Rewilding - concepts, scientific background, and current state of the science

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MegaPast2Future

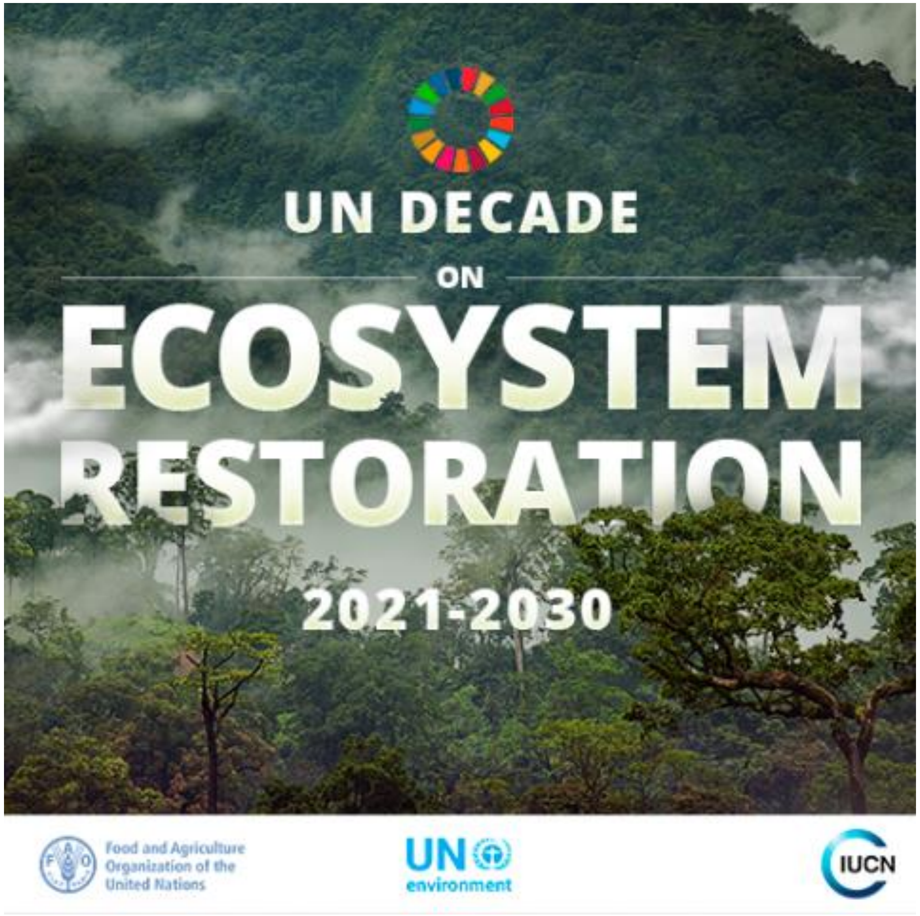
BIOCHANGE
CENTER FOR BIODIVERSITY DYNAMICS
IN A CHANGING WORLD

AARHUS UNIVERSITY

Photos: JCS

UN Decade on Ecosystem Restoration

- 01 March 2019, New York – The UN Decade on Ecosystem Restoration, declared today by the UN General Assembly, aims to massively scale up the restoration of degraded and destroyed ecosystems as a proven measure to fight the climate crisis and enhance food security, water supply and biodiversity
- Restoration of 350 million hectares of degraded land between now and 2030 could generate USD 9 trillion in ecosystem services and take an additional 13-26 gigatons of greenhouse gases out of the atmosphere



Rewilding

- Rewilding
  - **Ecological restoration to promote <u>self-regulating</u> complex (biodiverse) ecosystems**
  - Key aspects (wildness)
    - Reducing human control
    - Restoring natural processes
  - Spontaneous ecological dynamics
  - Active initial steps to restore ecological integrity
    - Refaunation & trophic processes
    - Natural physical processes, e.g., hydrology

REVIEW SUMMARY

REWILDING

Rewilding complex ecosystems

Andrea Perino*, Henrique M. Pereira*, Laetitia M. Navarro, Néstor Fernández, James M. Bullock, Silvia Ceauşu, Ainara Cortés-Avizanda, Roel van Klink, Tobias Kuemmerle, Angela Lomba, Guy Pe'er, Tobias Plieninger, José M. Rey Benayas, Christopher J. Sandom, Jens-Christian Svenning, Helen C. Wheeler

BACKGROUND: Rapid global change is creating fundamental challenges for the persistence of natural ecosystems and their biodiversity. Conservation efforts aimed at the protection of landscapes have had mixed success, and there is an increasing awareness that the long-term protection of biodiversity requires inclusion of flexible restoration along with protection. Rewilding is one such approach that has been both promoted and criticized in recent years. Proponents emphasize the potential of rewilding to tap opportunities for restoration while creating benefits for both ecosystems and societies. Critics discuss the lack of a consistent definition of rewilding and insufficient knowledge about its potential outcomes. Other criticisms arise from the mistaken notion that rewilding actions are planned without considering societal acceptability and benefits. Here, we present a framework for rewilding actions that can serve as a guideline for researchers and managers. The framework is applicable to a variety of rewilding approaches, ranging from passive to trophic rewilding, and aims to promote beneficial interactions between society and nature.

ADVANCES: The concept of rewilding has evolved from its initial emphasis on protecting large, connected areas for large carnivore conservation to a process-oriented, dynamic approach. On the basis of concepts from resilience and complexity theory of social-ecological systems, we identify trophic complexity, stochastic disturbances, and dispersal as three critical components of natural ecosystem dynamics. We propose that the restoration of these processes, and their interactions, can lead to increased self-sustainability of ecosystems and should be at the core of rewilding actions. Building on these concepts, we develop a framework to design and evaluate rewilding plans. Alongside ecological restoration goals, our framework emphasizes people's perceptions and experiences of wildness and the regulating and material contributions from restoring nature. These societal aspects are important outcomes and may be critical factors for the success of rewilding initiatives (see the figure). We further identify current societal constraints on rewilding and suggest actions to mitigate them.

OUTLOOK: The concept of rewilding challenges us to rethink the way we manage nature and to broaden our vision about how nature will respond to changes that society brings, both intentionally and unintentionally. The effects of rewilding actions will be specific to each ecosystem, and thus a deep understanding of the processes that shape ecosystems is critical to anticipate these effects and to take appropriate management actions. In addition, the decision of whether a rewilding approach is desirable should consider stakeholders' needs and expectations. To this end, structured restoration planning—based on participatory processes involving researchers, managers, and stakeholders—that includes monitoring and adaptive management can be used. With the recent designation of 2021–2030 as the "decade of ecosystem restoration" by the United Nations General Assembly, policy- and decision-makers could push rewilding topics to the forefront of discussions about how to reach post-2020 biodiversity goals. ■

ON OUR WEBSITE

Read the full article at http://dx.doi.org/10.1126/science.aav5570

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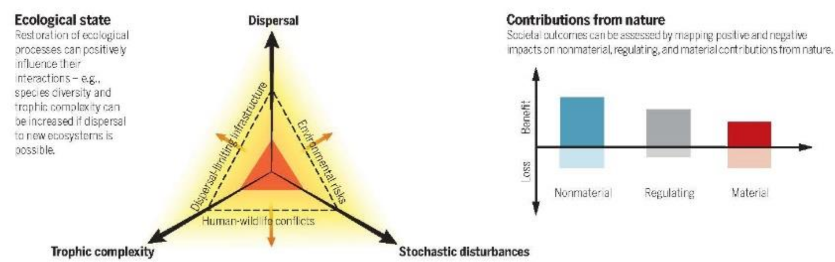
Cite this article as A. Perino *et al.*, *Science* **364**, eaav5570 (2019). DOI: 10.1126/science.aav5570



Rewilding actions and outcomes are framed by societal and ecological context. Rewilding can be assessed by representing the state of ecosystems in a three-dimensional space where each dimension corresponds to an ecological process. The difference in volume between the restored (yellow pyramid) and the degraded ecosystem (orange pyramid) is a proxy for the effects of rewilding on the self-sustainability of the ecosystem. The dashed line within the yellow pyramid represents the societal boundaries that determine to what extent ecological processes can be restored. Rewilding actions can help push societal boundaries toward the ecological potential (orange arrows) by promoting societal support and opportunities for people to experience the autonomy of ecological processes in enjoyable ways.

Perino *et al*. 2019 *Science* 364:eaav5570, http://bit.ly/rwScience.

Three key ecological components

- Trophic complexity
- Natural disturbances
- Connectivity/Dispersal

Wolf (Poland [zoo]; JCS)

Dieback from bark beetles (Poland; JCS)

Perino *et al*. 2019 *Science* 364:eaav5570, http://bit.ly/rwScience.

Trophic rewilding

- Definition
  - **Species introductions to restore top-down trophic interactions and associated trophic cascades to promote self-regulating biodiverse ecosystems** (Svenning et al. 2016 PNAS)
- Mostly megafauna-based

SPECIAL FEATURE: PERSPECTIVE

PNAS

SPECIAL FEATURE: PERSPECTIVE

CrossMark

click for updates

Science for a wilder Anthropocene: Synthesis and future directions for trophic rewilding research

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Edited by Yadvinder Malhi, Oxford University, Oxford, United Kingdom, and accepted by the Editorial Board August 5, 2015 (received for review March 16, 2015)

Trophic rewilding is an ecological restoration strategy that uses species introductions to restore top-down trophic interactions and associated trophic cascades to promote self-regulating biodiverse ecosystems. Given the importance of large animals in trophic cascades and their widespread losses and resulting trophic downgrading, it often focuses on restoring functional megafaunas. Trophic rewilding is increasingly being implemented for conservation, but remains controversial. Here, we provide a synthesis of its current scientific basis, highlighting trophic cascades as the key conceptual framework, discussing the main lessons learned from ongoing rewilding projects, systematically reviewing the current literature, and highlighting unintentional rewilding and spontaneous wildlife comebacks as underused sources of information. Together, these lines of evidence show that trophic cascades may be restored via species reintroductions and ecological replacements. It is clear, however, that megafauna effects may be affected by poorly understood trophic complexity effects and interactions with landscape settings, human activities, and other factors. Unfortunately, empirical research on trophic rewilding is still rare, fragmented, and geographically biased, with the literature dominated by essays and opinion pieces. We highlight the need for applied programs to include hypothesis testing and science-based monitoring, and outline priorities for future research, notably assessing the role of trophic complexity, interplay with landscape settings, land use, and climate change, as well as developing the global scope for rewilding and tools to optimize benefits and reduce human–wildlife conflicts. Finally, we recommend developing a decision framework for species selection, building on functional and phylogenetic information and with attention to the potential contribution from synthetic biology.

conservation | megafauna | reintroduction | restoration | trophic cascades

Human impacts are so pervasive that a new geological epoch has been proposed: the Anthropocene (1). The effects on ecosystems and biodiversity are one of the biggest challenges facing modern society. Large-bodied animals are particularly affected, with massive prehistoric extinctions (2–4) and severe declines in many extant species (5). Over the last decades it has become increasingly clear that large animals are often important for ecosystem function and biodiversity via trophic cascades, the propagation of consumer impacts downward through food webs (6, 7). Their widespread losses have led to trophic downgrading on a global scale, with negative effects on ecosystems and biodiversity (6–8).

These observations have inspired a new ecological restoration approach that we here refer to as "trophic rewilding." The rewilding concept was introduced in the late 20th century as a large-scale conservation

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Author contributions: J.-C.S., P.B.M.P., and S.F. designed research; J.-C.S., P.B.M.P., S.F., and D.M.H. performed research; P.B.M.P. and S.F. analyzed data; and J.-C.S., P.B.M.P., C.J.D., R.E., S.F., M.G., D.M.H., B.S., C.J.S., J.W.T., and F.W.M.V. wrote the paper.

The authors declare no conflict of interest.

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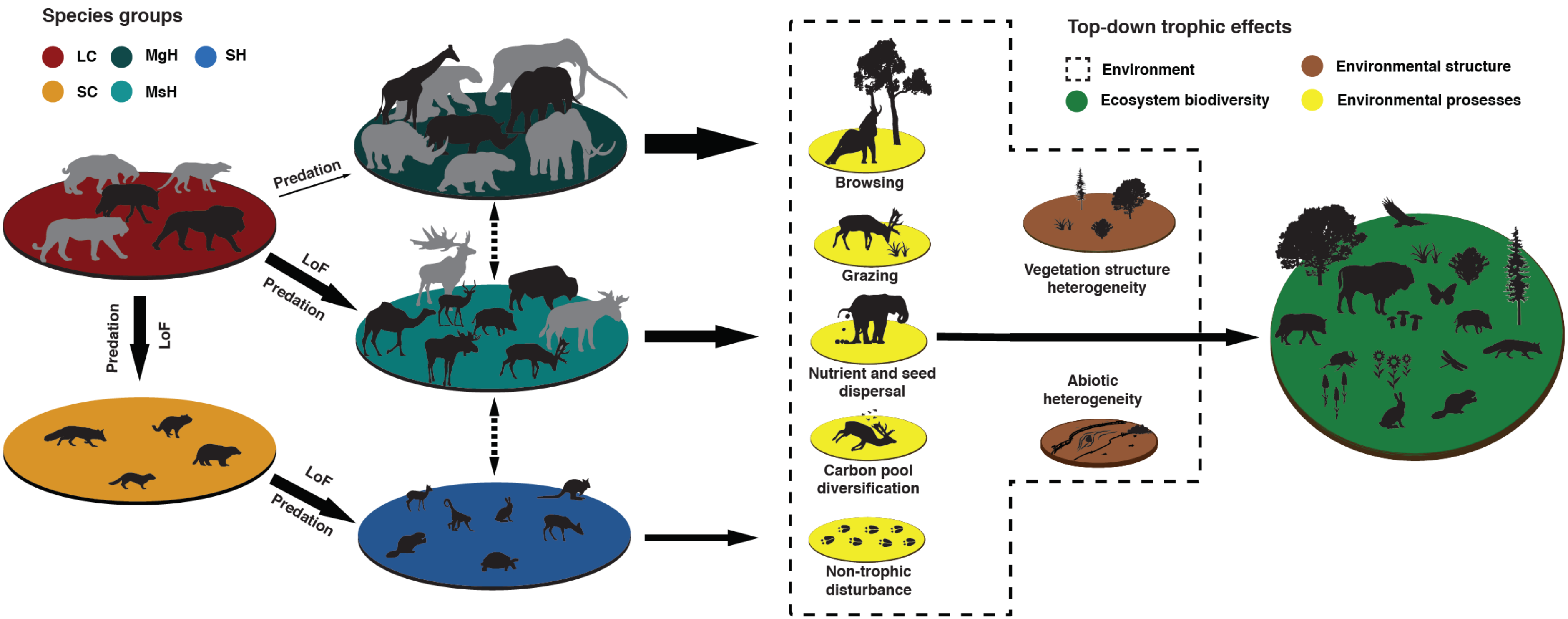
This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1502556112/-/DCSupplemental.

Svenning et al. 2016 *PNAS 113:898-906* http://bit.ly/rewildingPNAS.

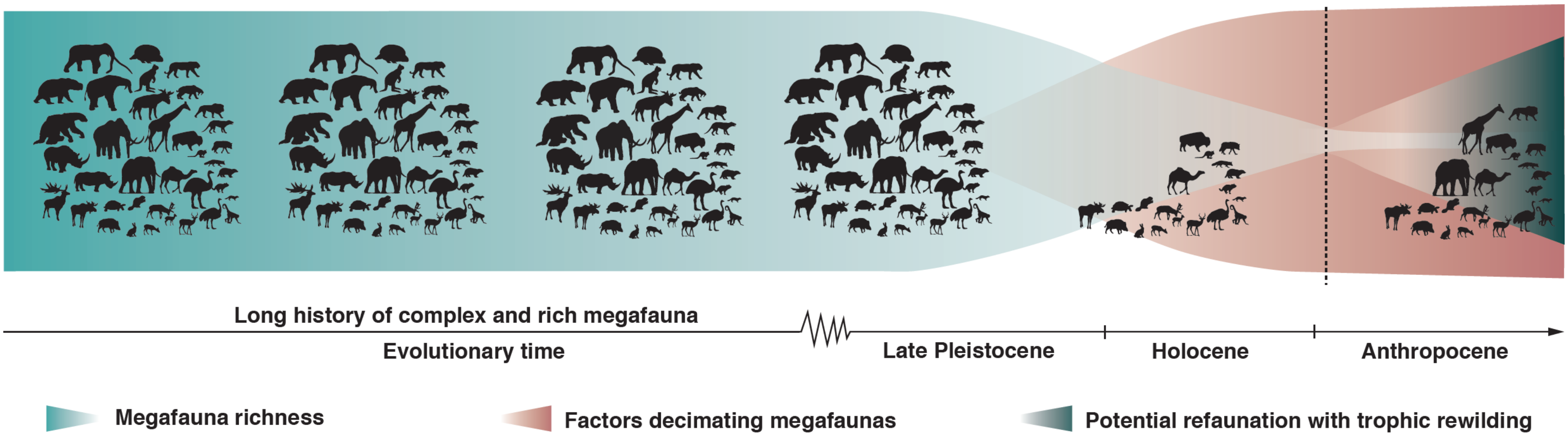
Idea: Megafauna promotes biodiversity via top-down trophic processes+



<u>Increase diversity capacity of natural and semi-natural areas</u>

Svenning et al., in Pettorelli et al. 2019 ”Rewilding”, *Cambridge University Press*, http://bit.ly/rwBESbook

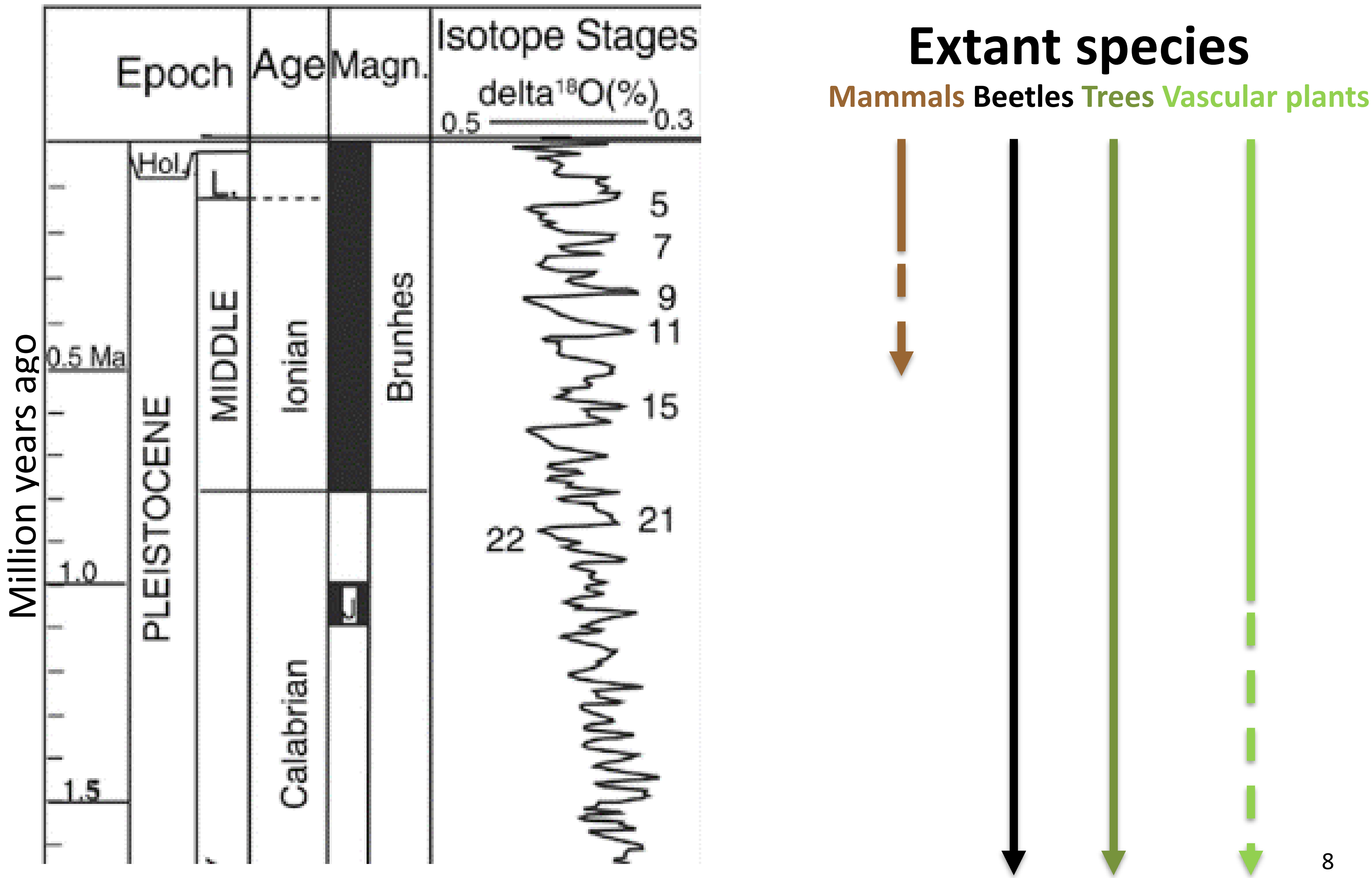
Background I:
Current species diversity evolved in megafauna-rich ecosystems



Rich megafaunas the evolutionary norm
(an evolutionary base-line)

Svenning et al., in Pettorelli et al. 2019 "Rewilding", *Cambridge University Press*, http://bit.ly/rwBESbook

Most extant species are 'ancient'



Estudios Geológicos 71:e026; Kurtén 1968, Coope 2004 Phil. Trans. R. Soc. Lond. B, Mai 1995, Lang 1994

Evolutionary background of ecological adaptations even deeper

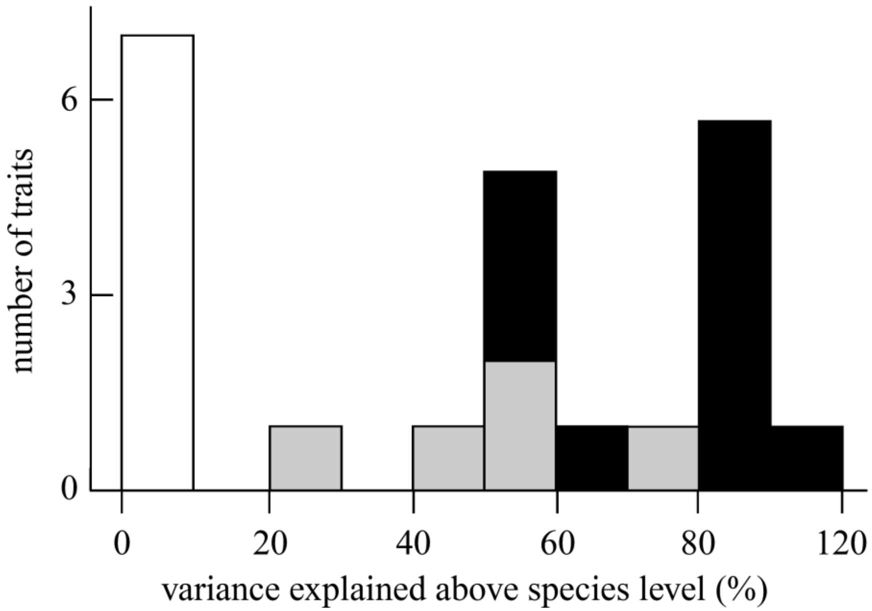


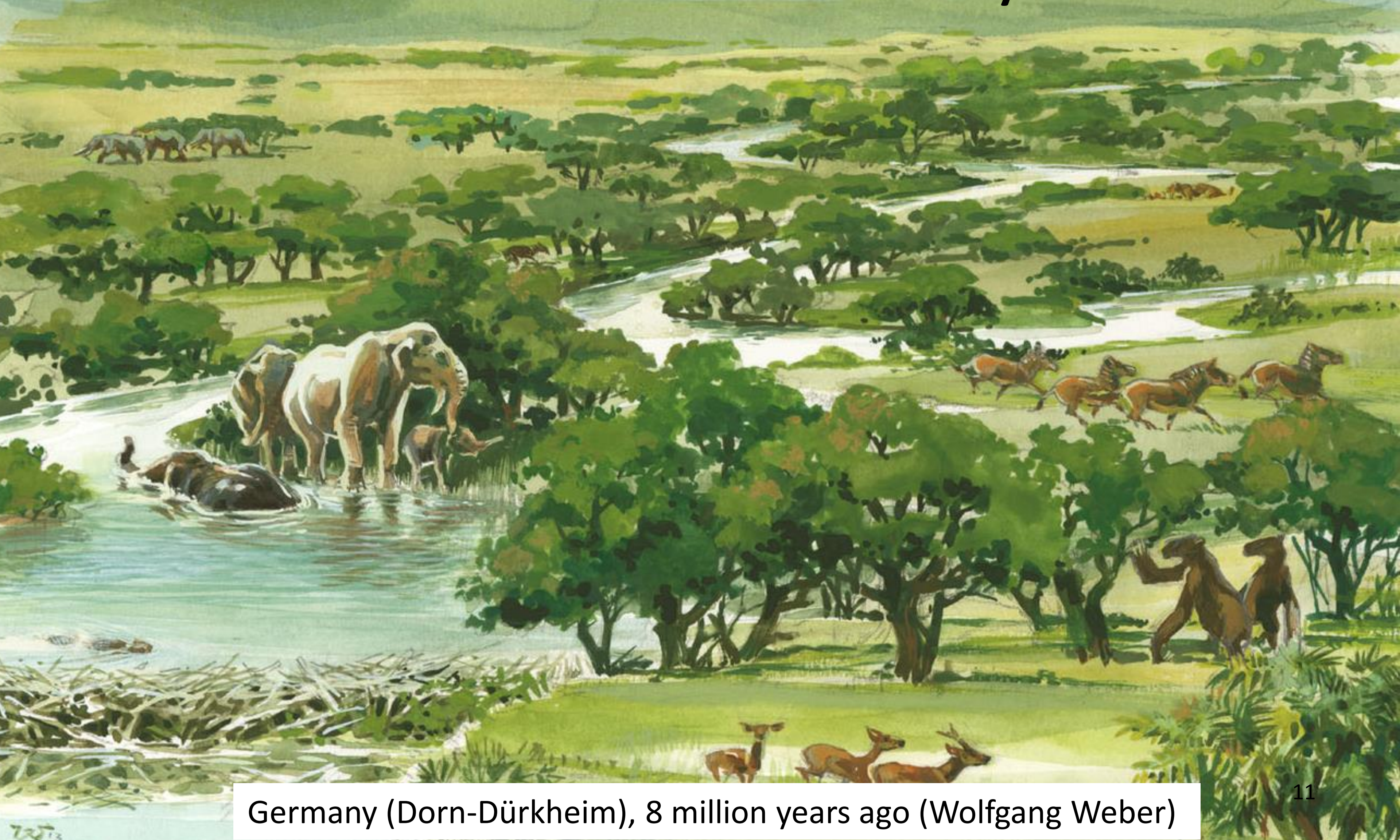
Figure 3. Conservatism of different traits measured by (*a*) one minus the QVI and (*b*) by the variance explained above species level. Grey bars: conservatism of niches along environmental gradients (present study). Black bars: conservatism of morphological and physiological traits (from (*a*) Ackerly & Reich (1999) and (*b*) Peat & Fitter (1994)). White bars: the result of our null models, which simulate the expected values of conservatism for traits without conservatism.

Prinzing. 2001. The niche of higher plants: evidence for phylogenetic conservatism. *Proceedings Roy Soc B* 268:1483.

Rich megafaunas have been the standard for millions of years

England (Trafalgar Square) 125,000 years ago (Roman Uchytel)

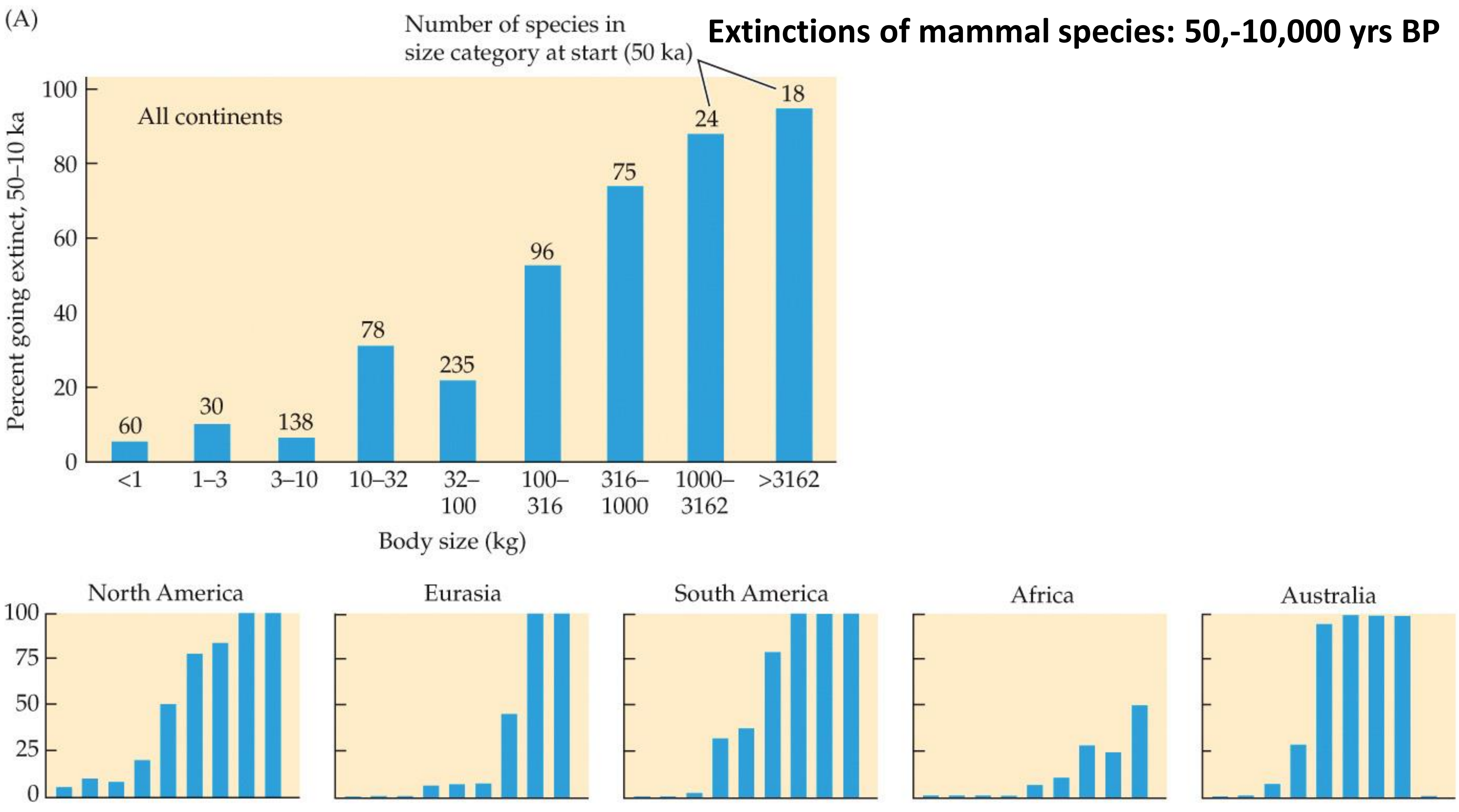
Rich megafaunas have been the standard for millions of years



Germany (Dorn-Dürkheim), 8 million years ago (Wolfgang Weber)

Strong size-biased defaunation globally across last 50,000 years

Extinctions of mammal species: 50,-10,000 yrs BP



BIOGEOGRAPHY 5e, Figure 9.30 (Part 1)

+ Smith et al. 2018 *Science* 360:310-313.

Very little extinction in non-megafauna

- Late Pleistocene temperate non-megafauna from Europe

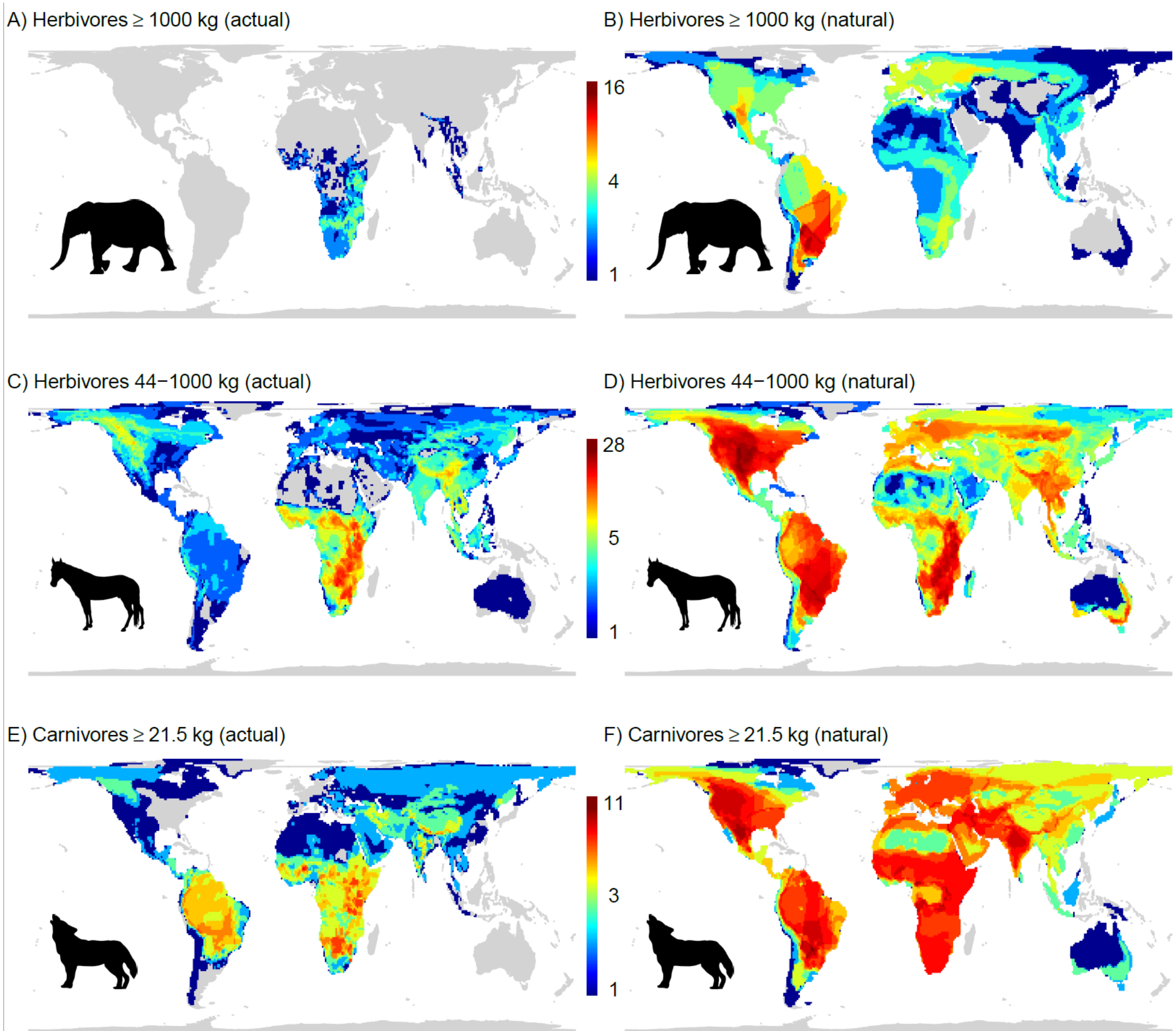
JCS + tristanba, kerbtier.de, www.rios-galegos.com , //r.a.r.e.free.fr/ , www.selgasfoto.lv , Peter Mlakar, G. Mittenecker.

Megafauna losses strongly linked to expansion of *Homo sapiens*

Sandom et al. & Svenning 2014 *Proc Roy Soc B* 281:20133254, http://bit.ly/megafauna-extinction;
Smith et al. 2018 *Science* 360:310-313.

Field Museum Library + Bill Whittaker, https://en.wikipedia.org/wiki/Clovis_culture#/media/File:Clovis_Rummells_Maske.jpg

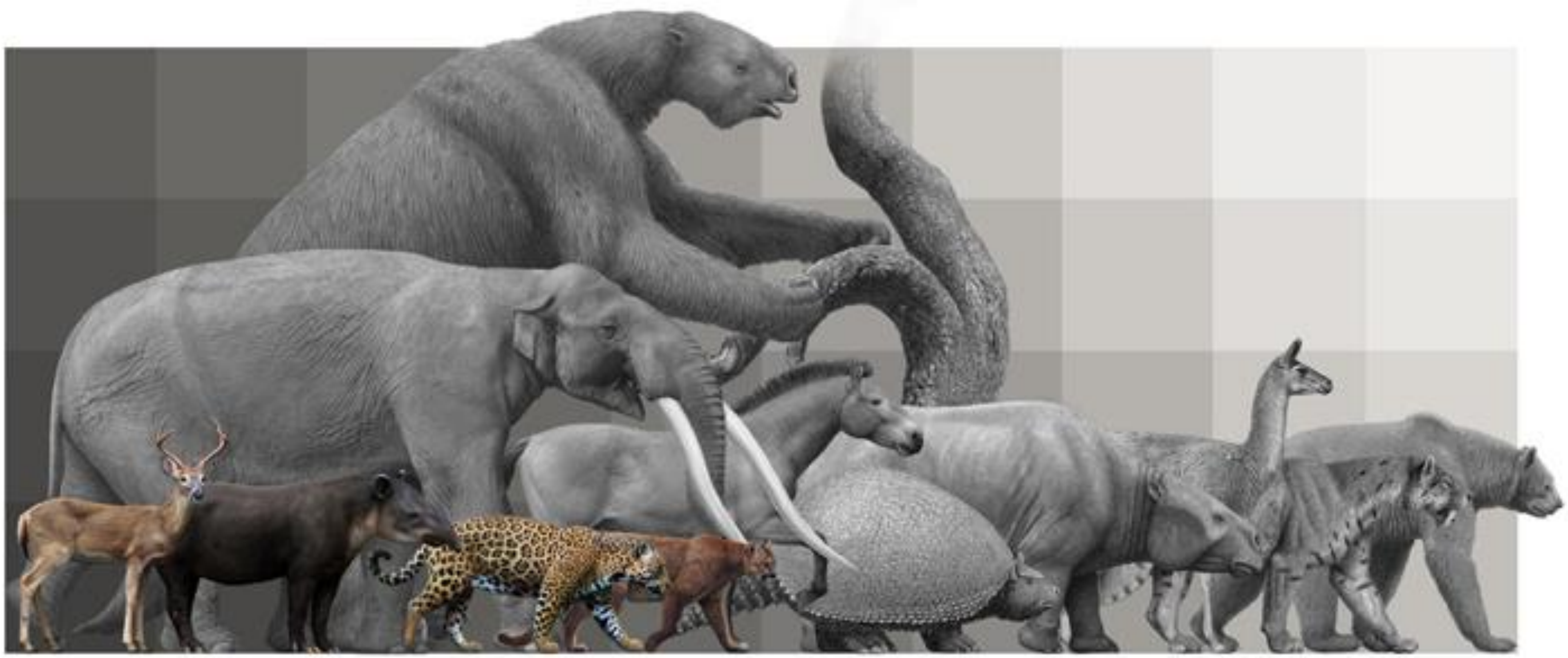
Impacts on megafauna functional groups



Svenning et al. 2016 *PNAS 113:898-906* http://bit.ly/rewildingPNAS

Deep-time perspective – take home

- **Current species evolved in megafauna-rich ecosystems (an evolutionary baseline)**
- **Modern standard of megafauna-poor ecosystems**
  - **Highly ununsual condition on an evolutionary time scale**
  - Completely or largely anthropogenic



End-Pleistocene/early Holocene plus extant (color) megafauna in South American savannas

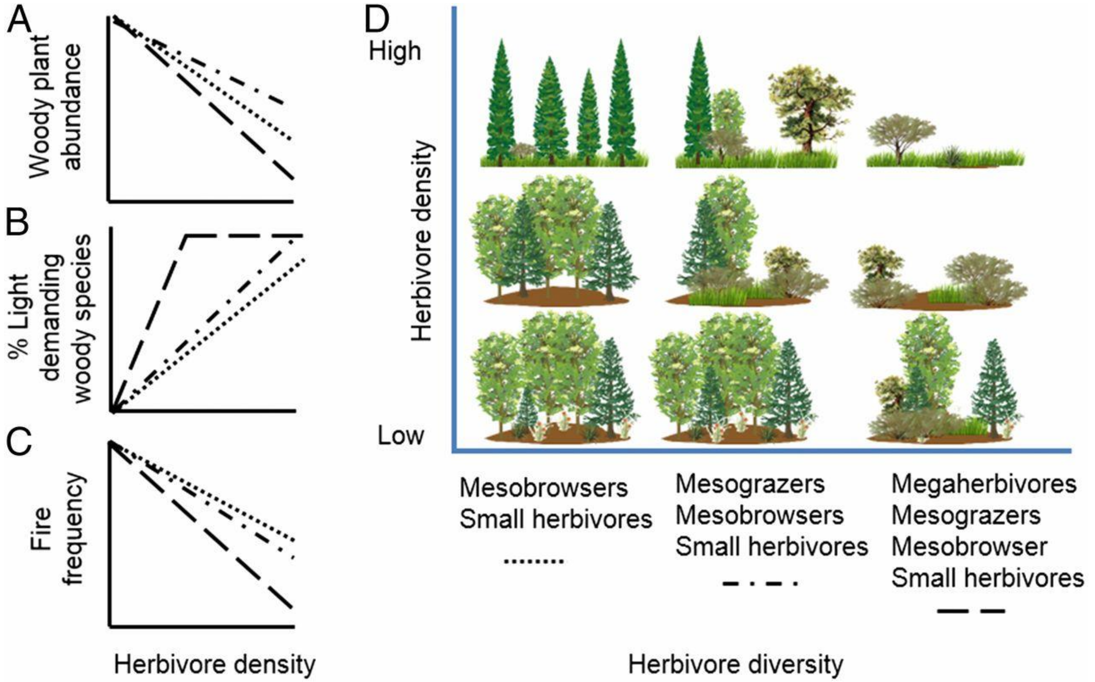
Sandom et al. & Svenning 2014 *Proc Roy Soc B* 281:20133254, http://bit.ly/megafauna-extinction; Ill.: M. Antón.

Background 2: Strong role of top-down trophic effects via megafauna in many ecosystems

Photo: JC Svenning 2011

Role of big and very big herbivores

- Strong potential for generating vegetation heterogeneity
  - Benefits biodiversity
  - Even more relevant in a warmer, CO_2-rich world
- Other functions
  - Seed dispersal
  - Nutrient dispersal
  - Carbon diversification



Bakker et al. & Svenning 2016 *PNAS* 113:848-855 http://bit.ly/herbivorePNAS

Role of big and very big herbivores

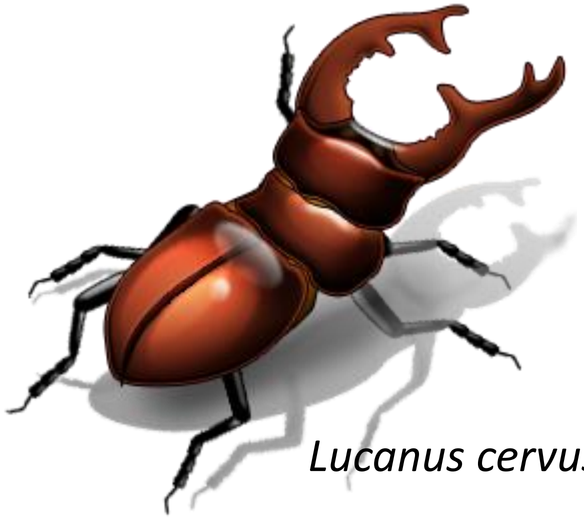
Herbivore exclosure in Yellowstone National Park

Photo: JC Svenning 2011

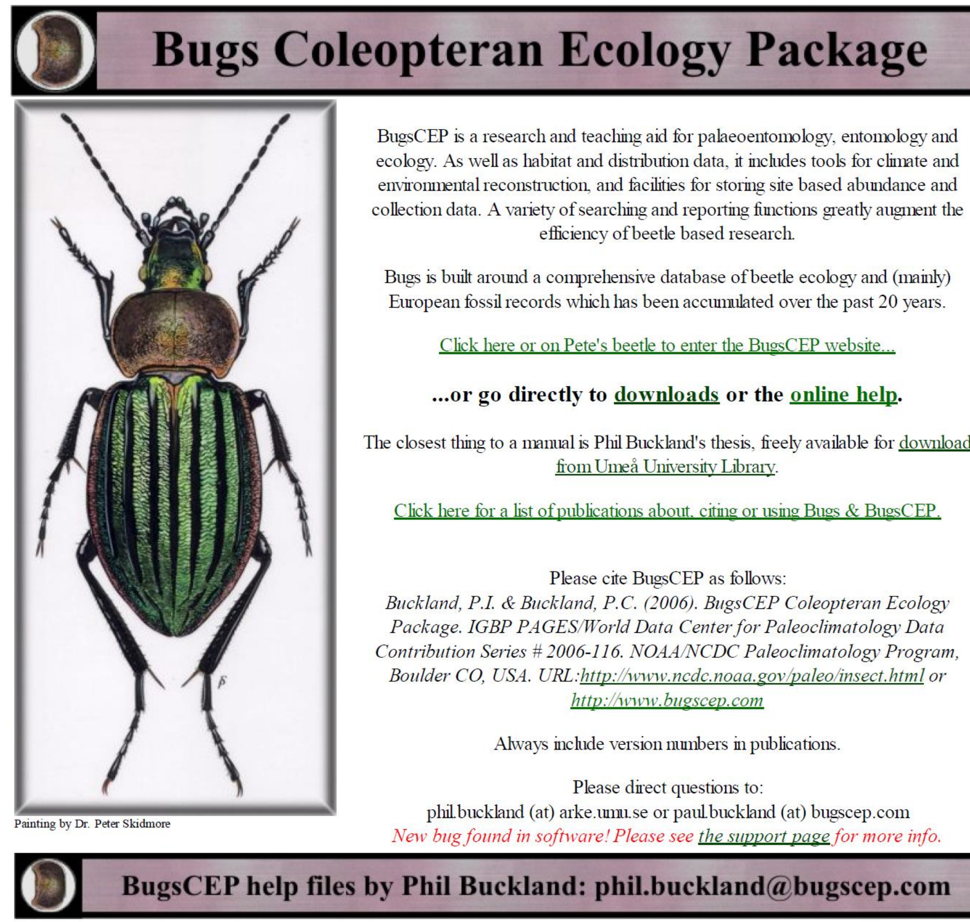
Europe: Forest or wood pasture, or…?

Svenning 2002 *Biological Conservation* 104:133-148; Sandom et al. 2014 *PNAS* 111:4162-4167; photos: JCS.

Beetles as indicators



Lucanus cervus



Bugs Coleopteran Ecology Package

BugsCEP is a research and teaching aid for palaeoentomology, entomology and ecology. As well as habitat and distribution data, it includes tools for climate and environmental reconstruction, and facilities for storing site based abundance and collection data. A variety of searching and reporting functions greatly augment the efficiency of beetle based research.

Bugs is built around a comprehensive database of beetle ecology and (mainly) European fossil records which has been accumulated over the past 20 years.

Click here or on Pete's beetle to enter the BugsCEP website...

...or go directly to downloads or the online help.

The closest thing to a manual is Phil Buckland's thesis, freely available for download from Umeå University Library.

Click here for a list of publications about, citing or using Bugs & BugsCEP.

Please cite BugsCEP as follows:
Buckland, P.I. & Buckland, P.C. (2006). BugsCEP Coleopteran Ecology Package. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series # 2006-116. NOAA/NCDC Paleoclimatology Program, Boulder CO, USA. URL:http://www.ncdc.noaa.gov/paleo/insect.html or http://www.bugscep.com

Always include version numbers in publications.

Please direct questions to:
phil.buckland (at) arke.umu.se or paul.buckland (at) bugscep.com
New bug found in software! Please see the support page for more info.

Painting by Dr. Peter Skidmore

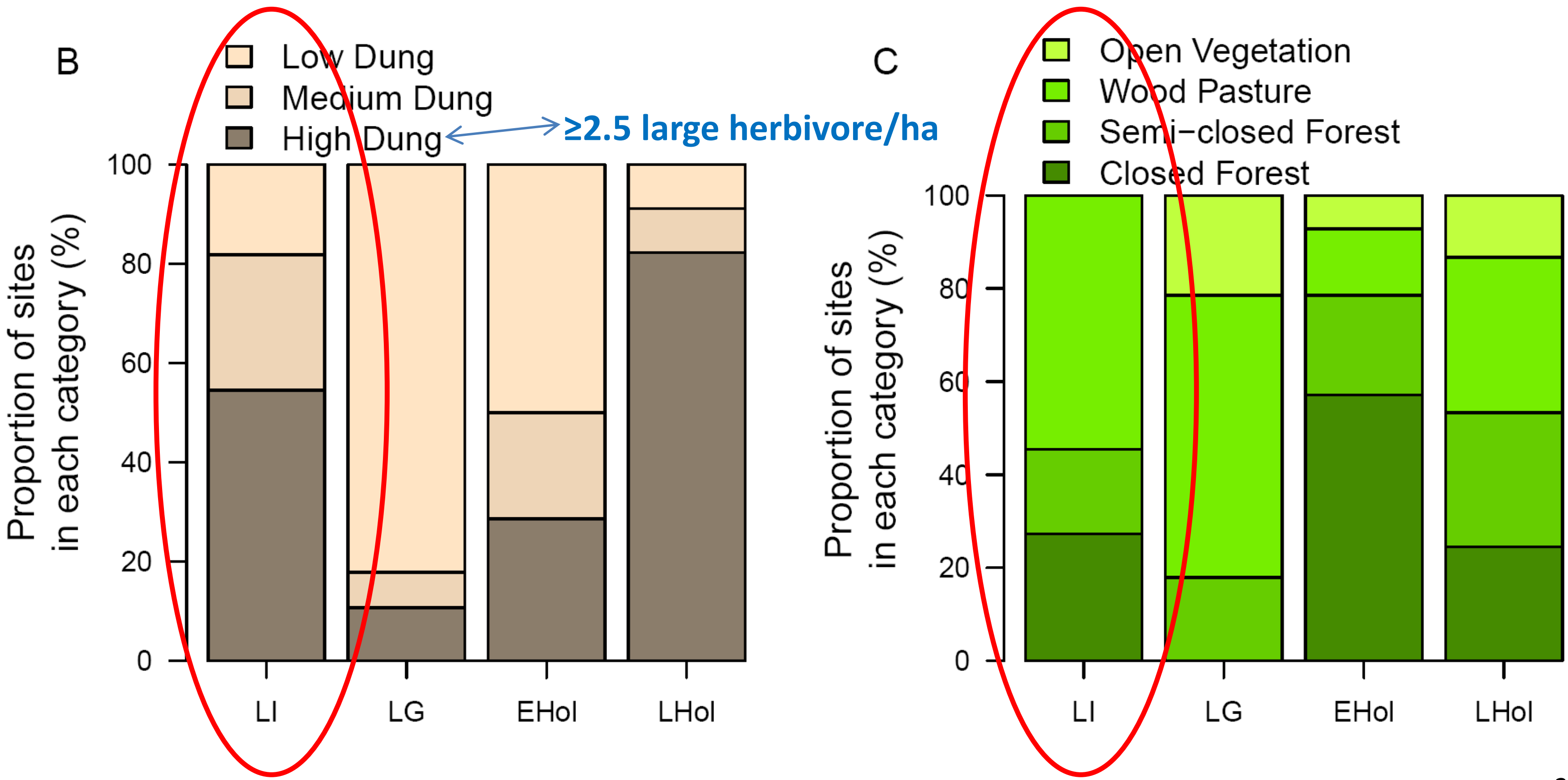
BugsCEP help files by Phil Buckland: phil.buckland@bugscep.com

Copris lunaris

Sandom, Ejrnæs, Hansen & Svenning 2014 PNAS 111:4162-4167, http://bit.ly/interglacialveg.

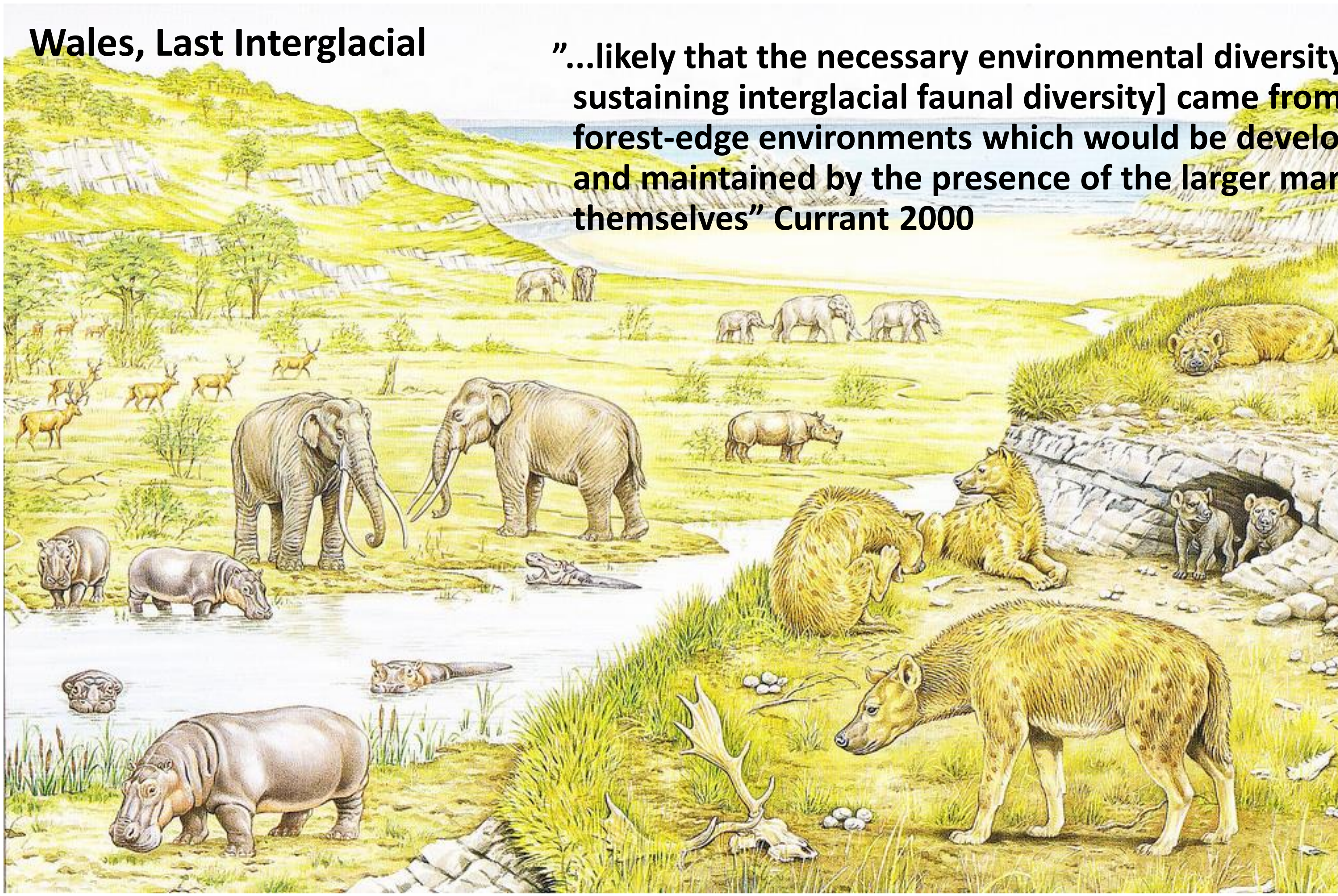
Often high herbivore densities and a mosaic semi-open/forest landscape during the Last Interglacial

- Ecosystem reconstructions based on fossil beetles (Britain):



Sandom, Ejrnæs, Hansen & Svenning 2014 PNAS 111:4162-4167, http://bit.ly/interglacialveg.

High habitat diversity prior to the late-Quaternary megafauna loss



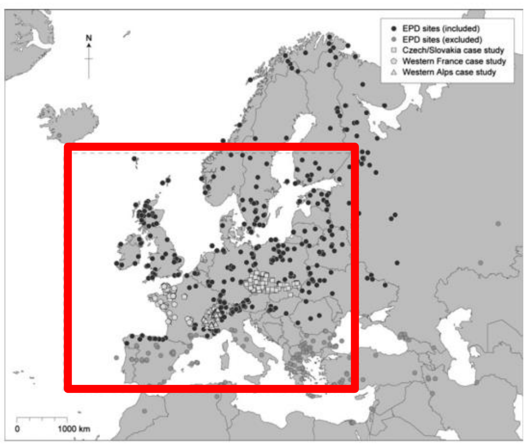
Wales, Last Interglacial

”...likely that the necessary environmental diversity [for sustaining interglacial faunal diversity] came from forest-edge environments which would be developed and maintained by the presence of the larger mammals themselves” Currant 2000

Sandom, Ejrnæs, Hansen & Svenning 2014 PNAS 111:4162-4167, http://bit.ly/interglacialveg; Currant 2000

Mesolithic- also some openness after loss of elephants, hunting pressure etc.

Pre-agricultural Holocene – pollen ”big data”



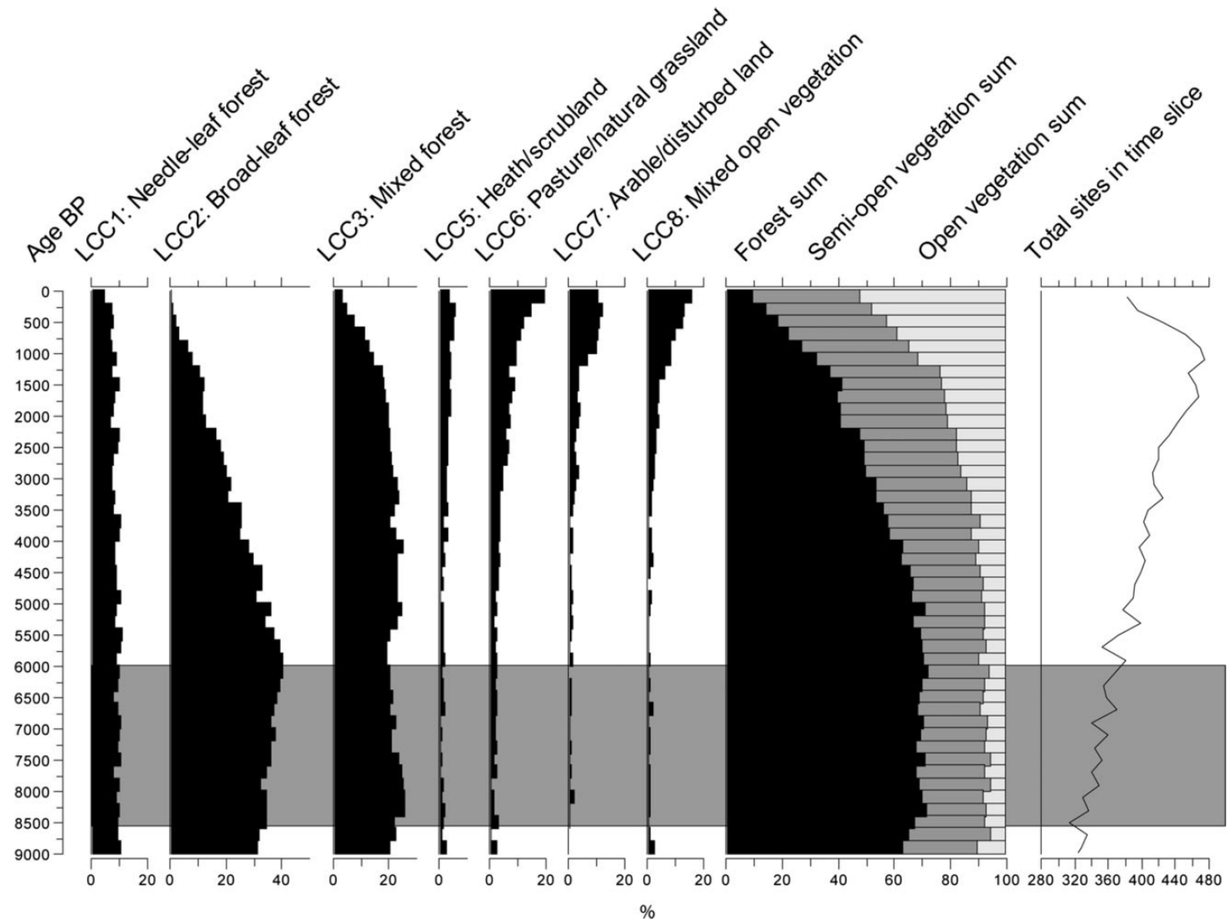


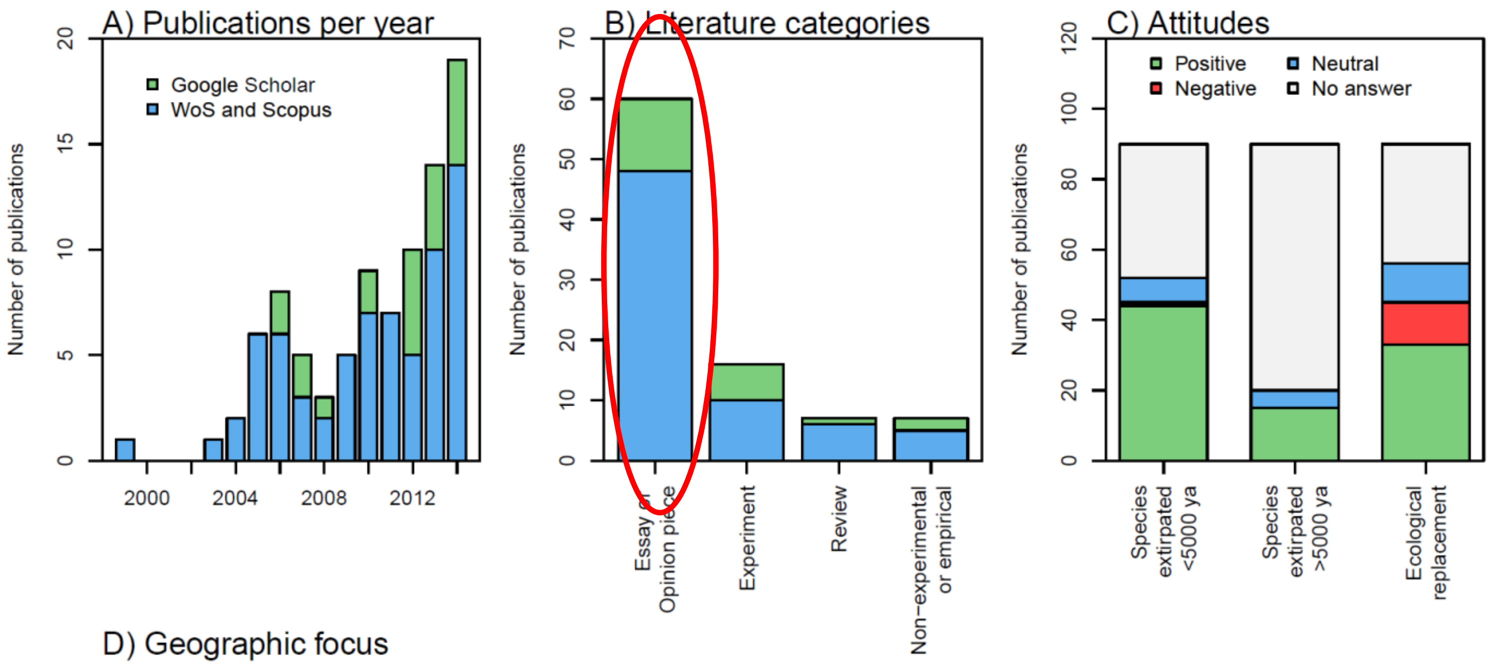
Fig. 2 Spatially aggregated pseudobiomization (PBM) results for temperate and northern Europe (813 sites): percentage of sites assigned to each LCC per 200 year time interval (9000–0 BP). Grey box shows forest maximum.

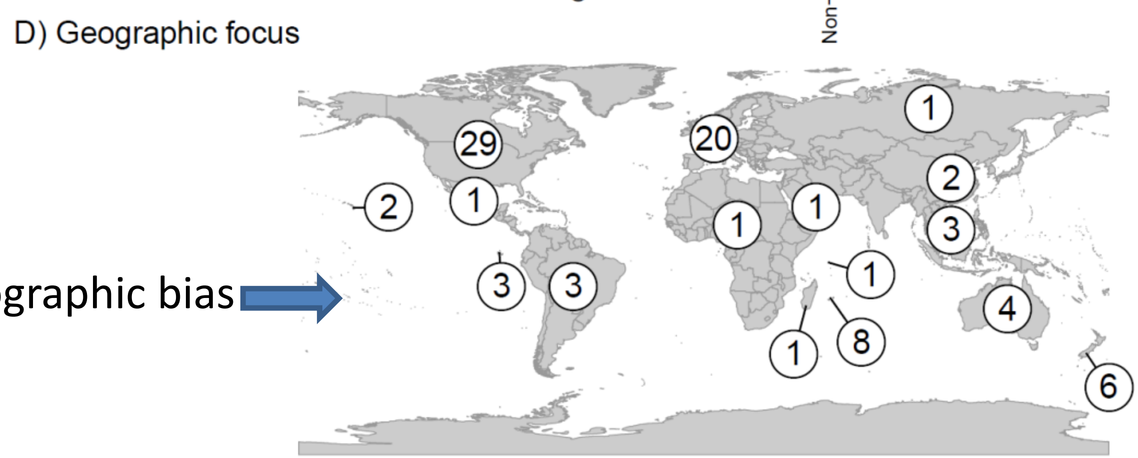
Fyfe et al. 2015 Glob. Chang. Biol. 21:1197+

Iberá rewilding project, Argentina (JCS)

STATUS OF REWILDING SCIENCE

Systematic review of rewilding research



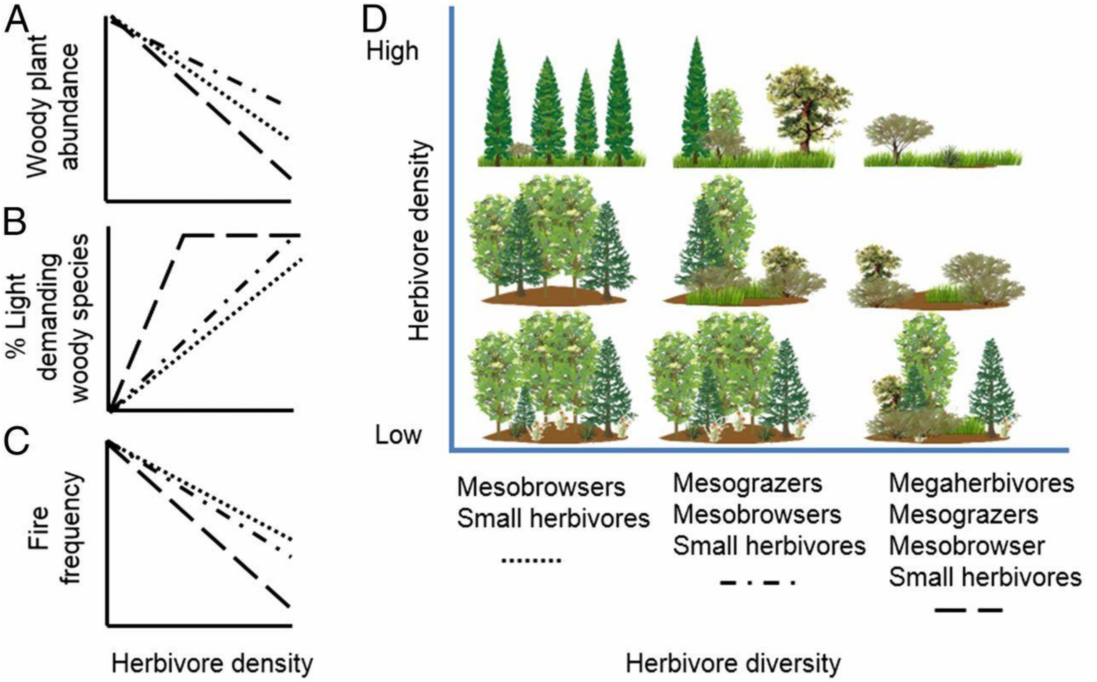


Strong geographic bias

Svenning et al. 2016 *PNAS 113:898-906* http://bit.ly/rewildingPNAS.

Much work on megafauna

- Strong potential for generating vegetation heterogeneity
  - Benefits biodiversity
  - Even more relevant in a warmer, CO_2-rich world
- Other functions
  - Seed dispersal
  - Nutrient dispersal
  - Carbon diversification

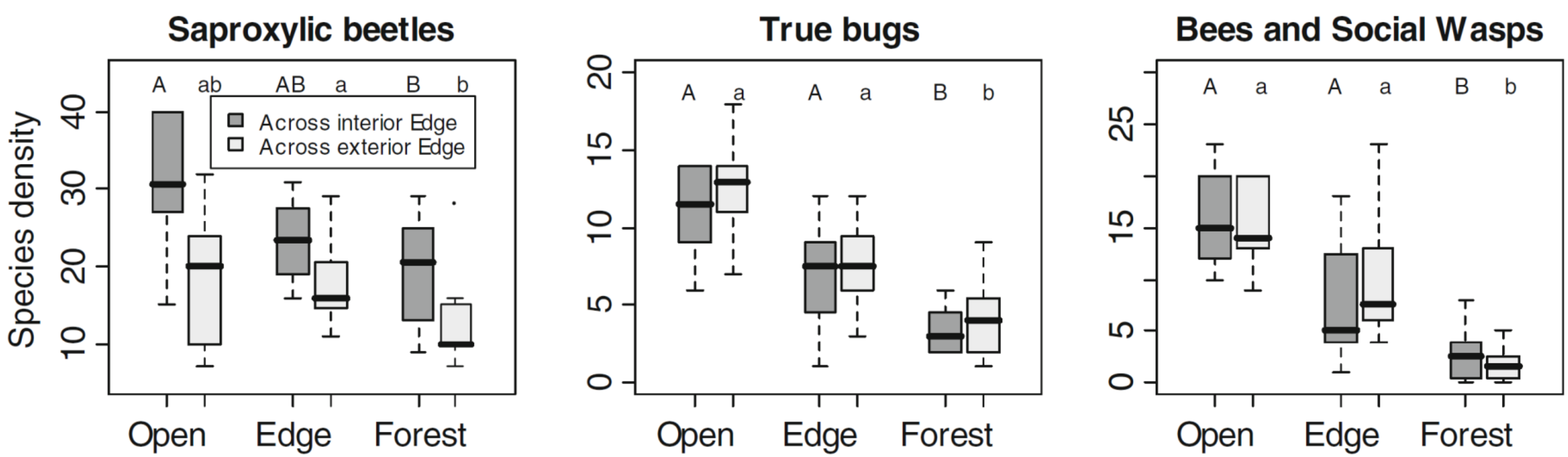


Bakker et al. & Svenning 2016 *PNAS* 113:848-855 http://bit.ly/herbivorePNAS

Much work on natural disturbances and connectivity

- Bark beetles + fire

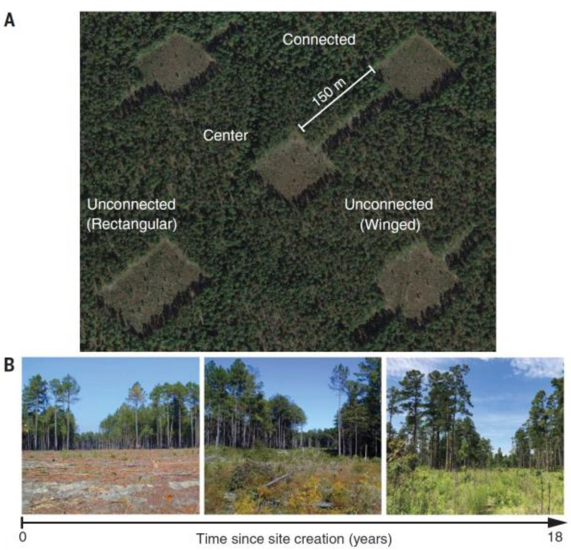
National Park “Bavarian Forest”

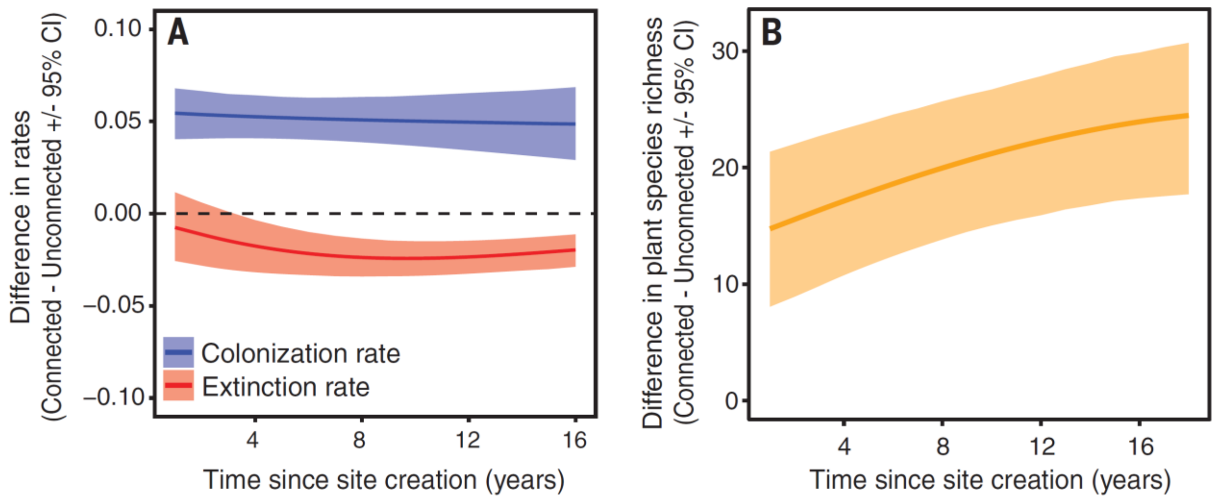


“The European spruce bark beetle *Ips typographus* in a national park: from pest to keystone species” Müller et al. 2008 Biol. Cons. 17:2979–3001.

Much work on natural disturbances and connectivity

- Connectivity

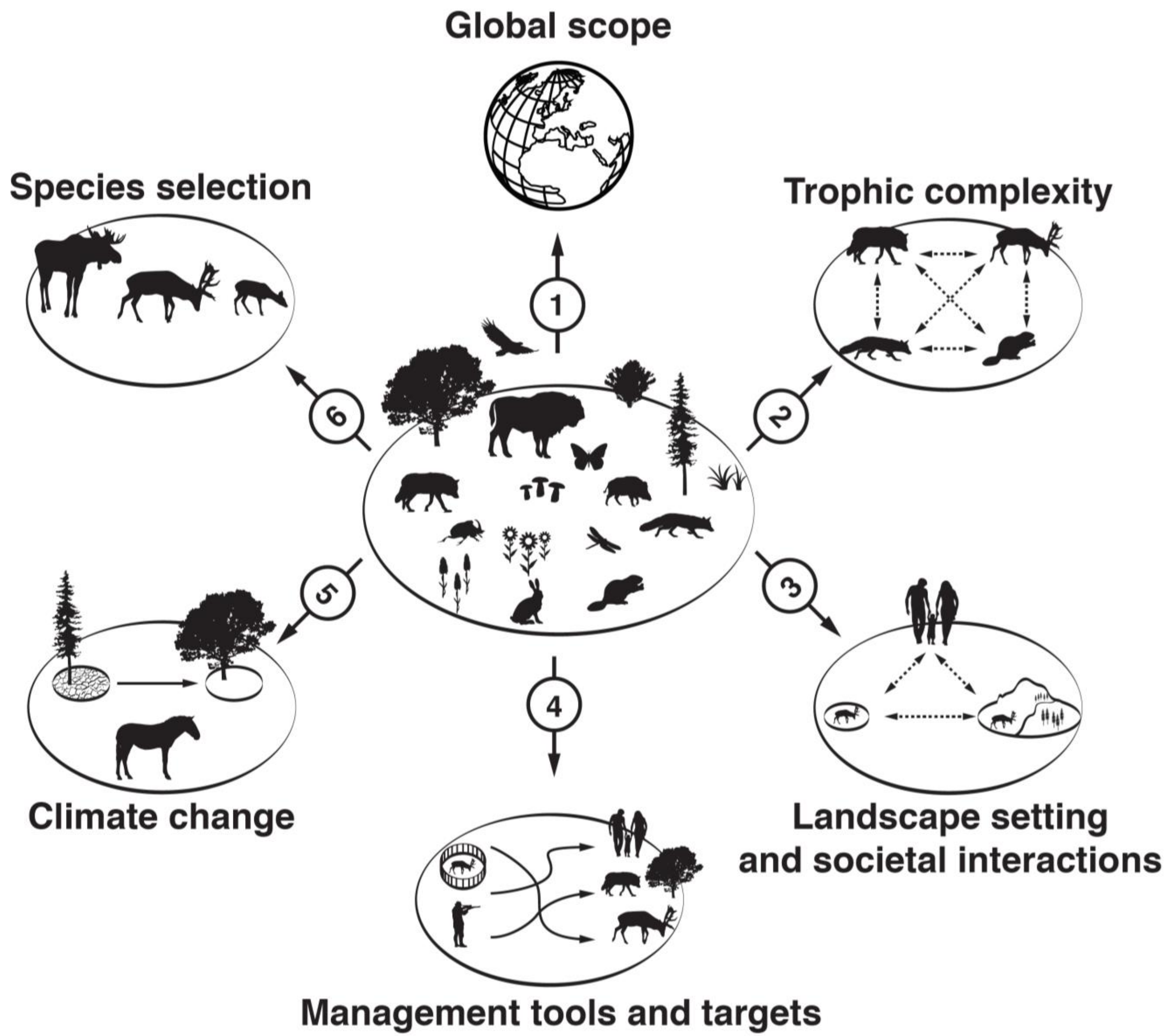




ig. 2. Connectivity reduces extinction and increases colonization rates over two decades, result-ng in accruals of species in connected fragments. (**A**) Average colonization rates are 5% greater and xtinction rates are 2% lower for species in connected fragments than rates for those in unconnected ragments. These rates are constant over time. The net accrual of colonization credits increases iodiversity in connected fragments. (**B**) Plant species richness in connected fragments has increased at a reater rate than in unconnected fragments. Shown is the difference in estimated species richness over ime, illustrating greater increases in richness in connected versus unconnected fragments. This rate increase has been consistent for nearly two decades and has resulted in connected fragments having 24 more plant species than unconnected fragments (fig. S3). A linear model (on the logit scale) is the best fit for the difference in species richness between connected and unconnected fragments over time (*26*). Shaded regions represent 95% confidence intervals.

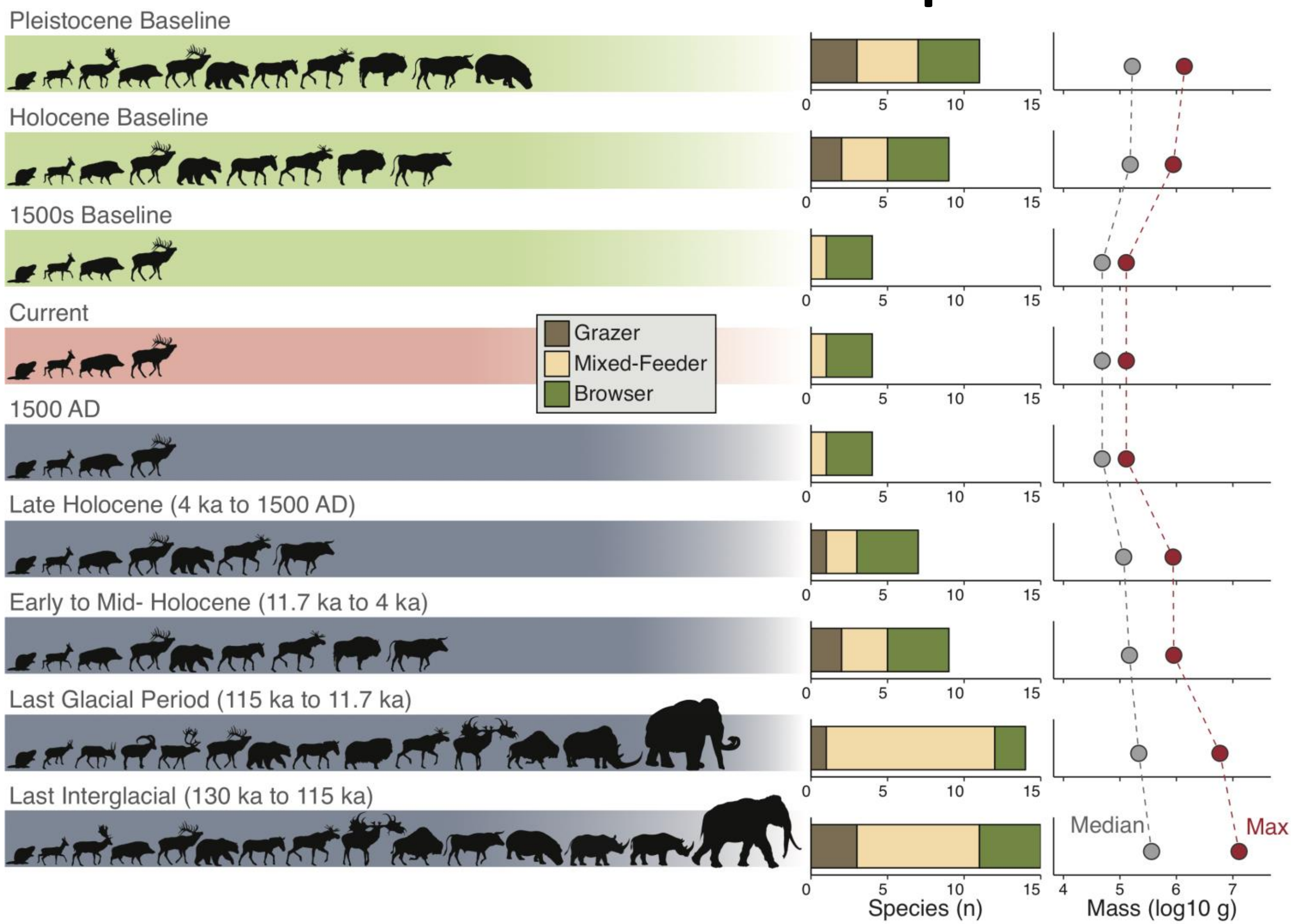
"Ongoing accumulation of plant diversity through habitat connectivity in an 18-year experiment" Damschen et al. 2019 Science 365:1478-1480.

Priorities for trophic rewilding research



Svenning et al., in Pettorelli et al. 2019 "Rewilding", *Cambridge University Press*, http://bit.ly/rwBESbook

How far is restoration possible with native extant species?

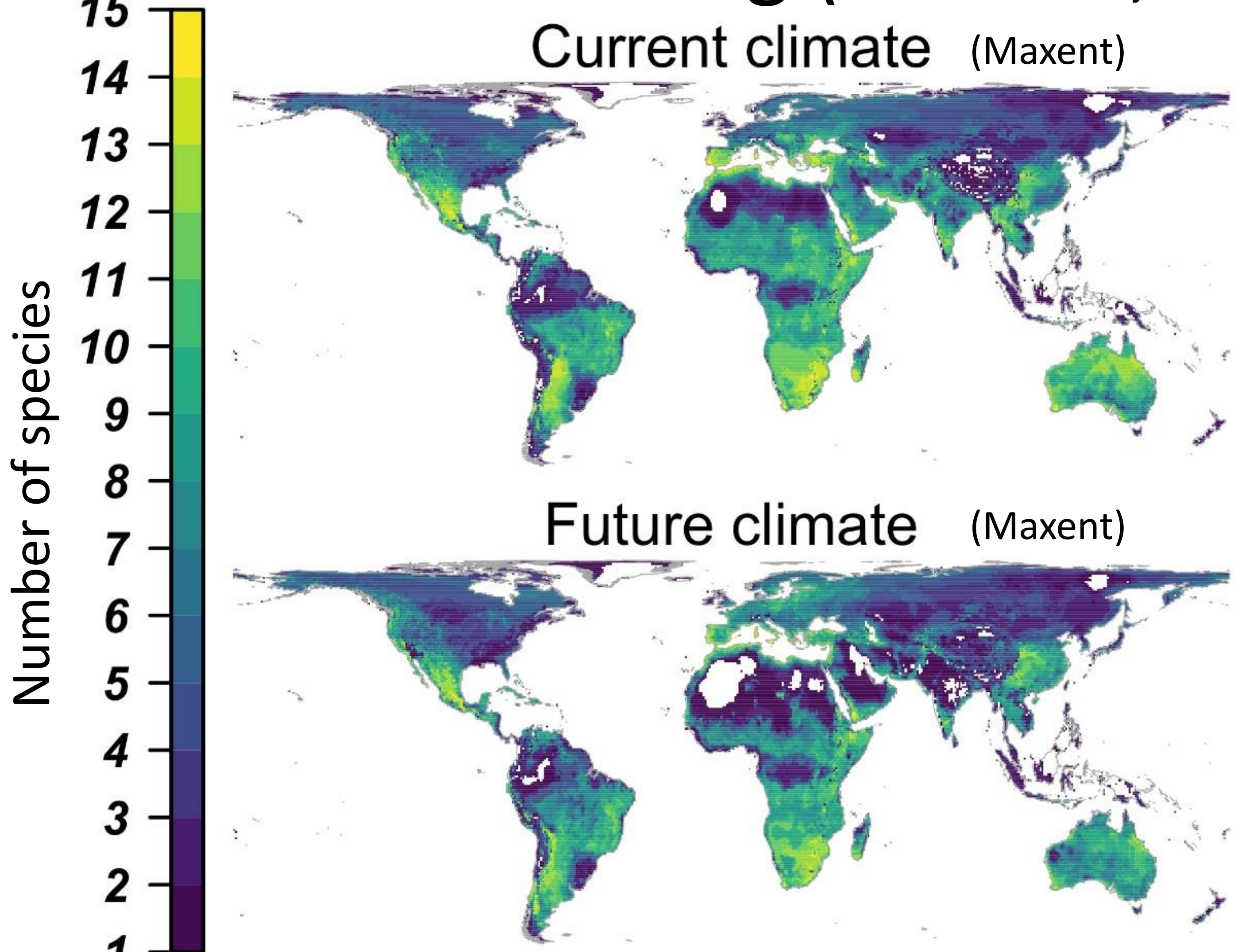


Simon Schowanek

Climate change effects on rewilding

Jarvie & Svenning 2018 *Philosophical Transactions of the Royal Society B* 373: 20170446, http://bit.ly/ccRWspp.

Climate change with limited effect on potential for rewilding (RCP 8.5, 2070)



Jarvie & Svenning 2018 *Philosophical Transactions of the Royal Society B* 373: 20170446, http://bit.ly/ccRWspp.

IMPLEMENTATION RESEARCH

Framework for design & implementation

- Design:
  - Trophic complexity
  - Natural/Stochastic disturbances
  - Dispersal/Connectivity
- Implementation
  1) Ecosystem status assessment
  2) Social-ecological constraints
  3) Adaptive management

REVIEW SUMMARY

REWILDING

Rewilding complex ecosystems

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BACKGROUND: Rapid global change is creating fundamental challenges for the persistence of natural ecosystems and their biodiversity. Conservation efforts aimed at the protection of landscapes have had mixed success, and there is an increasing awareness that the long-term protection of biodiversity requires inclusion of flexible restoration along with protection. Rewilding is one such approach that has been both promoted and criticized in recent years. Proponents emphasize the potential of rewilding to tap opportunities for restoration while creating benefits for both ecosystems and societies. Critics discuss the lack of a consistent definition of rewilding and insufficient knowledge about its potential outcomes. Other criticisms arise from the mistaken notion that rewilding actions are planned without considering societal acceptability and benefits. Here, we present a framework for rewilding actions that can serve as a guideline for researchers and managers. The framework is applicable to a variety of rewilding approaches, ranging from passive to trophic rewilding, and aims to promote beneficial interactions between society and nature.

ADVANCES: The concept of rewilding has evolved from its initial emphasis on protecting large, connected areas for large carnivore conservation to a process-oriented, dynamic approach. On the basis of concepts from resilience and complexity theory of social-ecological systems, we identify trophic complexity, stochastic disturbances, and dispersal as three critical components of natural ecosystem dynamics. We propose that the restoration of these processes, and their interactions, can lead to increased self-sustainability of ecosystems and should be at the core of rewilding actions. Building on these concepts, we develop a framework to design and evaluate rewilding plans. Alongside ecological restoration goals, our framework emphasizes people's perceptions and experiences of wildness and the regulating and material contributions from restoring nature. These societal aspects are important outcomes and may be critical factors for the success of rewilding initiatives (see the figure). We further identify current societal constraints on rewilding and suggest actions to mitigate them.

OUTLOOK: The concept of rewilding challenges us to rethink the way we manage nature and to broaden our vision about how nature will respond to changes that society brings, both intentionally and unintentionally. The effects of rewilding actions will be specific to each ecosystem, and thus a deep understanding of the processes that shape ecosystems is critical to anticipate these effects and to take appropriate management actions. In addition, the decision of whether a rewilding approach is desirable should consider stakeholders' needs and expectations. To this end, structured restoration planning—based on participatory processes involving researchers, managers, and stakeholders—that includes monitoring and adaptive management can be used. With the recent designation of 2021–2030 as the "decade of ecosystem restoration" by the United Nations General Assembly, policy- and decision-makers could push rewilding topics to the forefront of discussions about how to reach post-2020 biodiversity goals. ■

ON OUR WEBSITE

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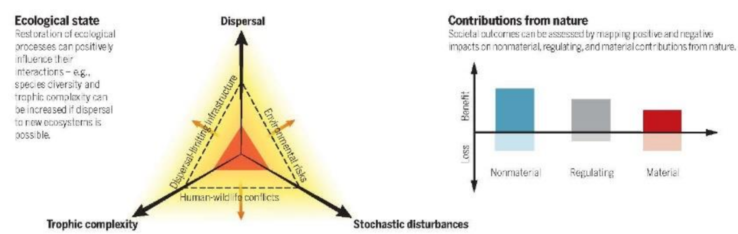
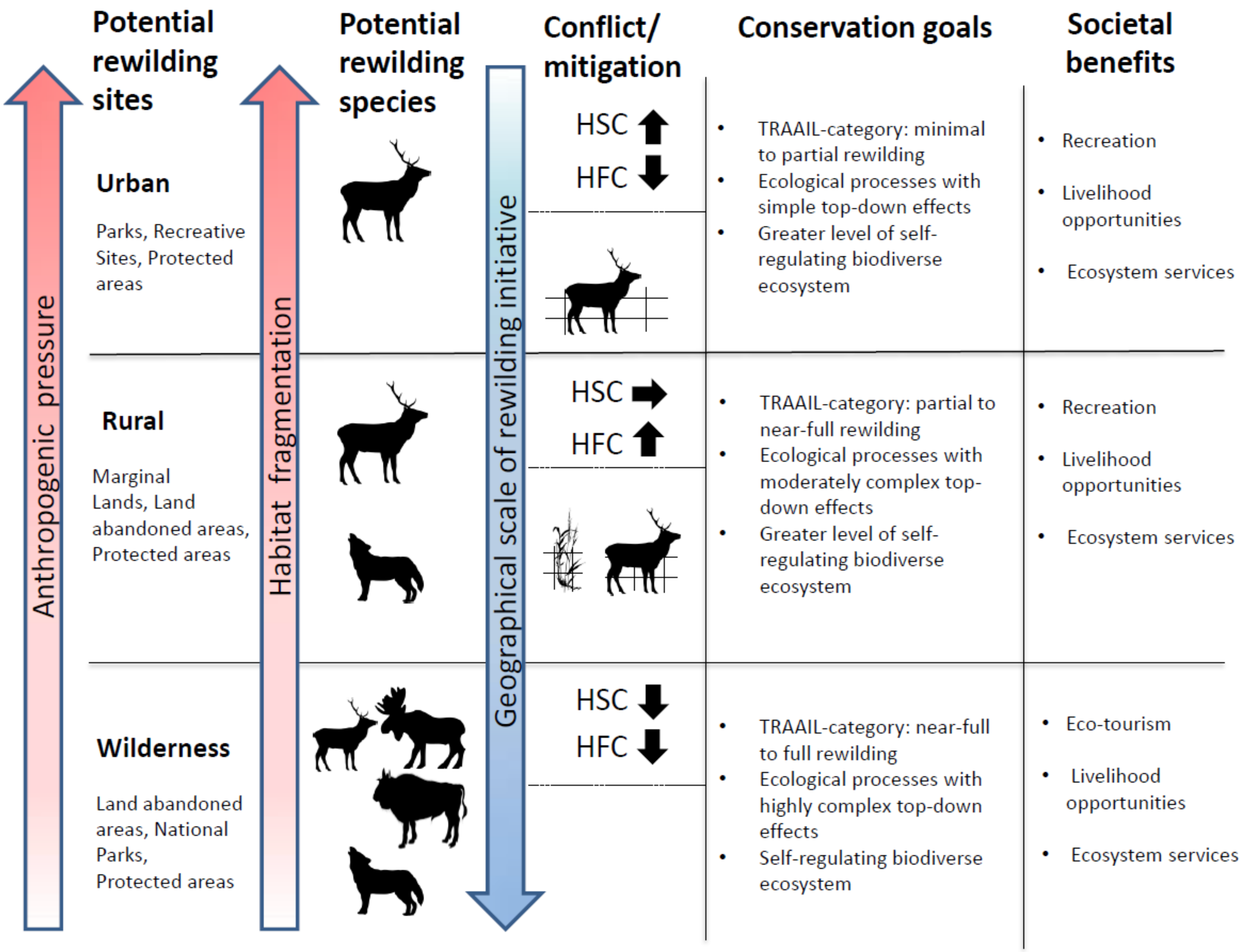


Rewilding actions and outcomes are framed by societal and ecological context. Rewilding can be assessed by representing the state of ecosystems in a three-dimensional space where each dimension corresponds to an ecological process. The difference in volume between the restored (yellow pyramid) and the degraded ecosystem (orange pyramid) is a proxy for the effects of rewilding on the self-sustainability of the ecosystem. The dashed line within the yellow pyramid represents the societal boundaries that determine to what extent ecological processes can be restored. Rewilding actions can help push societal boundaries toward the ecological potential (orange arrows) by promoting societal support and opportunities for people to experience the autonomy of ecological processes in enjoyable ways.

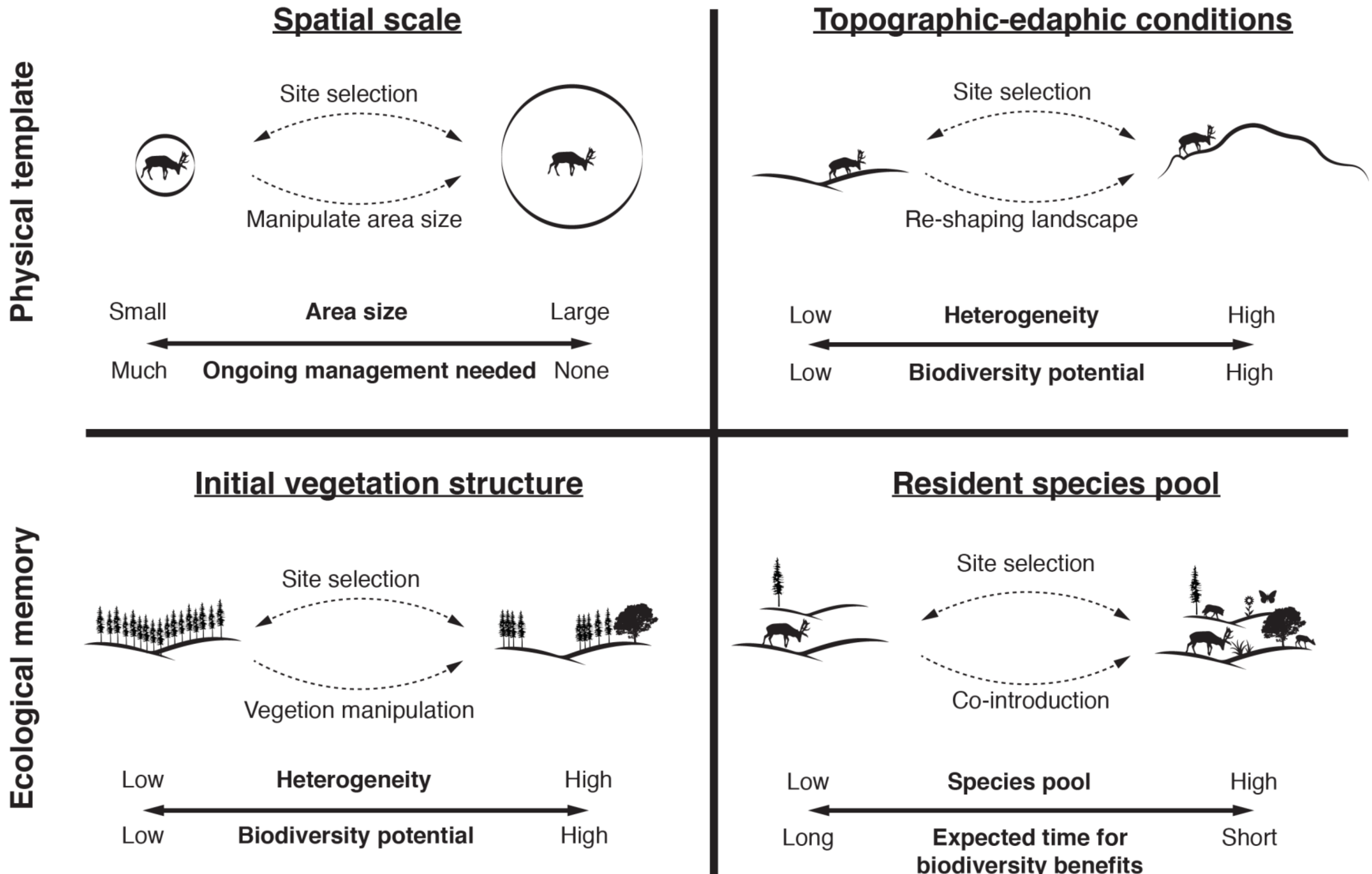
Perino *et al*. 2019 *Science* 364:eaav5570, http://bit.ly/rwScience.

Socio-ecological context



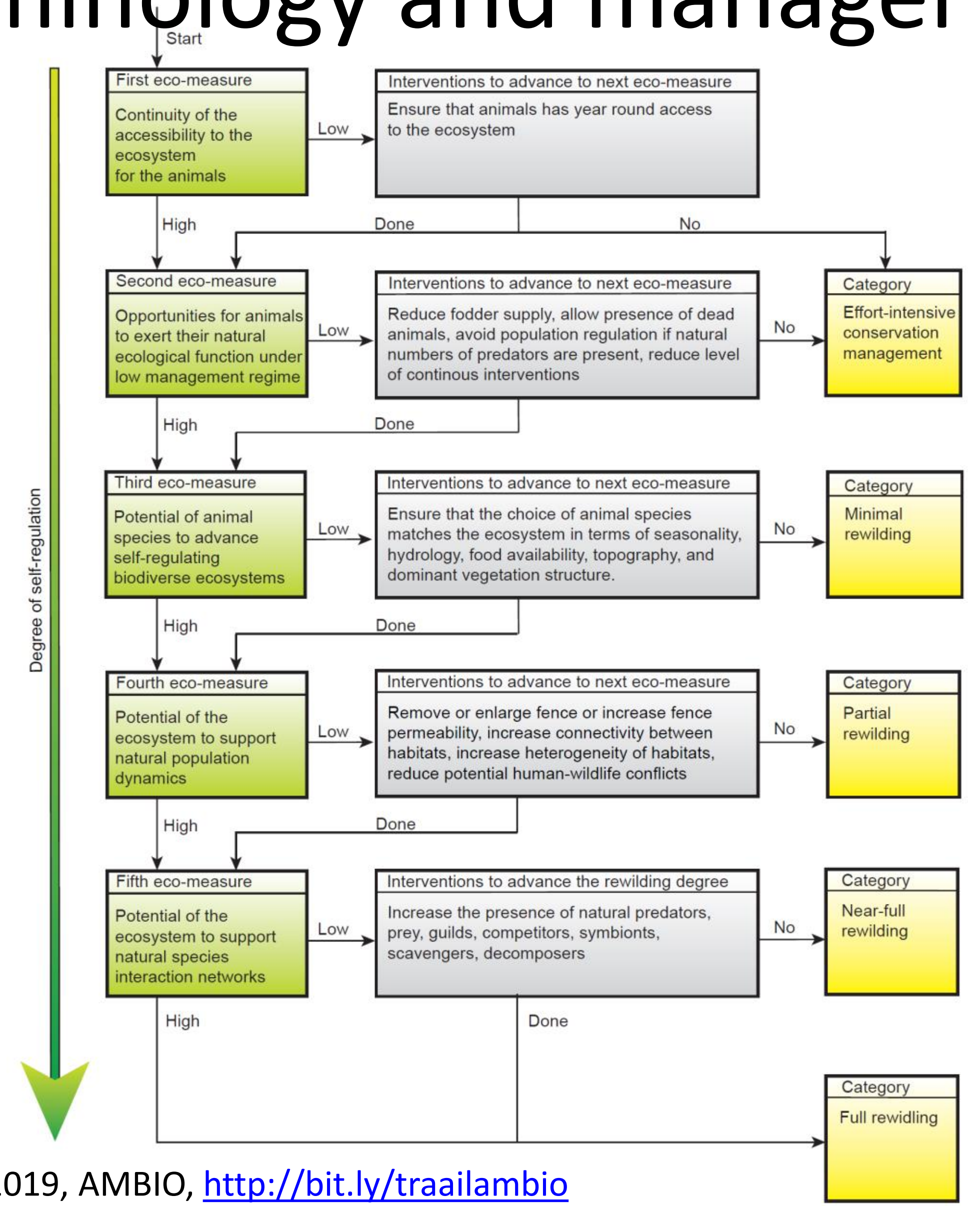
Pedersen *et al*. & Svenning, in press, *AMBIO*

Design considerations



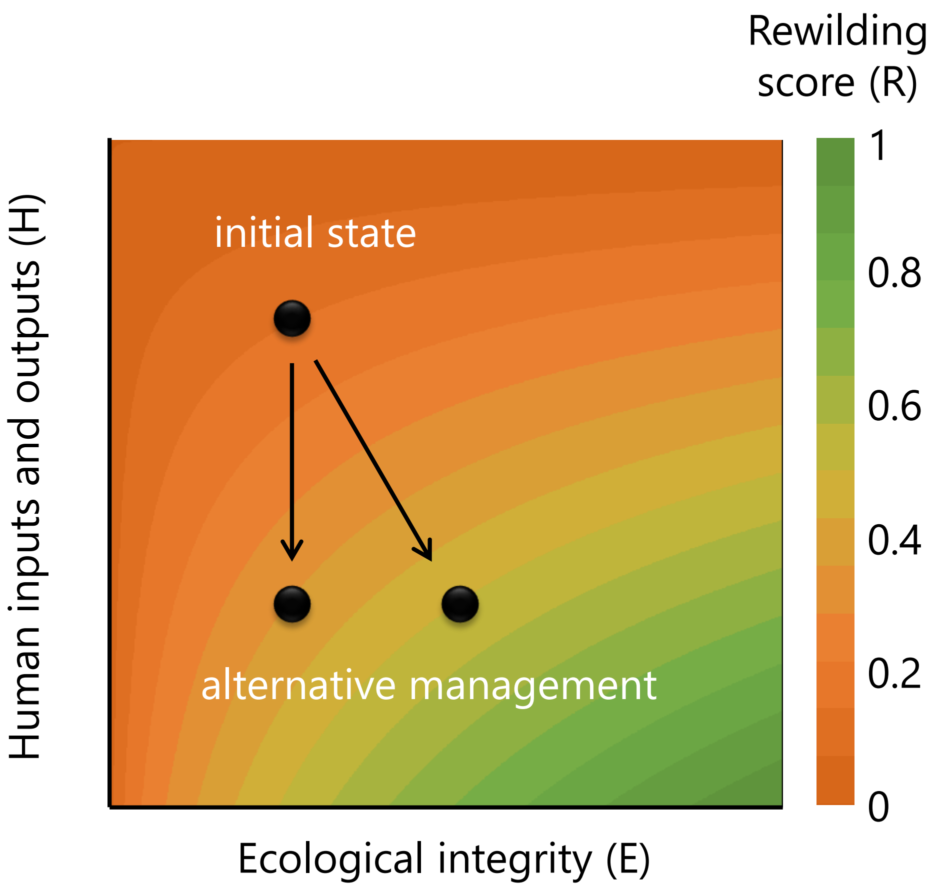
Svenning et al., in Pettorelli et al. 2019 ”Rewilding”, *Cambridge University Press*, http://bit.ly/rwBESbook

A trophic rewilding scale to guide terminology and management



Pedersen et al. & Svenning, 2019, AMBIO, http://bit.ly/traailambio

Framework for measuring progress in general rewilding projects



H axis

$H = f(i, o)$

- ☐ Supplementary feeding to wildlife
- ☐ Population reinforcement (e.g., reintroductions)
- ☐ Agricultural inputs and outputs
- ☐ Forestry inputs and outputs
- ☐ Grassland inputs and outputs
- ☐ Mining inputs and outputs
- ☐ Harvesting of terrestrial wildlife
- ☐ Harvesting of aquatic wildlife
- ☐ Carrion removal
- ☐ Deadwood removal

N axis

$N = f(d, c, t)$

- ☐ Natural snow and rock avalanche regimes
- ☐ Natural fire regimes
- ☐ Natural hydrological regimes
- ☐ Natural pest regimes and mortality events
- ☐ Terrestrial landscapes fragmentation
- ☐ Aquatic landscapes fragmentation
- ☐ Spontaneous vegetation dynamics (ecological succession)
- ☐ Absence of harmful invasive species
- ☐ Terrestrial species composition (occupancy, viability, time spent in the area)

Restored megafauna species

Torres *et al*. 2019 *Philosophical Transactions of the Royal Society B* B 373: 20170433, http://bit.ly/RWprog.

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BIOCHANGE
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VILLUM FONDEN

CARLSBERG FOUNDATION

MegaPast2Future

Megafauna ecosystem ecology from the deep prehistory to a human-dominated future

erc

Innovationsfonden

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Rewilding - & Questions

- Ecological restoration to promote <u>self-regulating</u> complex ecosystems
- A key element: Trophic rewilding
  - Key background
  - Megafauna-rich evolutionary baseline
  - Ecological importance of megafauna
  - Working hypothesis:
    - Megafauna promotes landscape- to local-level biodiversity
- Research need, but solid background
- Literature
  - **Concept**: Svenning et al. 2016 *PNAS 113:898-906* http://bit.ly/rewildingPNAS
  - **Concept**: Svenning et al., in Pettorelli et al. 2019 "Rewilding", *Cambridge University Press*, http://bit.ly/rwBESbook
  - Interactions with **global change**: Theme issue in *Philosophical Transactions Roy Soc B*, Bakker & Svenning (eds) 2018 http://bit.ly/trwPTB
  - Role of **ecological memory**: Schweiger et al. & Svenning, 2018, *Biological Reviews*: http://bit.ly/rwmem