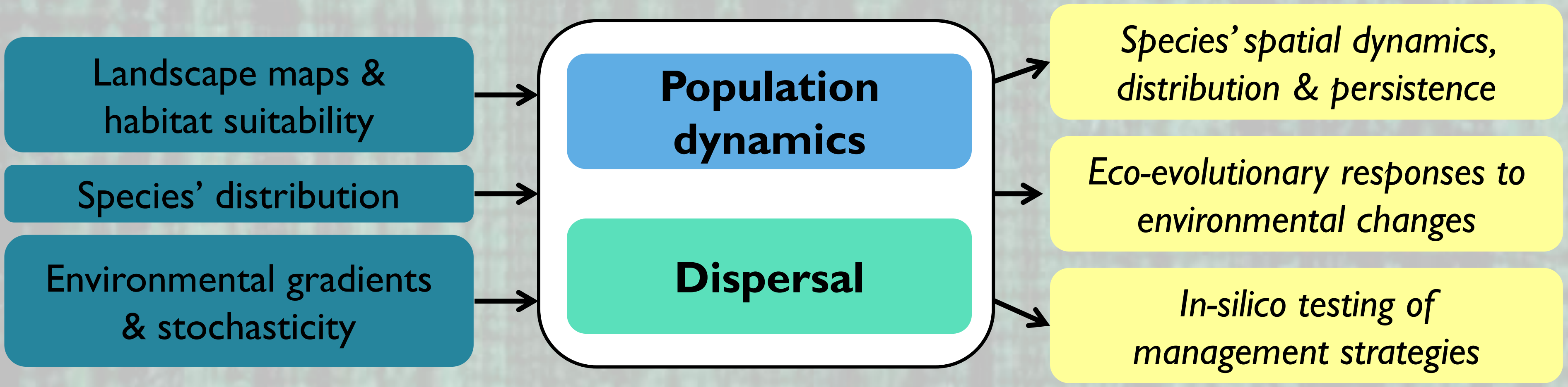
Methods in Ecology and Evolution 2014, **5**, 388–396 doi: 10.1111/2041-210X.12162

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



Range Shifter

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Methods in Ecology and Evolution
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RangeShiftR

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

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

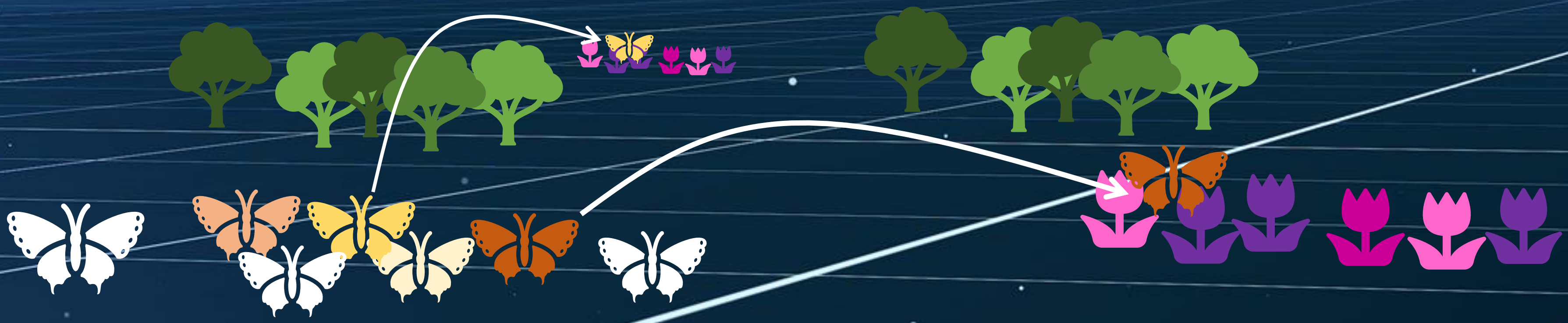
@BocediGreta

INDIVIDUAL-BASED MODELS

Individuals and their interactions are the units of the simulation

INDIVIDUAL VARIABILITY

ECOLOGY



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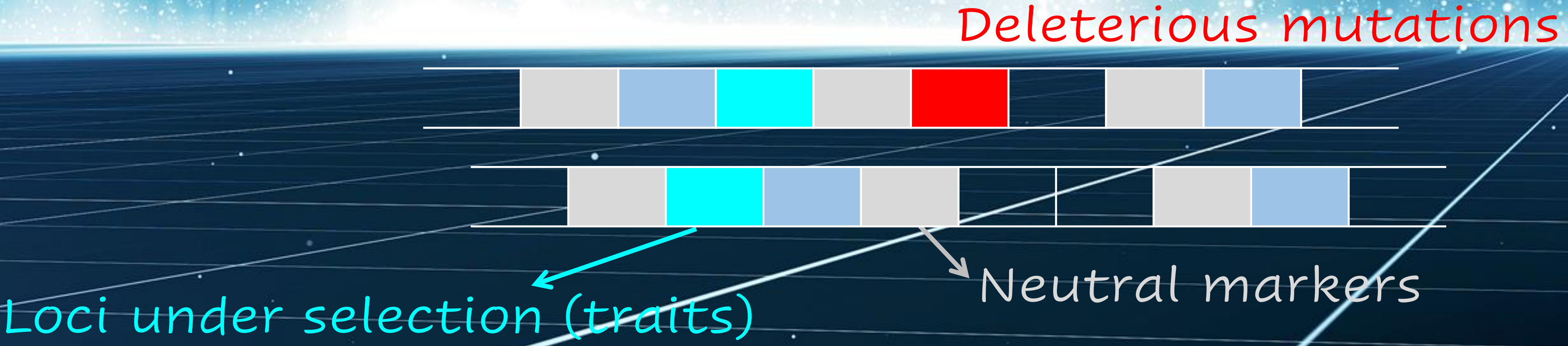
Individuals and their interactions are the units of the simulation

INDIVIDUAL VARIABILITY

GENETICS

ECOLOGY



EVOLUTION

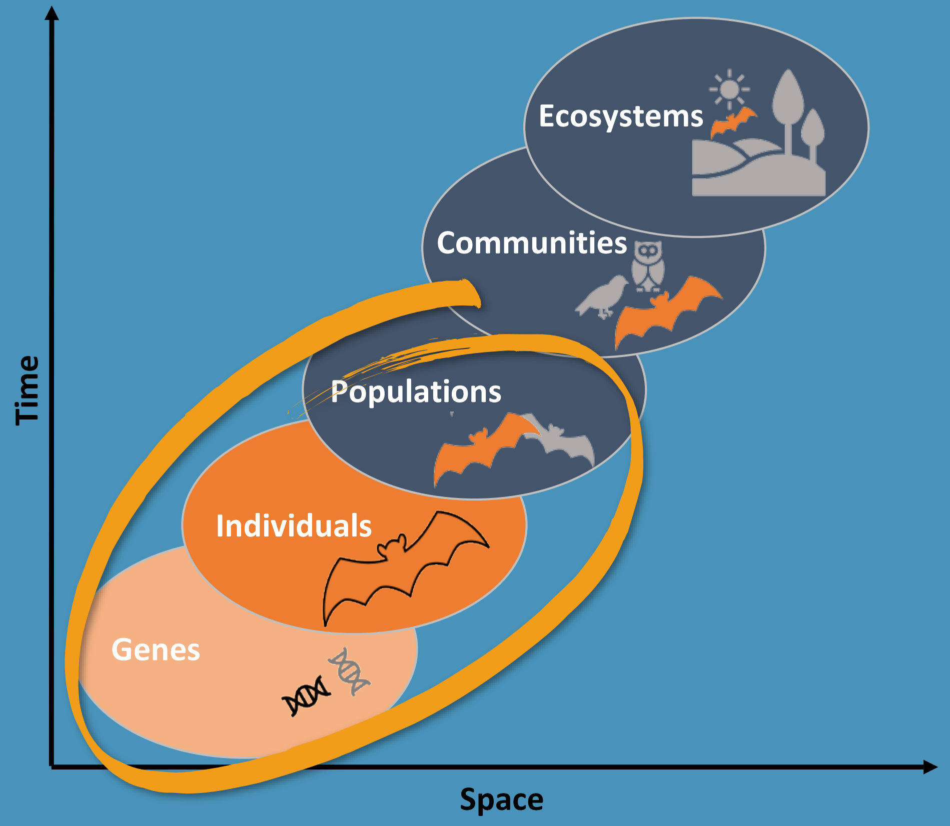
INDIVIDUAL-BASED MODELS

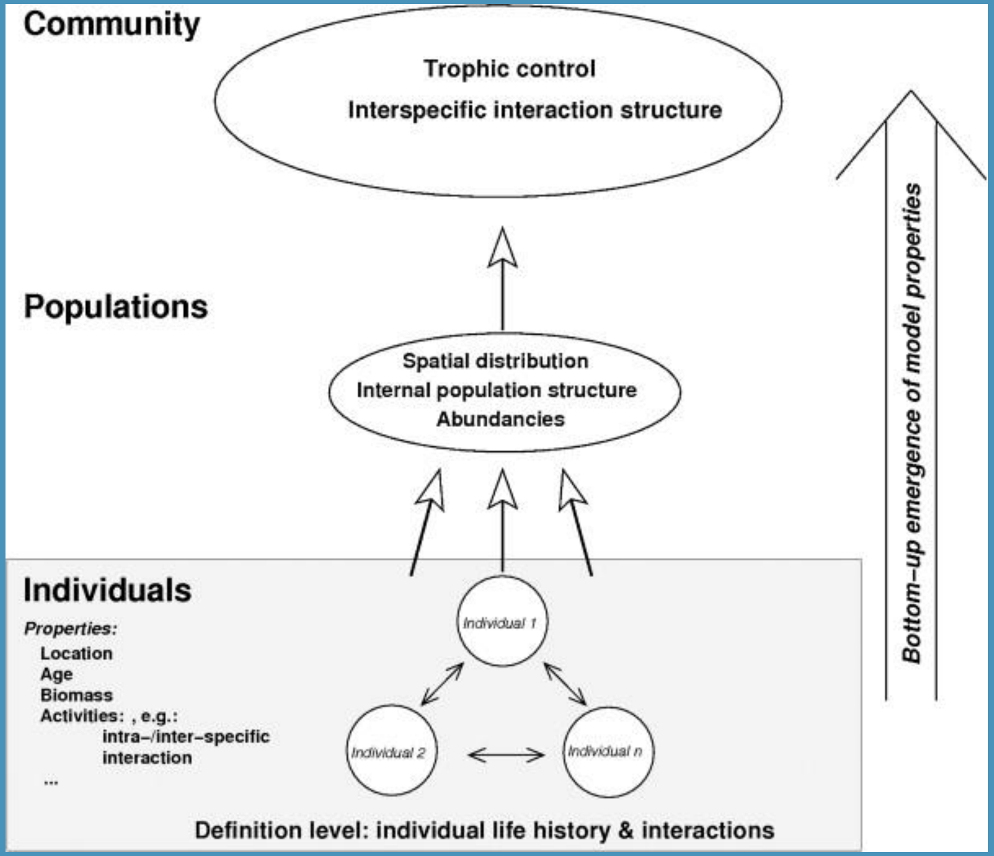
Emerging population dynamics

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

Bottom-up approach

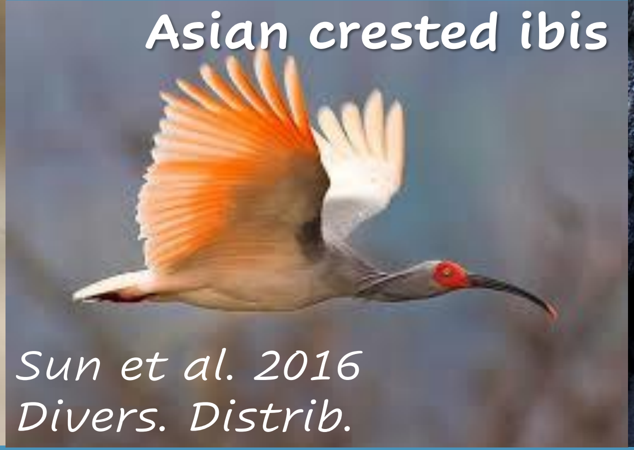
use knowledge about behaviour of single individuals to infer properties of the larger population or community



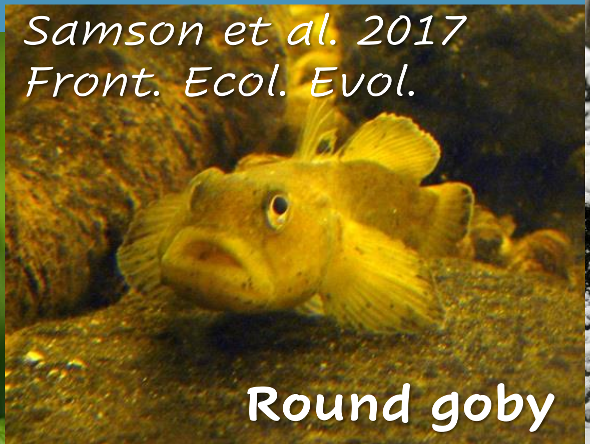


Reuter, et al. (2010) Basic Appl Ecol 11: 572-581.

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



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]

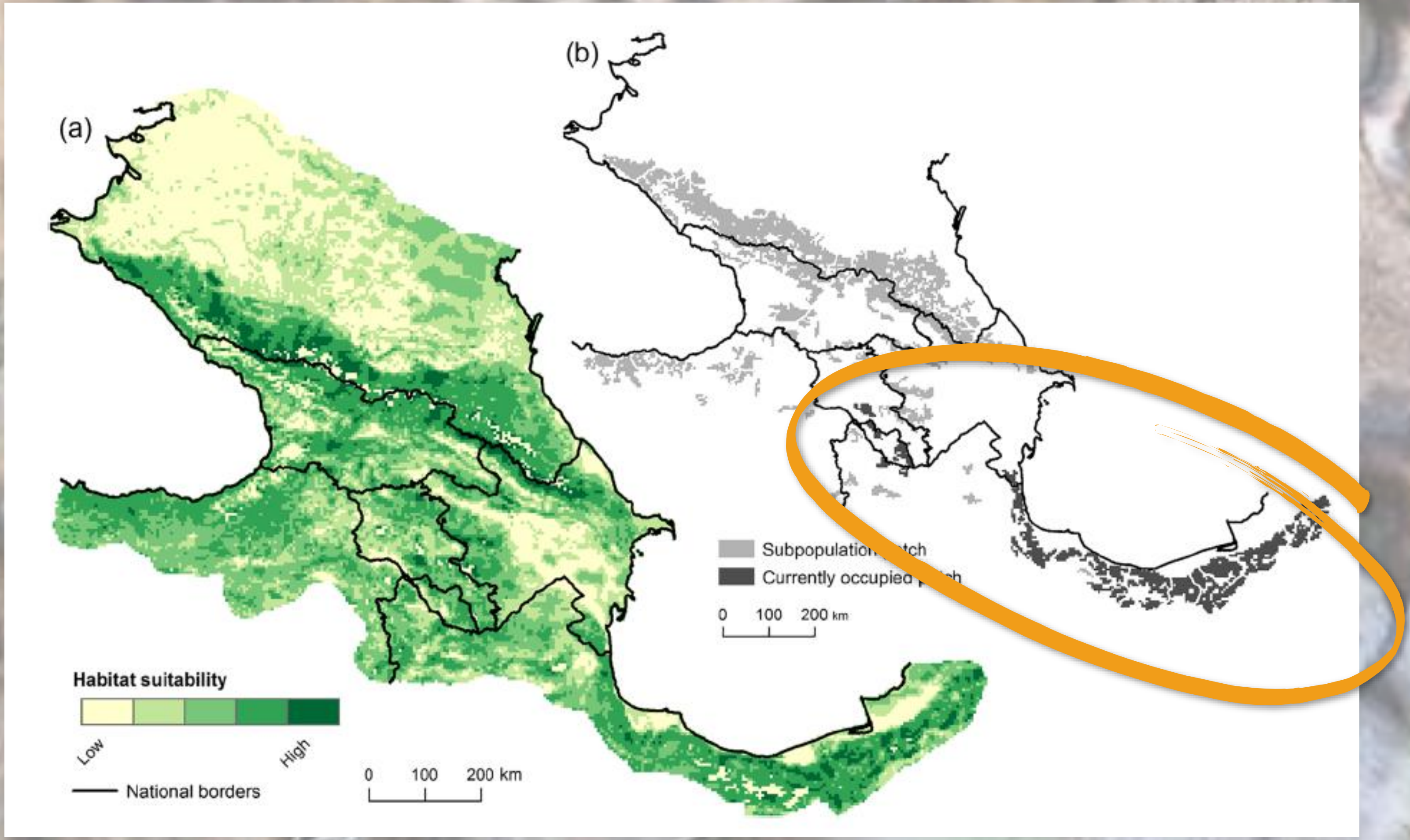
x Persecution

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?

- Rule-based habitat suitability model

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



Bleyhl et al. 2021, Ecol. Appl.

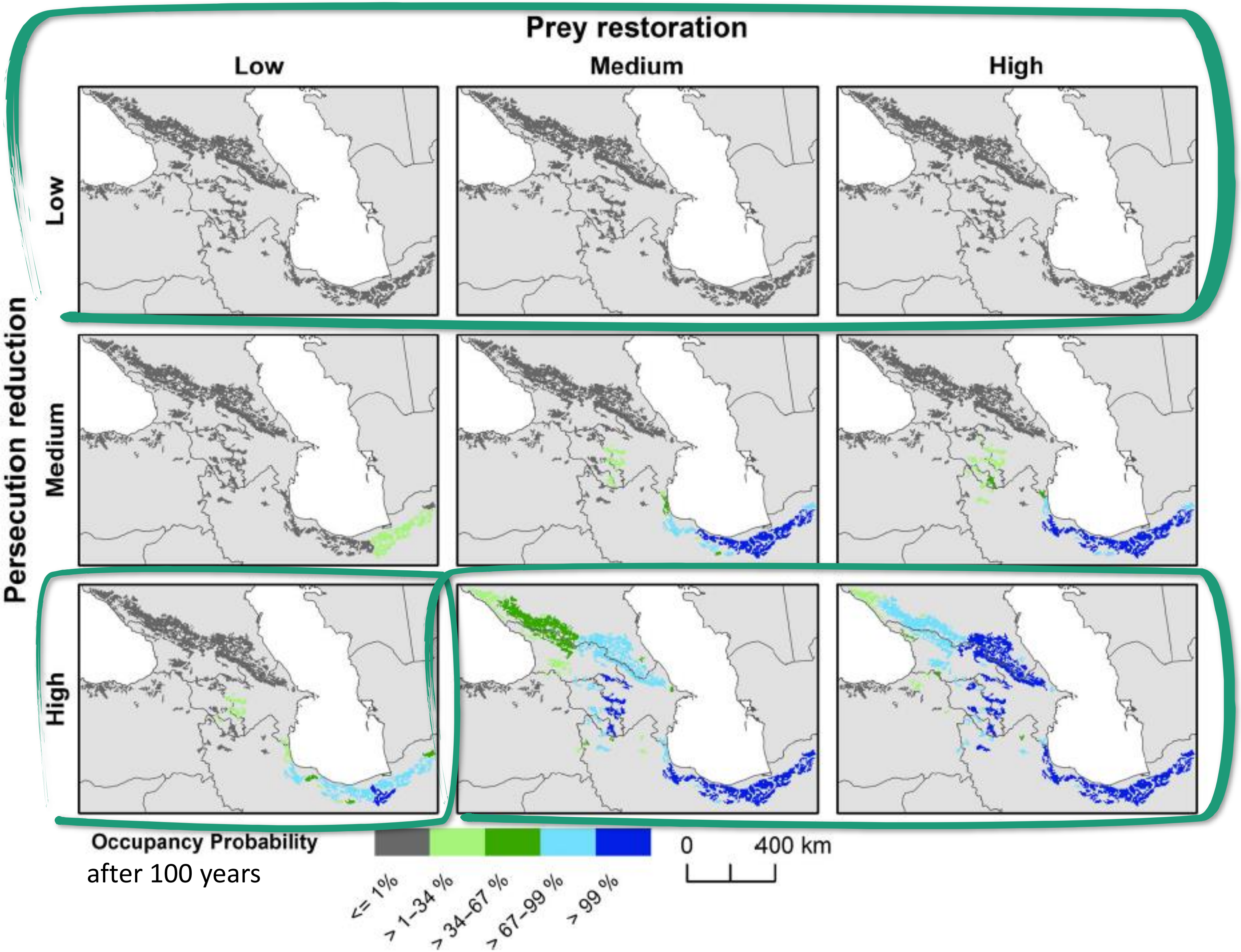
- Rule-based habitat suitability model

  (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**

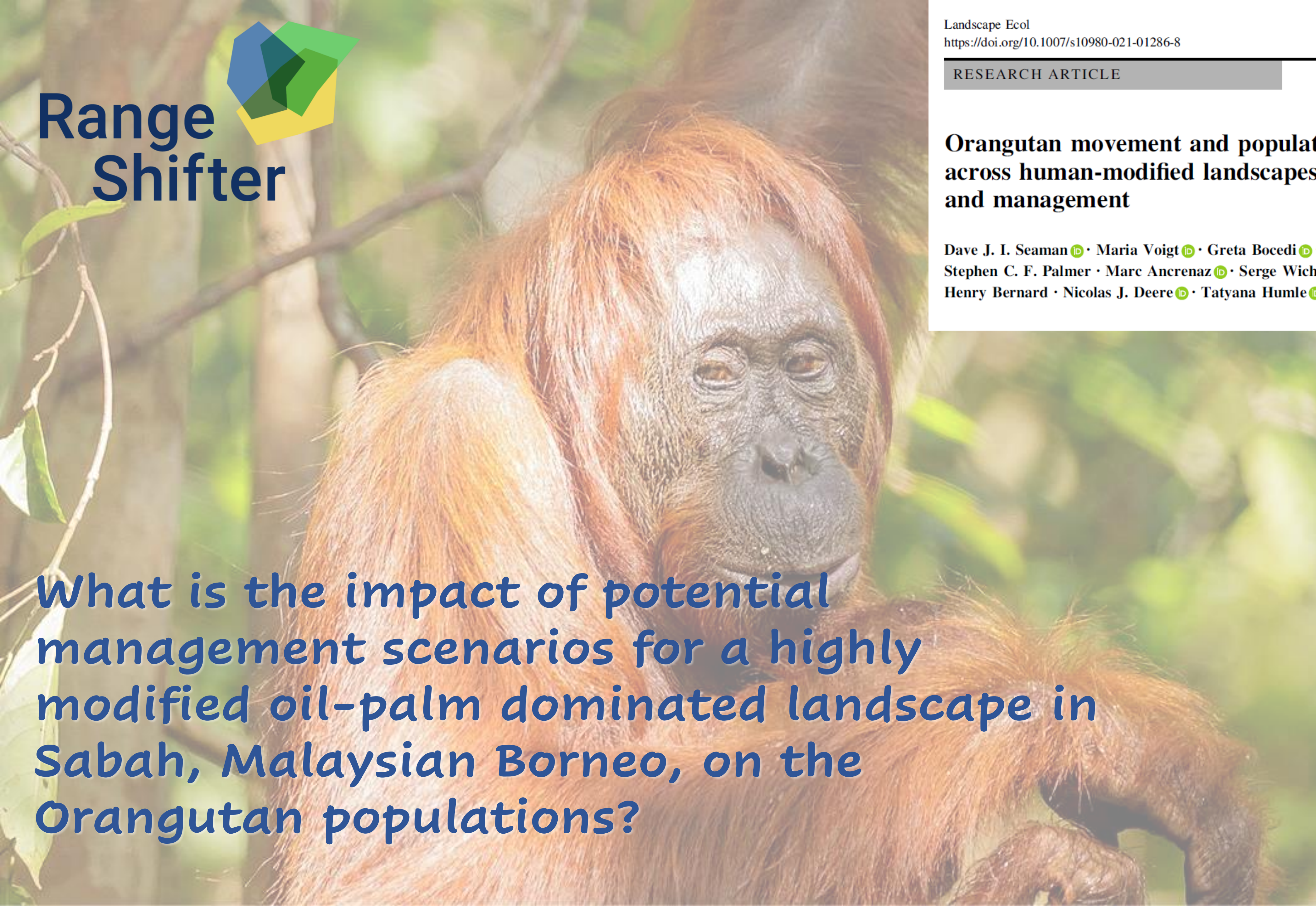
  if the appropriate conservation measures are implemented

- ✓ **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

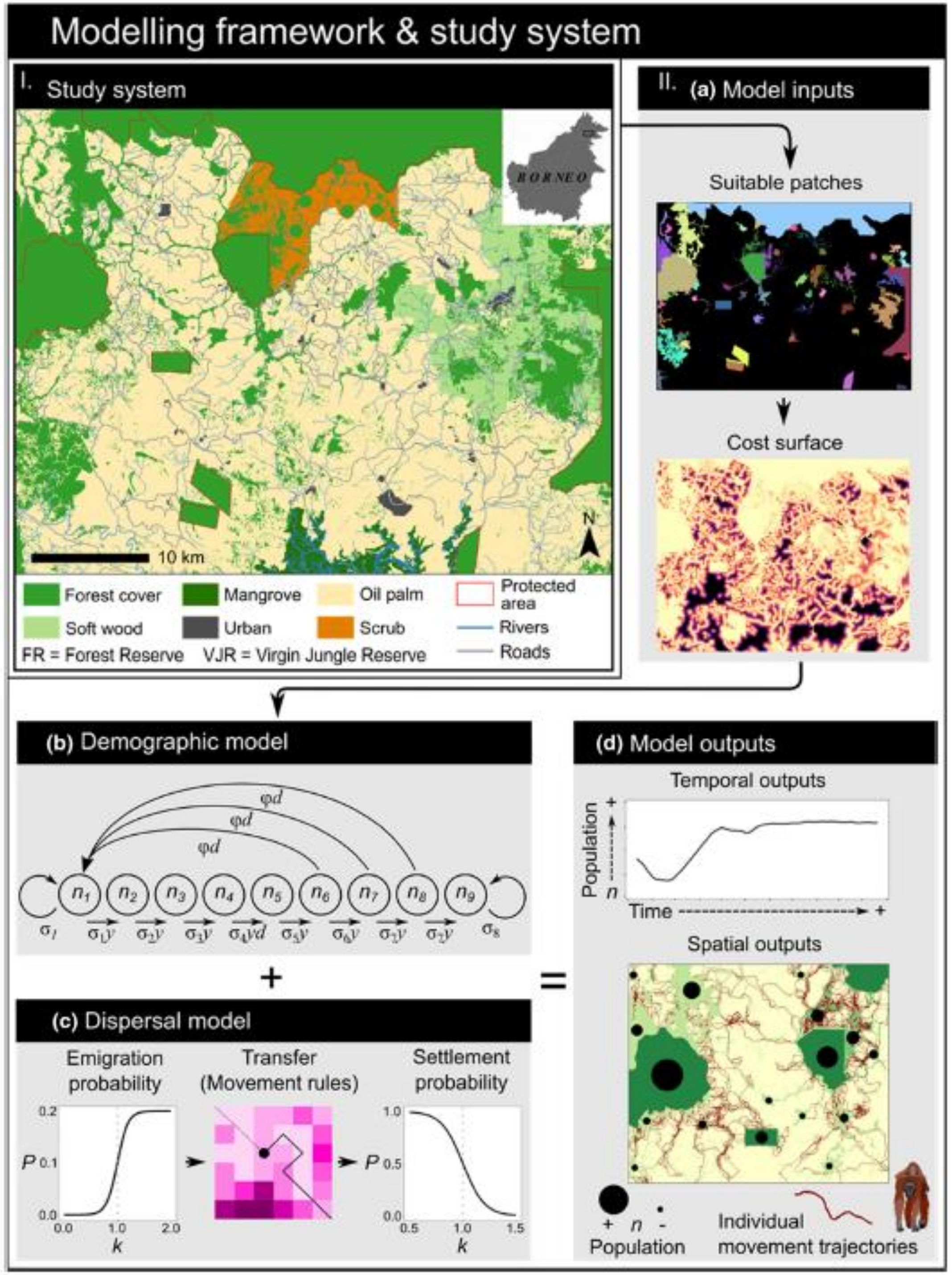
RESEARCH ARTICLE

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

Dave J. I. Seaman · Maria Voigt · Greta Bocedi · Justin M. J. Travis · Stephen C. F. Palmer · Marc Ancrenaz · Serge Wich · Erik Meijaard · Henry Bernard · Nicolas J. Deere · Tatyana Humle · Matthew J. Struebig

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 Shifter

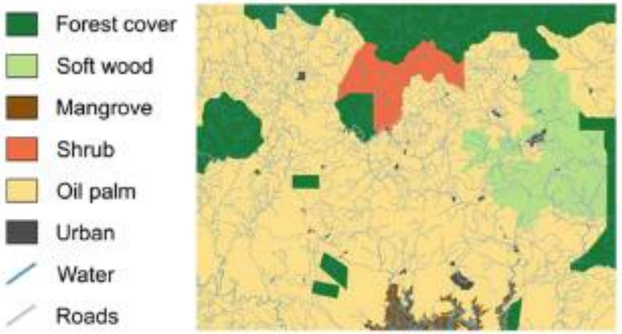


Seaman et al. 2021, Landscape Ecol.

Range Shifter

Seaman et al. 2021, *Landscape Ecol.*

Landscape scenarios



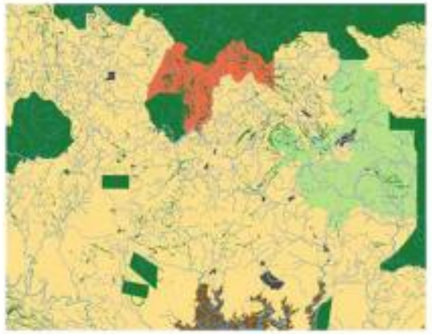
Land Sparing

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

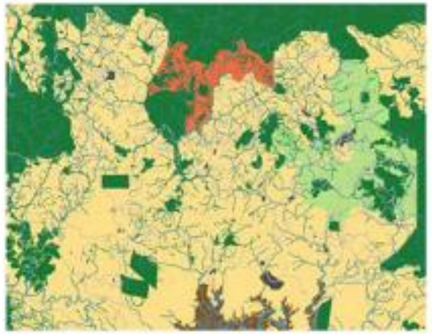
- 20 m buffers retained each side of permanent rivers (*Section 40 of Sabah Water Resources Enactment (1998), Malaysian Department of Irrigation and Drainage)*
- Forest retained on areas with ≥25° of slope *(Conservation of Environment Enactment (1996) and Conservation of Environment Order (1999), Environmental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

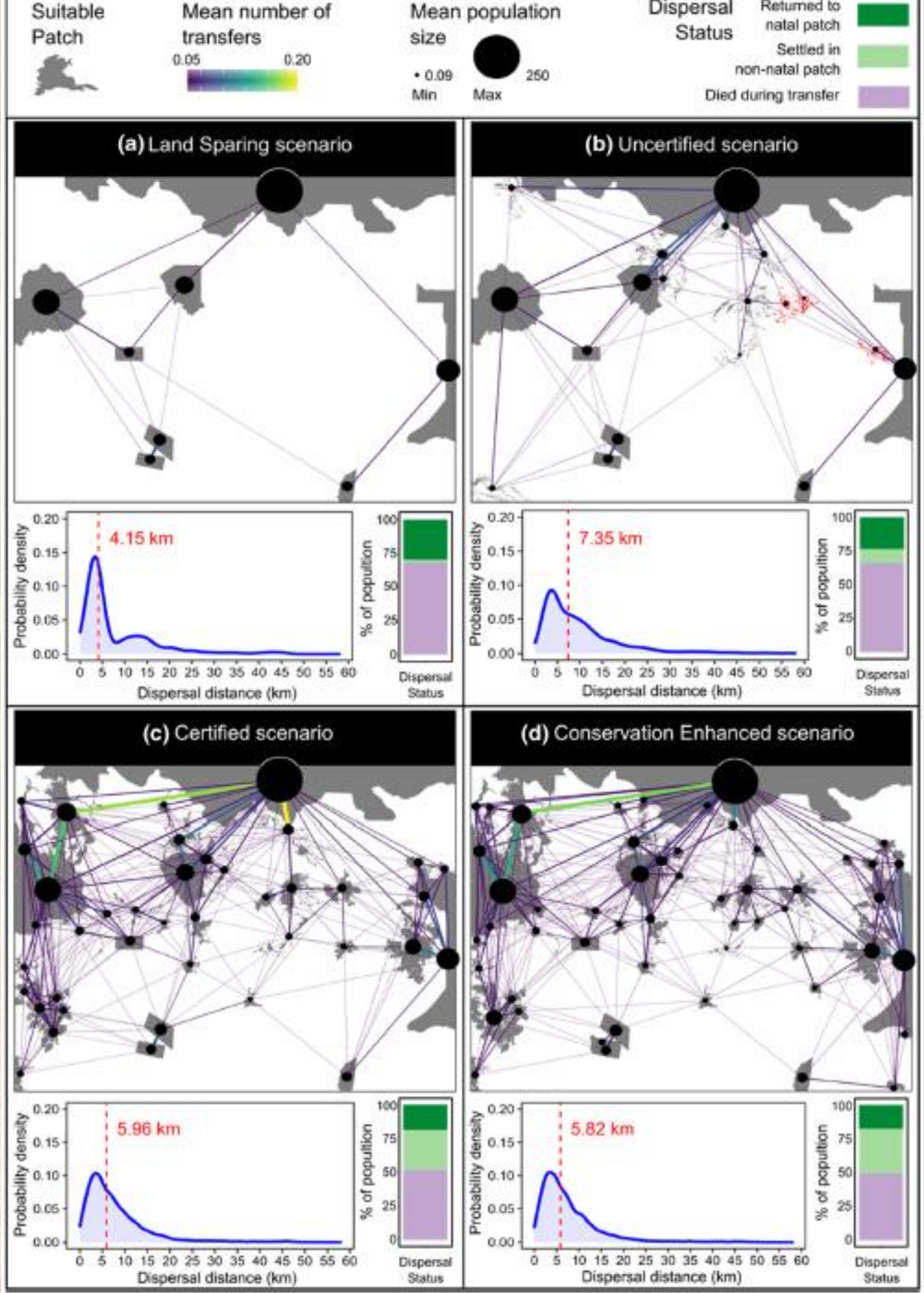
- Increasing riparian buffer width from 20m to 45m each side of permanent rivers
- Increasing core areas of Medium Priority patches to 100 ha and remove Low Priority patches <200 m of a High priority patch '*give and take development*'

Range Shifter

(a) Limited connectivity – individuals confined in protected areas

(b) Increased connectivity but not population size

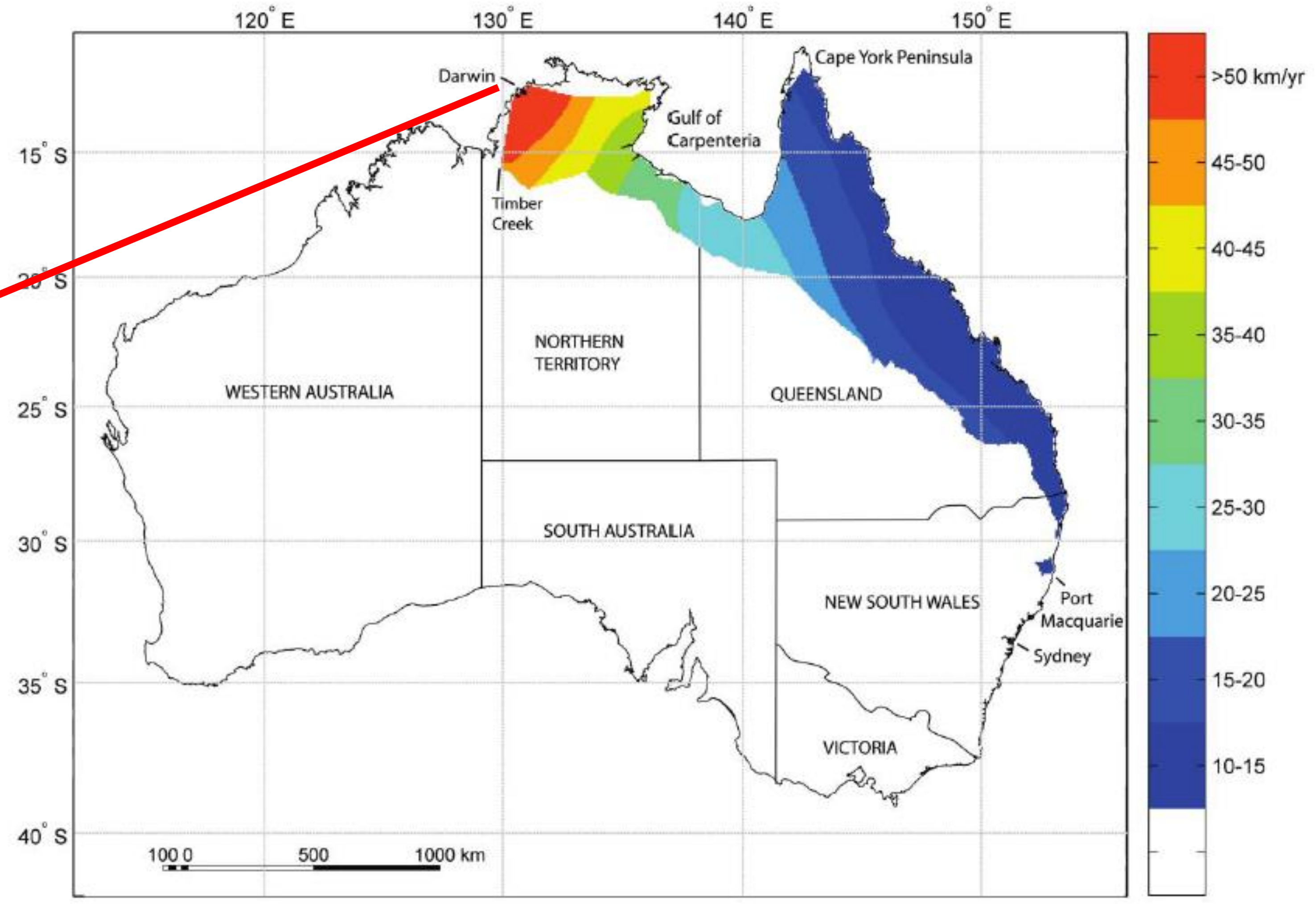
(c) Much increased connectivity and increased population size



Potential of human-modified landscapes to support orangutan populations

Seaman et al. 2021, Landscape Ecol.

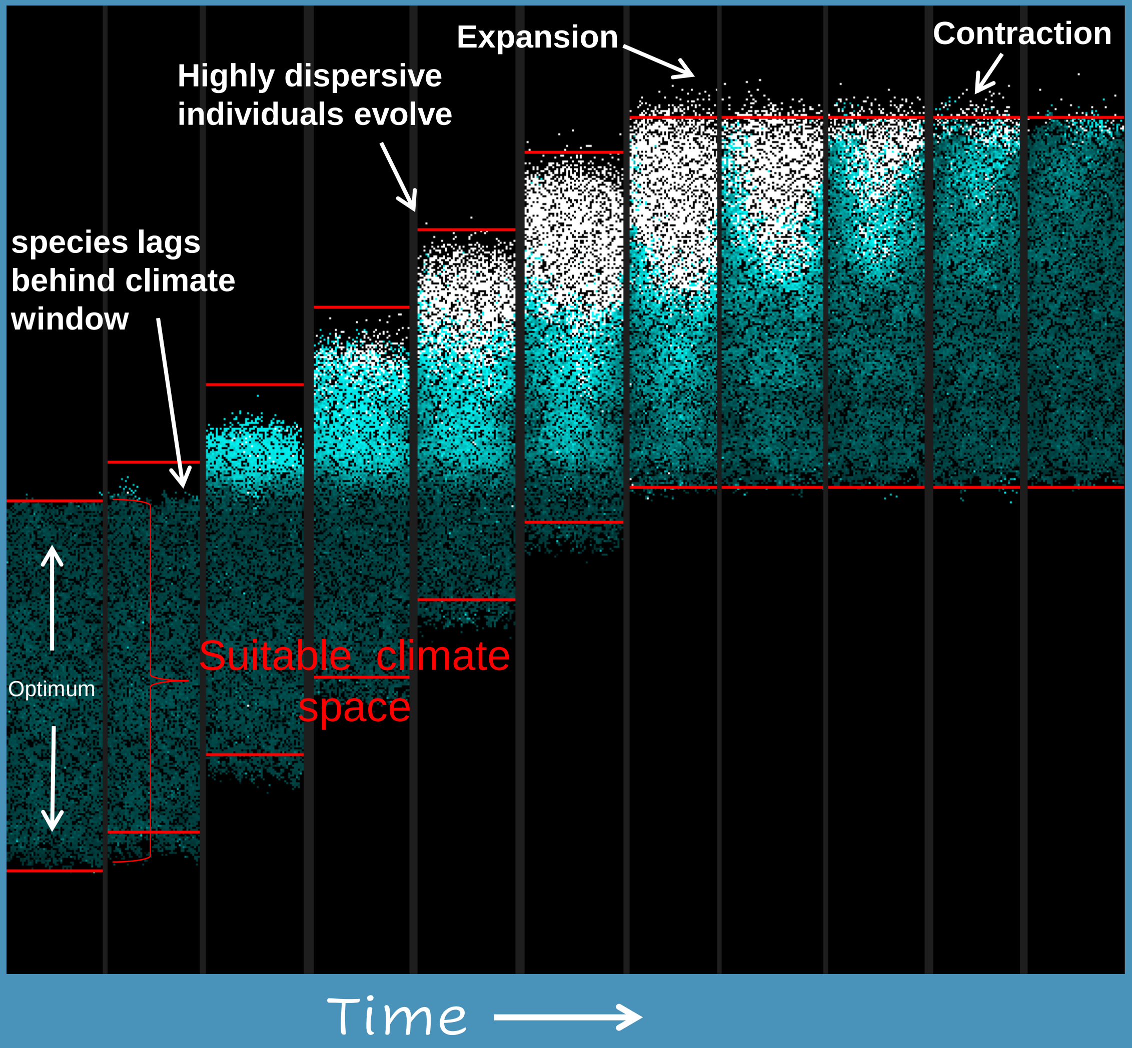
Eco-evolutionary dynamics during species' range shifting: EVOLUTION of DISPERSAL



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

21 years before 1985 forecast that assumed constant expansion rates!

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

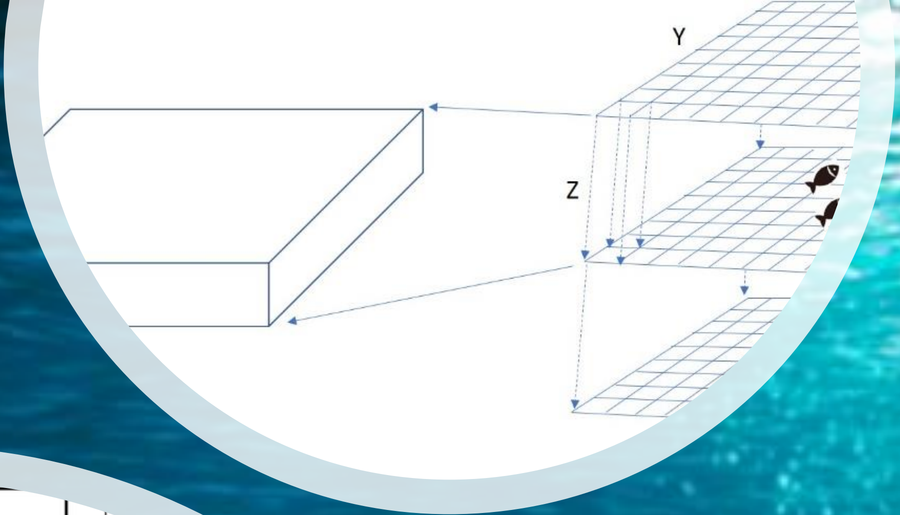


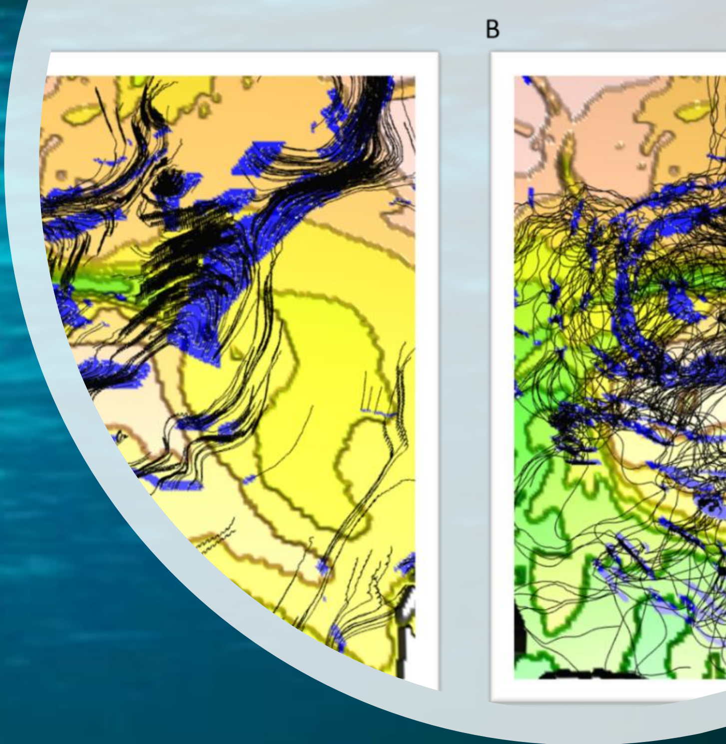
- At the start of climate change the species lags behind the climate window
- Higher dispersal distances evolve (light blue/white)

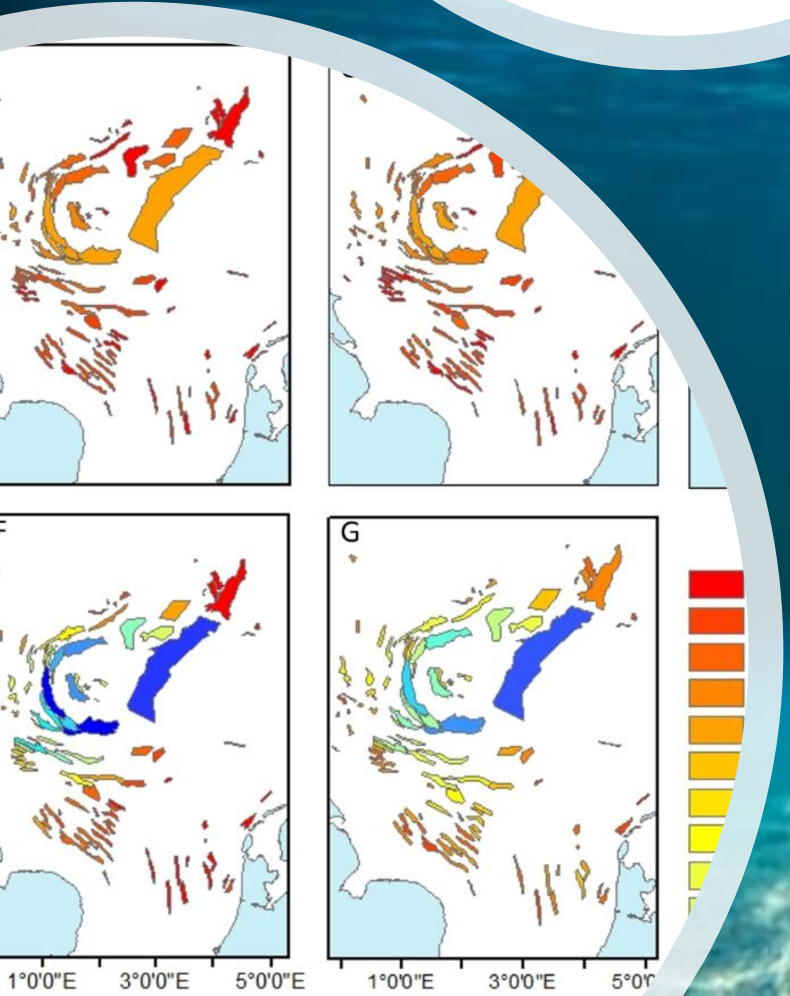
  ↓

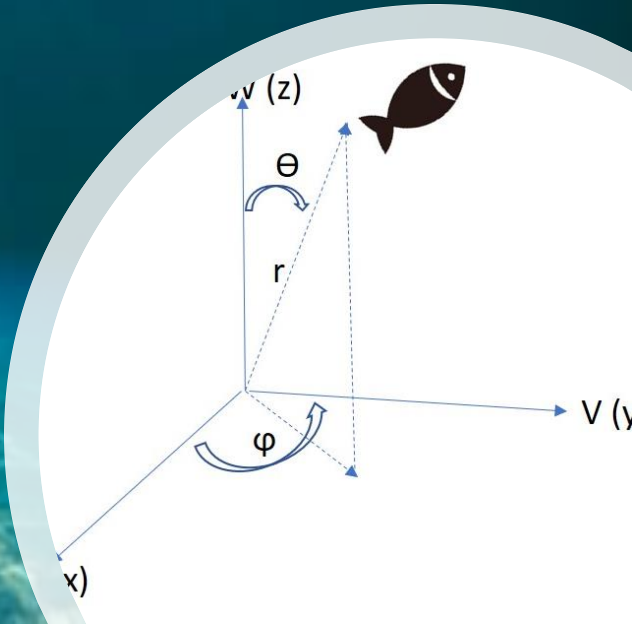
  Range catches up with climate
- At the end of climate change, dispersal evolves back → range contracts, '**elastic margin**'

Henry, Bocedi & Travis 2013, Journal of Theoretical Biology









Coming very soon:

MerMADE

(RangeShifter for Marine environments)