AARHUS UNIVERSITY

BIOCHANGE
CENTER FOR BIODIVERSITY DYNAMICS
IN A CHANGING WORLD

ANNUAL REPORT 2021

BIOCHANGE
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IN A CHANGING WORLD

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Annual Report 2021

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BIOCHANGE
Center for Biodiversity Dynamics in a Changing World
Annual Report 2021

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Aarhus University

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FRONT-PAGE
Reserva Ecológica Costanera Sur, a protected natural area within Buenos Aires, Argentina. The subtropical vegetation is a mix of native and alien species (such as the Eurasian yellow flag, *Iris pseudacorus*), constituting a clear example of a novel ecosystem, i.e., an ecosystem with composition or functioning without historical precedent. Photo: Jens-Christian Svenning, BIOCHANGE.

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NOTE FROM THE EDITOR
Our annual reports usually cover one year of research from August to July the following year. Due to the corona situation in 2020 and 2021, which restricted many of the research activities of BIOCHANGE, we did not publish a report in 2021 covering 2020/2021. Therefore, the current report covers the full calendar year of 2021 and the last half of 2020 i.e., August 2020 – December 2021. Future reports will cover only one calendar year.

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WORDS FROM **THE DIRECTOR**

Dear readers,
It is my pleasure to present the fourth annual report from BIOCHANGE – Center for Biodiversity Dynamics in a Changing World. The basis for starting the BIOCHANGE center in 2017 was a VILLUM Investigator grant of nearly 40 million DKK (~5.4 million EUR) awarded to me by VILLUM FONDEN for 2017-2023. My ambition with the VILLUM Investigator project is to improve our understanding of the complex biodiversity dynamics under human-driven global change and their consequences for people and society, and to develop novel solutions to promote a biodiverse, liveable future to the benefit of humans and all our co-beings on this planet.

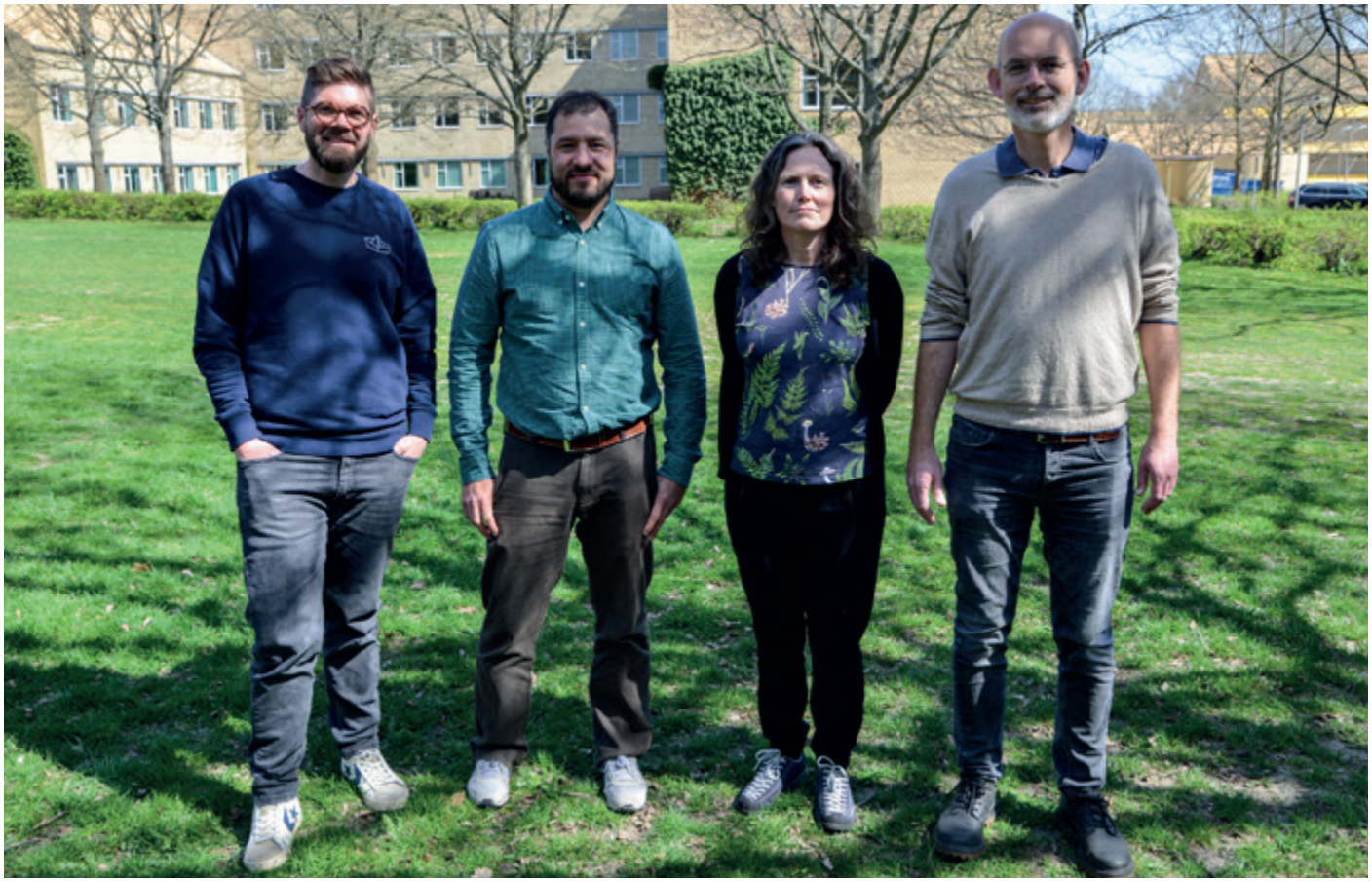
To maximize progress in this crucial research area, I decided to build a research center around it, joining forces with a select team of innovative colleagues sharing this ambition and providing complementary expertise. The core group members of the BIOCHANGE center are Professor Felix Riede (archaeologist with expertise on human-environment relations and quantitative approaches; recipient of an ERC Consolidator Grant, 2019-); Professor Signe Normand (ecologist with expertise on vegetation dynamics under climate change and new technologies for ecological field-based research; director for the Novo Nordisk Foundation Center for Sustainable Landscapes under Global Change [SustainScapes], 2021-); and tenure-track Assistant Professor Alejandro Ordonez Gloria (ecologist with expertise in ecological Big Data and ecology-climatology integration), all at Aarhus University. All bring their own projects and funding to the center, which in essence, is a committed research collaborative. Since BIOCHANGE was initiated, we have also included three early-career team leaders: Tenure-track Assistant Professors Robert Buitenwerf (ecologist with specialty in remote sensing and savanna/rangeland ecology) and Elizabeth Le Roux (ecologist with expertise on megafauna effects on soils and vegetation), both initially funded by my VILLUM Investigator grant; and Associate Professor Trine Kellberg Nielsen (archaeologist, with expertise on Neanderthals and their ecology). The central idea in forming a center is that scientific progress is best achieved in a cooperative, interdisciplinary research environment of critical mass and with a strong focus on joint development of ideas and expertise sharing.

We have organized the research in BIOCHANGE around four themes:
[1] Fundamental Biodiversity Dynamics,
[2] Global Challenges,
[3] Ecoinformatics and New Technologies,
[4] Interdisciplinary Innovation.

Notably, we work towards breakthroughs in:
(i) our understanding and predictive capacity of the complex Anthropocene ecological dynamics that will determine future levels of biodiversity and ecosystem functioning, including the many crucial services to society, in a world with a large, rapidly growing human population and massive climate change,
(ii) our ability to exploit the rapidly rising possibilities in the growing richness and quality of relevant Big Data, notably from remote sensing, for studying, monitoring, and handling these dynamics, and
(iii) the ways nature and society interact, notably in terms of our capacity to develop land-use strategies and design landscape development to promote biodiversity in the face of the human-driven pressures and to maximize associated co-benefits (ecosystem services) in relation to climate change adaptation, climate change mitigation, and human well-being.

On the following pages, we present the organization and activities of BIOCHANGE, covering both the basis for the center and updates on important outcomes of our efforts from August 2020 to December 2021. I hope you will enjoy reading about it. While you will have to read on to get the full picture, I want to highlight that in 2021, Signe Normand received the prestigious Elite Research (EliteForsk) Prize from the Danish Ministry for Higher Education and Science and obtained a 60 milllion DKK grant from to Novo Nordisk Foundation to establish the SustainScapes Center (with Svenning and Ordonez among the co-applicants), Felix Riede was promoted to full professor, Elizabeth Le Roux became BIOCHANGE's second appointed tenure-track assistant professor (in Megafauna Ecology and Restoration), and I was honored to receive the Villum Kann Rasmussen Annual Award in Science and Technology - the largest individual Danish research award from VILLUM FONDEN. Moreover, the center has had many successful activities including an active outreach program, the initiation of our BIOCHANGE seminar series, the continuation of the TerraNova project, an EU Marie Skłodowska-Curie Innovative Training Network aiming to promote sustainable, biodiverse landscape development in Europe (with AU as a member), as well as many important publications across BIOCHANGE's four research themes (in Nature, Science, PNAS, Science Advances and top journals within its fields).

Jens-Christian Svenning,
Professor VILLUM Investigator and Director for BIOCHANGE – Center for Biodiversity Dynamics in a Changing World



BIOCHANGE core group. From left: Professor Felix Riede, Assistant Professor Alejandro Ordonez Gloria, Professor Signe Normand, and Professor Jens-Christian Svenning, Aarhus University campus, 2022. Photo: Dennis Pedersen, BIOCHANGE.

BIOCHANGE early-career team leaders: From left: Assistant Professor Robert Buitenwerf, Associate Professor Trine Kellberg Nielsen, and Assistant Professor Elizabeth Le Roux, Kalø Vig, 2022. Photo: Dennis Pedersen, BIOCHANGE.

BIOCHANGE RESEARCH
THEMES AND OBJECTIVES

BIODIVERSITY is what makes Earth habitable, and a wonderful place to live. Critically, however, it is eroding and facing strong future risks from the large, growing human population, intensifying human activities, and massive climate change. To safeguard and restore biodiversity, we need to improve our understanding and predictive capacity of the complex human-driven biodiversity dynamics and their consequences for people and society, and to develop novel solutions to promote a biodiverse future.

BIOCHANGE will address this crucial challenge via four linked research themes:

THEME 1

FUNDAMENTAL BIODIVERSITY DYNAMICS

The key goal of this theme is to deepen our understanding of the likely biodiversity dynamics and ecological functioning that are likely to characterize future ecosystems, with focus on three phenomena, namely: (1) Transient biodiversity dynamics, as ongoing and future global change is likely to further increase ecological disequilibria. (2) Assembly and functioning of novel ecosystems, as such ecosystems without historical precedent are likely to become widespread due to globalization's transport of organisms around the world and due to the rise of anthropogenic novel environmental conditions. One crucial unresolved question that we will address concerns the biodiversity capacity of such ecosystems. (3) Megafauna ecosystem ecology, as there is a strong need to understand how the large animals affect the rest of biodiversity, ecosystem structure and even the whole biosphere, both from a fundamental perspective and because the planet is now experiencing both strong losses of large animals in much of the world (defaunation), but also comebacks via re-expansions and introductions elsewhere

THEME 2

GLOBAL CHALLENGES

Humanity is facing massive global challenges, as highlighted in the global sustainable development goals (SDGs). One of the most challenging is the looming, increasing risk of strong future climate change. We see this as one of the biggest future ecological risks, and while subject to much work and discussion, we think the scope is constantly underestimated. At the same time, our ability to forecast the consequences for biodiversity and ecosystems remains limited. Linking to theme [1] Fundamental Biodiversity Dynamics, we aim to: (1) Strengthen our predictive capacity by developing forecasting models that robustly capture the likely widespread disequilibrial transient dynamics and assembly of novel ecosystems and are able to predict the impacts on ecosystem functioning and services, as well as (2) develop methods for society to optimize its responses to these dynamics.

BIOCHANGE OBJECTIVES

- BIOCHANGE strives to produce excellent top-level science
- BIOCHANGE aims to make a real-world impact on the biodiversity crisis
- BIOCHANGE aims to be a platform for excellent research training

THEME 3

ECOINFORMATICS & NEW TECHNOLOGIES

We see the informatics revolution and the linked rapid development in sensor technologies as a key opportunity for achieving the urgently needed progress on how to tackle the massive and building pressure on the biosphere that we all depend on, as well as to address core unanswered questions in ecological science. Our research has two key foci: (1) Development of new and stronger ecoinformatics capabilities, to be able to realize the potential in the increasingly massive amounts of relevant data. There will be strong synergy with theme [2] Global Challenges in developing forecast models, so that they are computationally efficient and can run on the massive high-resolution spatiotemporal data sets needed for maximum relevancy for landscape planning. (2) Exploiting the rising potential for extremely high-resolution analyses and modelling of dynamics in biodiversity, ecosystems and their services using novel sources of remote sensing.

THEME 4

INTERDISCIPLINARY INNOVATION

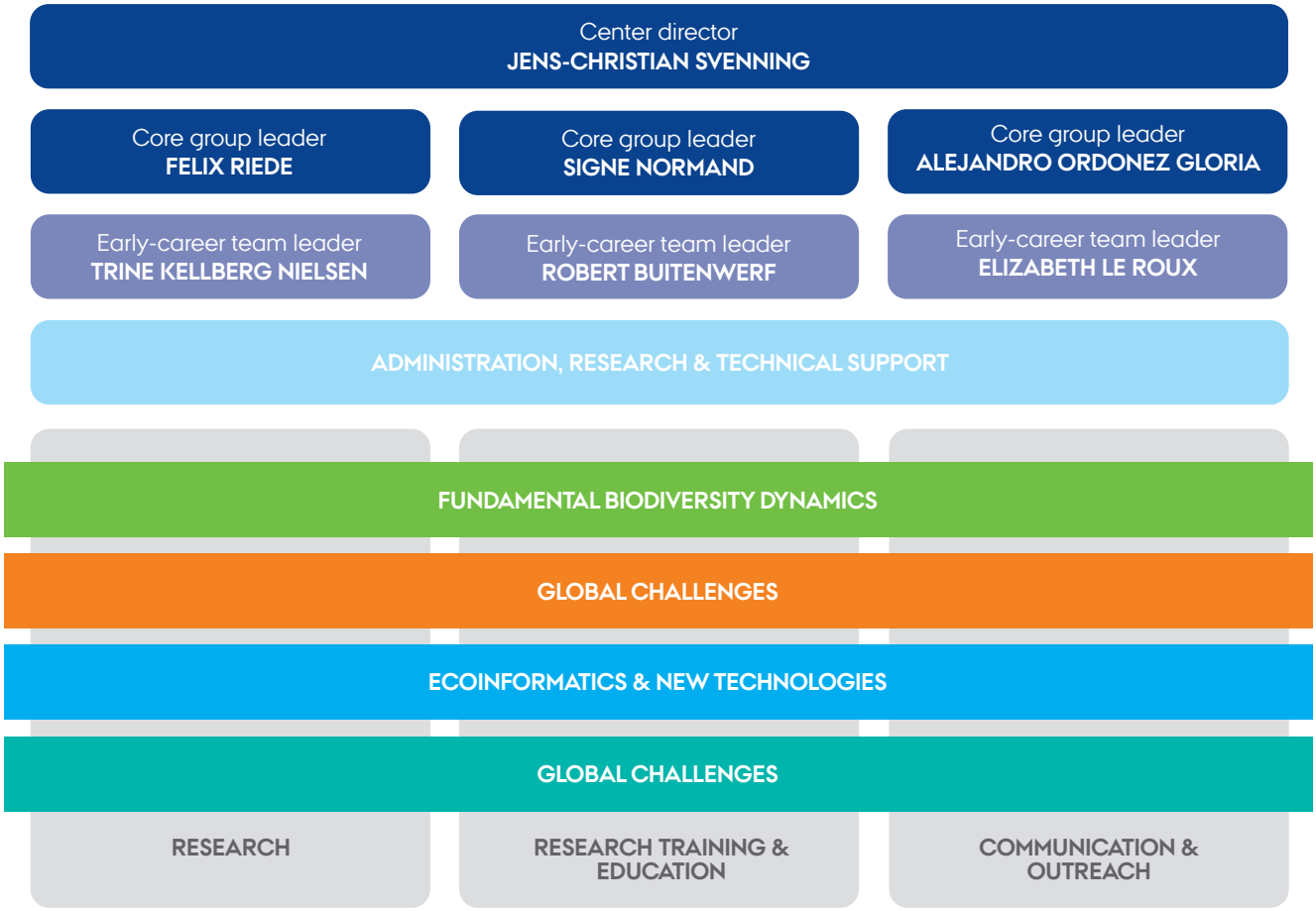
Our research has focus on big, complex issues, integrating topics such as global change, ecoinformatics, and human-environment relations. This entails a strong need for interdisciplinarity, and our goal with this theme is to explore the potential of novel cross-disciplinary development of perspectives and methods in gaining new ground on important and often complex issues related to biodiversity dynamics in this fast-changing world. We will keep a strategically open agenda to keep exploring novel interdisciplinary possibilities, as we see this as essential for coming up with truly new ideas, new methods, and perspectives needed for breakthroughs on established questions. However, focus areas are: (1) Enhance the collaboration with computer science to unfold the potential for Big Data studies on biodiversity and the global challenges. (2) Increase our understanding of human dependence on nature via application and integration of theory from a broad range fields, informatics, and remote sensing to study impacts of environment and biodiversity on societal development and human well-being. (3) Develop interdisciplinary research on landscape planning to safeguard biodiversity, ecosystem services and human well-being in an Anthropocene world with strong human population growth, strong urbanization, and looming massive climate change. This will involve linking fields such as ecology, archaeology, anthropology, environmental history, landscape architecture, and medicine, often using spatial Big Data modelling with remote sensing data in a key role.

ORGANIZATION AND STAFF

ORGANIZATION AND STAFF

BIOCHANGE members anno 2022 at Aarhus University campus. Photo: Dennis Pedersen, BIOCHANGE.

ORGANIZATIONAL DIAGRAM



BIOCHANGE is headed by Professor **Jens-Christian Svenning** and includes three additional senior core members from Aarhus University:
Professor **Felix Riede**,
Professor **Signe Normand**,
Tenure-track Assistant Professor **Alejandro Ordonez Gloria**.

In addition, from 2021 we have included three early-career team leaders in BIOCHANGE:
Tenure-track Assistant Professors **Robert Buitenwerf** and **Elizabeth Le Roux** and Associate Professor **Trine Kellberg Nielsen.**

The center is supported by a group of administrative, research and technical support staff members. BIOCHANGE is organized around three main functions, namely Research, Research Training and Education, and Communication and Outreach. All activities of the functions in BIOCHANGE are centered on four main research themes coordinated by the senior scientists of the Center:

[1] Fundamental Biodiversity Dynamics,
[2] Global Challenges,
[3] Ecoinformatics & New Technologies,
[4] Interdisciplinary Innovation

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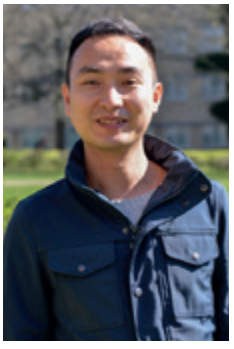

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3 Arctic Research Centre – Department of Biology
4 SustainScapes – Department of Biology
* New appointments since August 2020
** The organizational pages represent the current staff (June 2022)

In addition, the center included 23 Bachelor students and 33 Master students from August 2020 – December 2021 (further reading in section: Research Training and Education)

BIOCHANGE ALUMNI

POSTDOCS

Christopher Edward Gordon, Research Fellow,
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Jakob Johann Assmann, Postdoc,
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Wenyong Guo, Young Professor
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BIOCHANGE visitors 2020-2021

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Swedish University of Agricultural Sciences, Sweden

Bent Johann Rech, Erasmus intern,
Leuphana Univesität Lüneburg, Gernamy
(Long-term visitor at BIOCHANGE)

Celina Aznarez, PhD Student,
Basque Center for Climate Change (BC3) and ICTA- University of Barcelona, Spain
(Long-term visitor at BIOCHANGE)

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Esraa Ammar, PhD Student,
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Haibao Ren, Associate Professor,
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Jeppe Aagaard Kristensen, Postdoc,
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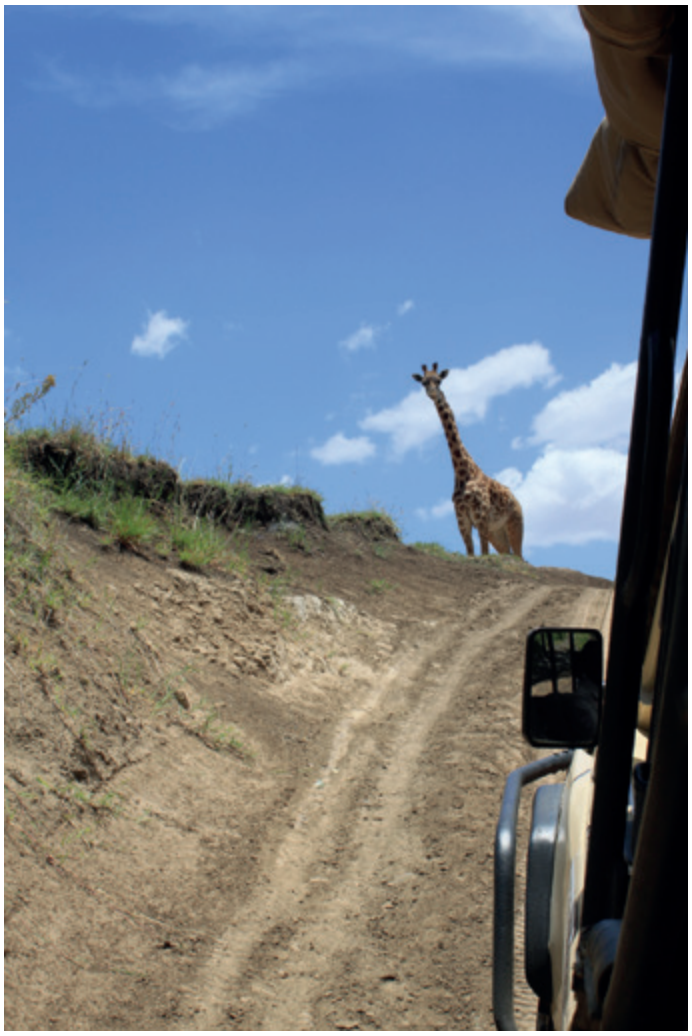
Wenting Wang, Associate Professor,
Northwest Minzu University, China
(Long-term visitor at BIOCHANGE)

Xue Yin, Guest Researcher,
School of Life Sciences, Sun Yat-sen University, China
(Long-term visitor at BIOCHANGE)



Giraffe in the Maasai Mara, Kenya.
Photo: Anne Blach Overgaard, BIOCHANGE.

PORTRAITS OF CORE GROUP LEADERS AND EARLY-CAREER TEAM LEADERS

JENS-CHRISTIAN SVENNING

WHO ARE YOU?

My name is Jens-Christian Svenning. I am a broadly based ecologist with a strong interest in biodiversity, global change biology, human-nature interrelations, ecological restoration, and sustainable development. My overall aim is to improve the scientific basis for planetary stewardship to ensure Earth's rich biodiversity in a human-dominated era. My work has led to many major recognitions, notably the Villum Kann Rasmussen Annual Award in Science and Technology in 2021, a VILLUM Investigator grant in 2017, Queen Margrethe II's Science Award in 2016, a Carlsberg Foundation Semper Ardens grant in 2016, the Ministry for Higher Education and Science's Eliteforsk award in 2014, a Consolidator-phase European Research Council (ERC) Starting Grant in 2013, and identification as a Clarivate Highly Cited Researcher in 2018-2021.

POSITION AND BACKGROUND

I am professor in geospatial ecology, VILLUM Investigator, and director for BIOCHANGE – Center for Biodiversity Dynamics in a Changing World at the Department of Biology, Aarhus University. I obtained my PhD in 1999 in tropical plant community ecology, based on work on palms in the Amazonian lowlands and Andes Mountains of Ecuador.

MAIN RESEARCH AREAS

I have developed a research agenda on biodiversity dynamics in a changing world focused on four linked themes:

[1] Fundamental Biodiversity Dynamics,
[2] Global Challenges,
[3] Ecoinformatics and New Technologies, and
[4] Interdisciplinary Innovation,
i.e., the themes I have chosen as the focal themes for BIOCHANGE.

MAIN RESEARCH FOCI

My current research concentrates on developing the four research themes in BIOCHANGE. More specifically, I have key focus on:

(1) Fundamental biodiversity dynamics on a human-dominated planet, with special attention to transient biodiversity dynamics in response to strong, fast climate change and other human-induced changes, food-web down- and upgrading linked to the strong human impacts on megafauna via over-hunting and persecution and, conversely, via restoration and conservation actions, and novel ecosystems (i.e., human-caused self-sustaining ecosystems with species assemblages and/or environmental conditions without historical precedent), notably as driven by the globalization-fostered spread of non-native species.

(2) Next-generation predictive models in relation to current and future climate change.

(3) The rapidly rising potential in "Big Data" for fundamental and applied biodiversity and ecosystem studies and in space-based and other remote sensing technologies for extremely high-resolution spatiotemporal monitoring and analyses of ecological dynamics and for environmental management under global change.

(4) Human-nature inter-relations, notably the role of socio-ecological perspectives in understanding current biodiversity dynamics and in the design and outcomes of conservation and restoration initiatives, and the macroecology of the human species.

(5) Ecosystem and landscape management to safeguard biodiversity and maximize co-benefits for society (nature-based solutions, e.g., climate change mitigation and adaptation), with emphasis on rewilding as a key approach to ecosystem restoration and its potential to promote long-term biodiversity maintenance under human-driven global change.

FUTURE PLANS

As I see it, the four research themes of BIOCHANGE and the five associated specific foci outlined above are among the most exciting and important research areas with many open questions and multifaceted research opportunities. Broadly speaking, this is where I plan to have my focus in the coming time. In fact, I see these research areas as absolutely necessary to overcome the biodiversity crisis (including avoiding massive biodiversity loss from human-induced climate change) and foster sustainable planetary stewardship that not only safeguards Earth's biodiversity but also facilitates a functional biosphere, stable climate, and decent, fair living conditions for the billions of people on our planet.

Photo: VILLUM FONDEN/photographer Christian Alsing.

KEY PAPERS (last two years)

Fricke, E.C., Ordonez, A., Rogers, H.S., & **Svenning, J.-C**. 2022. The effects of defaunation on plants' capacity to track climate change. *Science* 375:210-214.

Gatti, C., et al., **Svenning, J.-C**., et al. 2022. The number of tree species on Earth. *Proceedings of the National Academy of Science USA* 119:e2115329119.

Van Meerbeek, K., Jucker, T., & **Svenning, J.-C**. 2021. Unifying the concepts of stability and resilience in ecology. *Journal of Ecology* 109:3114-3132.

Ellis, E.C., et al., **Svenning, J.-C.** & Watson, E.M. 2021. People have shaped most of terrestrial nature for at least 12,000 years. *Proceedings of the National Academy of Science USA* 118:e2023483118.

Carver, S., et al., **Svenning, J.-C**., et al. 2021. Guiding principles for rewilding. *Conservation Biology* 35:1882-1893.

Schowanek, S.D., Davis, M., Lundgren, E.J., Middleton, O., Rowan, J., Pedersen, R.Ø., Ramp, D., Sandom, C.J. & **Svenning, J-C**. 2021. Reintroducing extirpated herbivores could partially reverse the late Quaternary decline of large and grazing species. *Global Ecology and Biogeography* 30:896-908.

Williams, J.W., Ordonez, A.O. & **Svenning, J.-C.** 2021. A unifying framework for studying and managing climate-driven rates of ecological change. *Nature Ecology & Evolution* 5:17–26.

Fricke, E.C. & **Svenning, J.-C.** 2020. Accelerating homogenization of the global plant–frugivore meta-network. *Nature* 585:74–78.

Svenning, J.-C. 2020. Rewilding should be central to global restoration efforts. *One Earth* 3:657-660.

FELIX RIEDE

Photo: Søren Kjeldgaard.

WHO ARE YOU?
My name is Felix Riede; I was born and raised in Germany but have lived in Denmark since 2009 with my Danish-American wife and our two boys, Alexander (10) and Oskar (6).

POSITION AND BACKGROUND
I received my entire university education in the UK with a BA from Durham, then a MPhil and PhD from Cambridge, albeit with a period as visiting scholar at KU. Throughout my studies and career, I have been straddling the interface between the human, biological, and environmental sciences. After a stint as Junior Research Fellow at Wolfson College and the Leverhulme Centre for Human Evolutionary Studies (Cambridge), I went to the Centre for the Evolution of Cultural Diversity at UCL with a British Academy Postdoctoral Fellowship. In 2009, I joined Aarhus University, initially as Assistant Professor, then Associate Professor, with intermittent visiting appointments at Harvard (Anthropology) and Cambridge (Geography). After being Head of Department for a few years, I became Professor MSO in Environmental Humanities and Climate Change Archaeology. As of Sept 1, 2021, I am Full Professor of Prehistoric Archaeology. I am currently affiliated with the Aarhus Institute of Advanced Studies as a so-called Associate Fellow - and in February 2022, I was awarded one of the prestigious EliteForsk prizes by the Ministry of Higher Education and Research. In addition to my position at AU, I am also Visiting Professor II (since late 2019) at the Oslo School of Environmental Humanities.

MAIN RESEARCH AREAS
At Campus Moesgård, I lead the ERC Consolidator Grant project CLIOARCH, which in turn continues the work we did in the so-called Laboratory for Past Disaster Science. Those initial efforts were funded by two successive Sapere Aude grants from the Independent Research Council Denmark. In my group, we investigate how past climate change and extreme environmental events – especially volcanic eruptions but also earthquakes, storms, and rapid climate change – have impacted human communities in Europe and elsewhere. Furthermore, we explore how

KEY PAPERS

Riede, F. 2022. Deep history curricula under the mandate of the Anthropocene. Insights from interdisciplinary shadow places. *FECUN* 1:172–185.

Abbott, P.M., Niemeier, U., Timmreck, C., & **Riede, F.**, et al. 2021. Volcanic climate forcing preceding the inception of the Younger Dryas: Implications for tracing the Laacher See eruption. *Quaternary Science Reviews* 274:107260.

Lundström, V., Peters, R., & **Riede, F.** 2021. Demographic estimates from the Palaeolithic–Mesolithic boundary in Scandinavia: comparative benchmarks and novel insights. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376:20200037.

Niemeier, U., **Riede, F.**, & Timmreck, C. 2021. Simulation of ash clouds after a Laacher See-type eruption. *Climate of the Past* 17:633–652.

Reichstein, M., **Riede, F.**, & Frank, D. 2021. More floods, fires and cyclones — plan for domino effects on sustainability goals. *Nature* 592:347–349.

Riede, F., Barnes, G.L., Elson, M.D., Oetelaar, G.A., Holmberg, K.G., & Sheets, P. 2020. Prospects and pitfalls in integrating volcanology and archaeology: A review. *Journal of Volcanology and Geothermal Research* 401:106977.

Riede, F. & Kierdorf, U. 2020. The eruption of the Laacher See volcano (~13,000 years BP) and possible fluoride poisoning amongst contemporaneous wildlife and human foragers – Outline of a hypothesis and the way to test it. *International Journal of Osteoarchaeology* 30:855–871.

Riede, F. & Sheets, P. (Eds.). 2020. Going Forward by Looking Back: Archaeological Perspectives on Socio-Ecological Crisis, Response, and Collapse, Catastrophes in Context. *Berghahn Books*, New York, NY.

this research can be brought forward into current debates about climate change, resilience, and vulnerability. I am also interested in how learning and knowing about the past and present environment makes us better at handling rapid climate change.

MAIN RESEARCH QUESTIONS

My work focuses on human-environment relations, biocultural adaptations, and on how to study them in human societies - especially those of the past. I am a dedicated interdisciplinarian, and I work as much with Neanderthals as with the early human forager groups in northern Europe after the end of the last ice age. I am also interested in the Anthropocene and how we can approach this controversial epoch archaeologically. I am keen on bringing sophisticated quantitative and natural science methods to the humanities in general and to archaeology in particular. In addition, I am keen on bringing our research out into the world.

FUTURE PLANS

My ERC Consolidator Grant project CLIOARCH is reaching its mid-point. The group is still growing, and loads of exciting work is going on. I was just recently awarded two million kroner from Aarhus University Research Foundation for a project that will investigate the changing ways of how play and learning enabled or hampered past societies in adapting to climate change - so expect more on this front! In BIOCHANGE, I am involved in a variety of projects that are looking at past human-environment relations and the limits of growth for past human societies. These projects will be high on my agenda in the coming time.

SIGNE NORMAND

WHO ARE YOU?

My name is Signe Normand. I was born in Aarhus and lived the first six years of my life next to the botanical garden and greenhouses in the city. Later, I lived in other parts of Denmark (Grenaa & Ribe), Norway, the US, and Switzerland. I returned to Denmark 8 years ago, and now live downtown Aarhus with my Swiss husband and our three children: Liv (13), Sia (11), and Noe (6).

POSITION AND BACKGROUND

I am professor in botanical macroecology and Center director of Center for Sustainable Landscapes under Global Change (SustainScapes). My fascination for living organisms, especially plants, started in my early childhood when my grandfather introduced me to the wonders of nature. Later, I went to boarding school focused on biology. After high school, I moved to Norway for one year, where I attended a Folk High School specializing in outdoor life and sustainable use of nature. I studied Biology at Aarhus University, earning a bachelor's degree by studying palms in the Amazon, and afterward a master's and PhD degree by studying the distribution and diversity patterns of the European flora. After receiving my PhD degree, I went to a postdoc position at the Swiss Federal Research Institute for Forest, Snow and Landscape. Since 2014, I have been working at the Section for Ecoinformatics and Biodiversity, Department of Biology, Aarhus University. Here, I have established a research group focused on vegetation dynamics and the UAS4Ecology Lab, which is a research facility using the emerging Unmanned Aerial System (UAS) technology to answer questions in ecology. In 2021, I established Center for Sustainable Landscapes under Global Change (SustainScapes) based on a 60 million DKK "Novo Nordisk Foundation Challenge Programme" grant. In addition, I am the daily leader of the application initiative in the Danish Drone Infrastructure, associated with Arctic Research Center and iClimate (Aarhus interdisciplinary Centre for Climate Change), Aarhus University. I am also strongly involved in the establishment of a center focused on utilizing the potential of space science and Earth observations across Aarhus University. My work has led to a number of recognitions notably the prestigious Elite Research (EliteForsk) Prize from the Danish Ministry for Higher Education and Science in 2021, and the Victor Albeck Award at Aarhus University in 2022. In 2021, I was appointed chair of the first Danish Biodiversity Council – an independent and scientific expert panel in nature and biodiversity and became member of the board of the Climate Forest Foundation in Denmark.

MAIN RESEARCH AREAS AND QUESTIONS

I am a macro- and vegetation ecologist dedicated to understanding patterns of species' occurrence and biodiversity and providing methodological progress to bring more realism to models and predictions of vegetation and biodiversity dynamics. I have studied these questions from the tropics to the Arctic, where most of my research efforts and fieldwork have been centered in recent years. I mainly utilize remote sensing, range dynamic models, and dendro- and trait-based ecology. The goal of my research is to find answers to fundamental questions in ecology and inform nature conservation about the impact of global change on biodiversity. My current research has three main components:

(i) Empirical studies to gain insight into the factors and processes determining ecological patterns across space and time, with a special focus on the role of non-equilibrium and transient dynamics as well as scale-dependencies.
(ii) Gaining insight on current and future range dynamics through models of species responses to climatic change.
(iii) Utilizing the newest sensors mounted on drones in combination with air- and satellite-borne remote sensing for monitoring, understanding, and predicting vegetation and biodiversity dynamics across space and time.

FUTURE PLANS

I will continue to gain an in-depth understanding of vegetation dynamics through cross-scale integration in temperate and arctic ecosystems. Several grants have enabled me to build up my independent research group and infrastructure: The VILLUM Young Investigator program, The Carlsberg Foundation Distinguished Associate Professor Fellowships, and Aarhus University Research Foundation Associate Professor Starting Grant. Until 2022, I am funded by a Sapere Aude grant from the Danish Council for Independent Research with a focus on climate change impacts on Arctic shrub dynamics. Until 2027, I am funded by the Novo Nordisk Challenge grant with a focus on rethinking landscapes to restore biodiversity in a world with increasing resource needs and a changing climate.

Photo: Dennis Pedersen, BIOCHANGE.

KEY PAPERS

Bjorkman, A.D., I.H. Myers-Smith, S.C. Elmendorf, **S. Normand**, N. Rüger, et al. 2018. Plant functional trait change across a warming tundra biome. *Nature* 562:57-62.

Madsen, B., U.A. Treier, A. Luciier, A. Zlinszky, & **S. Normand**. 2020. Detecting shrub encroachment in semi-natural grasslands using UAS LiDAR. *Ecology and Evolution* 10:4876-4902

Normand, S., U.A. Treier, C. Randin, P. Vittoz, A. Guisan, & J.-C. Svenning. 2009. Importance of abiotic stress as a range limit determinant for European plants: insights from species responses along climatic gradients. *Global Ecology and Biogeography* 18:437-449.

Normand, S., R.E. Ricklefs, F. Skov, O. Tackenberg, & J.-C. Svenning. 2011. Postglacial migration supplements climate in determining plant species ranges in Europe. *Proceedings of the Royal Society B: Biological Sciences* 278:3644-3653.

Normand, S., C. Randin, R. Ohlemuller, C. Bay, T.T. Høye, et al. 2013. A greener Greenland? Climatic potential and long-term constraints on future expansions of trees and shrubs. Philosophical Transactions of the Royal Society B, *Biological Sciences* 368:20120479.

Normand S., N.E. Zimmermann, F.M. Schurr, & H. Lischke. 2014. Demography as the basis for understanding and predicting range dynamics. *Ecography* 37:1149–1154.

Normand, S., T.T. Høye, B.C. Forbes, J.J. Bowden, A.L. Davies, et al. 2017. Legacies of historical human activities in Arctic woody plant dynamics. *Annual Review of Environment and Resources* 42:541-567.

Prendin, A.L., M. Carrer, M. Karami, J. Hollesen, N.B. Pedersen, M. Pividori, U.A. Treier, A. Westergaard-Nielsen, B. Elberling, & **S. Normand**. 2020. Immediate and carry-over effects of insect outbreaks on vegetation growth in West Greenland assessed from cells to satellite. *Journal of Biogeography* 47:87-100.

Prendin, A.L., **S. Normand**, M. Carrer, Pedersen, N.B., Matthiesen, H., Westergaard-Nielsen, B. Elberling, U.A. Treier & J. Hollesen. 2022. Influences of summer warming and nutrient availability on Salix glauca L. growth in Greenland along an ice to sea gradient. *Scientific Reports* 12:3077.

ALEJANDRO ORDONEZ GLORIA

WHO ARE YOU?
My name is Alejandro Ordonez Gloria, but most people call me Alejo. I was born and raised in Colombia, but over the last 14 years, I have been moving across multiple countries and continents (the USA, The Netherlands, Australia, and Northern Ireland). Today, my family and I call Aarhus home.

POSITION AND BACKGROUND
I am a tenure-track Assistant Professor at the Department of Biology at Aarhus University (AU). I am a biologist by training and received a BSc from the Pontificia Universidad Javeriana (Colombia), and my MSc and PhD at the University of Groningen. In 2011, I became the Climate People and Environment Post-Doctoral researcher at the University of Wisconsin-Madison. This position was followed by a 4-year postdoc appointment (2013-2017) at AU as part of the ERC-funded HISTFUNC project led by Jens-Christian Svenning. In 2017, I became a lecturer in Global Change Biology at Queen's University Belfast. In 2018, I moved back to AU as Assistant Professor in Botanical Macroecology and became a core group member of BIOCHANGE. More recently, I became a Coordinating Lead Author of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) thematic assessment on invasive alien species.

MAIN RESEARCH AREAS
My research focuses on quantifying and explaining how environmental changes shape diversity patterns in space and time. In doing so, my work has evaluated how past, present, and future environmental changes can lead to the emergence of novel ecosystems, and the impact of this emergence on nature's contributions to people. My work has used a biogeographical and macroecological perspective to quantify and classify the implications of changes in the environment (natural and anthropogenic) for biodiversity and nature's contributions to people. The end goal of my research is to provide knowledge-based guidance on how to manage nature under Earth's changing ecological and climatic conditions. I further seek to define the best set of tools to facilitate the persistence and adaptation of biodiversity and ecosystems to a rapidly changing Earth.

MAIN RESEARCH QUESTIONS
The central theme of my most recent published work has been determining the influence of environmental changes (i.e., climate change and land degradation) on species distributions, community composition, as well as biodiversity patterns. For this, I have used a broad geographical and temporal perspective centered on extensive comparative studies. The second theme in my work has been the development of metrics useful to describe how current and future environmental changes will shape biodiversity, when and where novel ecosystems will emerge, evaluate the ecological implications of the impact of drivers of change (climatic change, land-degradation, and invasive species), and define policy-relevant recommendations to deal with these changes.

FUTURE PLANS
The central question gilding my upcoming work is: how should humanity respond to the challenges imposed by global drivers of change? For this, I will focus on quantifying the match between biodiversity and environmental rates of change and determine the marginal and compound gains to biodiversity. This will be achieved by addressing the three main drivers of ecological transformation: climate change, land degradation, and invasive species.

KEY PAPERS

Ordonez, A., Wright, I. J., & Olff, H. 2010. Functional differences between native and alien species: a global-scale comparison. *Functional Ecology* 24:1353-1361.

Ordonez, A., & Williams, J. W. 2013. Climatic and biotic velocities for woody taxa distributions over the last 16 000 years in eastern North America. *Ecology letters* 16:773-781.

Ordonez, A., & Olff, H. 2013. Do alien plant species profit more from high resource supply than natives? A trait-based analysis. *Global Ecology and Biogeography* 22:648-658.

Ordonez, A., Martinuzzi, S., Radeloff, V. C., & Williams, J. W. 2014. Combined speeds of climate and land-use change of the conterminous US until 2050. *Nature Climate Change* 4:811-816.

Ordonez, A., Williams, J. W., & Svenning, J. C. 2016. Mapping climatic mechanisms likely to favour the emergence of novel communities. *Nature Climate Change* 6:1104-1109.

Ordonez, A., & Svenning, J. C. 2017. Consistent role of Quaternary climate change in shaping current plant functional diversity patterns across European plant orders. *Scientific Reports* 7:1-11.

Ordonez, A., & Svenning, J. C. 2015. Geographic patterns in functional diversity deficits are linked to glacial-interglacial climate stability and accessibility. *Global Ecology and Biogeography* 24:826-837.

Photo: Dennis Pedersen, BIOCHANGE.

ELIZABETH LE ROUX

WHO ARE YOU?
I am Elizabeth le Roux, Liza for short. I am South African and started my life in Denmark in March 2021. I have briefly lived in Oxford, UK, and Umeå (Sweden). However, I have until recently been mostly a field-based ecologist in South Africa. That means that I not only worked, but also lived permanently in some of the most scenic and wild places remaining in South Africa. I would see elephants and antelopes from my bedroom window and considered monkeys playing on the roof my most frequent office disturbance.

POSITION AND BACKGROUND
I am a tenure-track Assistant Professor in megafauna ecology and restoration. My work generally falls into the categories of trophic ecology, zoogeochemistry, and community ecology. I completed my PhD in 2017, studying how predators may change herbivore population dynamics and their ability to shape vegetation structure and distribute nutrients. The work specifically focused on diverse herbivore communities comprising a mix of vulnerable prey species and species too large to be limited by predators. I received my PhD from Nelson Mandela University (NMU) in collaboration with the Swedish University of Agricultural Science. In the preceding years, I studied at the University of the Witwatersrand (MSc) and the University of Pretoria (BSc + BSc Honours) in South Africa. In addition, I held two postdoctoral appointments at NMU, one as a Claude Leon Postdoctoral Fellow. Following this, I was appointed as a Royal Society Newton International Fellow at the University of Oxford in the UK. I continue to collaborate with my former Universities, currently holding a Fellowship at the Mammal Research Institute at the University of Pretoria and an Honorary Research Associate position at the Environmental Change Institute at the University of Oxford. Since arriving in Aarhus, I have joined the Aarhus Institute of Advanced Studies (AIAS) as an Associate Fellow.

MAIN RESEARCH AREAS
My research predominantly focuses on how large animals change the structure, composition, and function of ecosystems through activities such as feeding, defecation, and damage. I am particularly interested in how the interactions between large animal species mediate these impacts. I want to understand which functions have been lost or altered in simplified communities (such as those without predators or those without the largest herbivores) and how to restore these functions.

MAIN RESEARCH QUESTIONS
Broadly speaking, my main questions are:

- How do animals shape the structure of grass layers and influence the abundance and distribution of trees? If so, what are the likely consequences to fire dynamics and plant species diversity?
- How do large mammals transport nutrients and minerals and shape the elemental availability in the environment?
- In which ways would animal impact on vegetation structure and nutrient availabilities influence climate mitigation and adaptation potential?
- How are the above-mentioned functions altered by aspects such as mammal species diversity, community composition, functional traits (e.g., animal body size), and trophic interaction (e.g., predator-prey relationships)?

I hope my research will illustrate how crucial the connection is between animal impact and well-functioning ecosystems and thereby to contribute the information needed to incentivize and guide restoration efforts.

FUTURE PLANS
I want to address more specifically the role of animals in creating an elemental environment for smaller species and species lower in the food chain than themselves. I aim to do this through a combination of modeling and field-based studies. First, I plan to look at intact systems where large animals have been playing a long-term structuring role. Second, I plan to study newly restored/rewilded systems to see if the reintroduction of this animal impact recreates similar patterns to those we see in intact systems.

Photo: Robert Buitenwerf, BIOCHANGE.

KEY PAPERS

Malhi, Y., Lander, T., **le Roux, E.**, Stevens, N., Macias-Fauria, M., Wedding, L., Girardin, C., Kristensen, J.Å., Sandom, C.J., Evans, T.D., & Svenning, J.C. 2022. The role of large wild animals in climate change mitigation and adaptation. *Current Biology* 32:R181-R196.

Hyvarinen, O., Te Beest, M., **le Roux, E.**, Kerley, G., de Groot, E., Vinita, R., & Cromsigt, J.P. 2021. Megaherbivore impacts on ecosystem and Earth system functioning: the current state of the science. *Ecography* 44:1579-1594.

Abraham, A. J., Webster, A. B., Prys-Jones, T. O., **le Roux, E.**, Smith, D., MacFadyen, D., de Jager, P. C. Clauss, M., & Doughty, C.E. 2021. Large predators can mitigate nutrient losses associated with off-site removal of animals from a wildlife reserve. *Journal of Applied Ecology* 58:1360-369.

le Roux, E., Van Veenhuisen, L., Kerley, G.I.H., & Cromsigt, J.P.G.M. 2020. Animal body size distribution influences the ratios of nutrients supplied to plants. *Proceedings of the National Academy of Sciences USA*. 117:22256-22263.

Flezar, U. **le Roux, E.,** Kerley, G.I.H., Kuijper, D.P.J., te Beest, M., Druce, D.J., Prinsloo, D., & Cromsigt, J.P.G.M. 2019. Simulated elephant-induced habitat changes can create dynamic landscapes of fear. *Biological Conservation* 237:267-279.

le Roux, E., Marneweck, D.G. Clinning, G. Druce, D. J., Kerley, G.I.H., & Cromsigt, J.P.G.M. 2019 Top-down limits on prey populations may be more severe in larger prey species, despite having fewer predators. *Ecography* 42:1-9.

Cromsigt, J.P.G.M, te Beest, M., Kerley, G.I.H., Landman, M., **le Roux, E**., & Smith F.A. 2018. Trophic rewilding as a climate change mitigation strategy? *Philosophical Transactions of the Royal Society B: Biological Sciences* 373:20170440.

le Roux, E., Kerley, G.I.H., & Cromsigt, J.P.G.M. 2018. Mega-herbivores modify trophic cascades triggered by fear of predation in an African savanna ecosystem. *Current Biology* 28:1-7.

ROBERT BUITENWERF

WHO ARE YOU?
My name is Robert Buitenwerf – Rob to most since I left the Netherlands 17 years ago. Earlier in my career, I spent many hours collecting ecological field data in various parts of the world. Although I still do fieldwork, most days are tied to the desk, which I try to balance with some hands-on work like woodworking and growing, cooking, and eating food. However, my best distraction is spending time with my kids and wife.

POSITION AND BACKGROUND
I am an assistant professor in ecology at Aarhus University. After my MSc in Biology from the University of Groningen, the Netherlands, I lived in South Africa for several years, working for various research and conservation organizations. I was exposed to many new and fascinating ecosystems and research questions, which inspired me to pursue a PhD based at Goethe University, Frankfurt am Main, Germany. I worked at understanding vegetation phenology across scales, which drove me to span the range from leaf-level ecophysiology to global changes in vegetation dynamics and functioning. The fun of trying to understand and link local-scale mechanisms and emergent patterns at larger scales stuck with me. Before coming to Aarhus as a postdoc in 2016, I spent two years working at Landcare Research in weird and wonderful New Zealand. I currently lead a consortium of academic and business partners for a project funded by the European Space Agency on studying and monitoring African rangelands using Earth observation satellites.

MAIN RESEARCH AREAS
I am concerned about the impact of humans on other species and ecosystems. Therefore, my overarching research theme is to quantify, understand, and predict how human impacts like climate change, land-use change, and ecosystem restoration affect biodiversity and the capacity of ecosystems to maintain ecosystem functioning. At large scales, I quantify patterns and dynamics in vegetation composition and functioning, often using data from Earth observation satellites. At smaller scales, I use ground-based LiDAR, manipulative field experiments, and data on functional traits. My time in South Africa left me fascinated with African savannas, some of which have escaped the most destructive human impacts like the extinction of megafauna or conversion to cropland. These systems can therefore provide key insights into how natural processes, including disturbances from large herbivores and fire, structure ecosystem dynamics. This should help inform ecosystem restoration efforts elsewhere in the world.

MAIN RESEARCH QUESTIONS
- How do fire and herbivores interact to determine ecosystem state and dynamics?
- What is the contribution of non-forest ecosystems and the disturbance processes that maintain them to biodiversity, climate change mitigation, and human wellbeing? How can this knowledge be used to inform ecosystem restoration?
- How can data from Earth observation satellites be better harnessed to address ecological questions?

FUTURE PLANS
I plan to develop a diverse research group capable of fully integrating work and questions across spatial scales, where field-based observations and results inspire, validate, and nuance studies based on remote sensing data at larger scales and vice versa. The main aim is to understand and capture key predictors of biodiversity potential and climate feedback of ecosystems that can ultimately contribute toward more sustainable management and policy.

Photo: Anne Blach Overgaard, BIOCHANGE.

KEY PAPERS

Buitenwerf, R., Rose, L., & Higgins, S. I. 2015. Three decades of multi-dimensional change in global leaf phenology. *Nature Climate Change* 5:364-368.

Buitenwerf, R., Bond, W., Stevens, N., & Trollope, W. 2012. Increased tree densities in South African savannas: >50 years of data suggests CO2 as a driver. *Global Change Biology* 18:675–684.

Higgins, S. I., **Buitenwerf, R.**, & Moncrieff, G. R. 2016. Defining functional biomes and monitoring their change globally. *Global Change Biology* 22:3583–3593.

Li, W., **Buitenwerf, R.**, Munk, M., Bøcher, P. K. & Svenning, J.-C. 2020. Deep-learning based high-resolution mapping shows woody vegetation densification in greater Maasai Mara ecosystem. *Remote Sensing of Environment* 247:111953.

Li, W., *et al.*, **Buitenwerf, R**. 2020. Accelerating savanna degradation threatens the Maasai Mara socio-ecological system. *Global Environmental Change* 60:102030.

Buitenwerf, R., & Higgins, S. I. 2016. Convergence among global biogeographical realms in the physiological niche of evergreen and deciduous vegetation. *Global Ecology and Biogeography* 25:704–715.

TRINE KELLBERG NIELSEN

WHO ARE YOU?
My name is Trine Kellberg Nielsen. I was born in a small town south of Aarhus. My studies and early archaeological career have brought me to various countries, including longer stays in the Netherlands and Germany. Now, I have returned home – and I live in (another) small town south of Aarhus with my husband.

POSITION AND BACKGROUND
I am currently working as an associate professor and PI in my DFF-funded Sapere Aude project, NeanderEDGE, based at the Department of Archaeology and Heritage Studies at Aarhus University.

I earned my bachelor's degree in anthropology from Aarhus University in 2008, followed by a research master's degree in Human Origins at Leiden University, the Netherlands. Ultimately, I earned my PhD degree in 2016 from Aarhus University. After my PhD, I did a postdoc at the Centre for Biocultural History at Aarhus University, followed by a shared postdoc at the University of Cologne and Neanderthal Museum in Mettmann, Germany. I then returned to Denmark to curate a Neanderthal special exhibition at the Moesgaard Museum in Aarhus, after which I started my current position at Aarhus University.

MAIN RESEARCH AREAS
As a palaeolithic archaeologist, I am interested in understanding the lives of our extinct human relatives, particularly Neanderthals (*Homo neanderthalensis).* The Pleistocene archaeological record is full of biases and hiatuses, and I am motivated to fill some of these knowledge gaps regarding northern Neanderthal dispersal, mobility, ecology, and adaptation. My research operates at various temporal and spatial scales, looking at both site-specific Neanderthal behavior, regional patterns, and continental range dynamics. Temporarily, I focus mainly on the last interglacial-glacial cycle (130.000-40.000 BP), as this is a period of Neanderthal range expansion and contraction as a response to both climatic and cultural dynamics.

Although the Neanderthal record is abundant compared to earlier extinct hominins, we still know very little about the northern and eastern boundaries of their range. Understanding the drivers and constraints of Neanderthal dispersal is a crucial first step towards a better understanding of their adaptive and behavioral range. However, multiple glacial advances during glacial periods pose an archaeological problem as this negatively affects site preservation and integrity. It is, therefore, entirely possible that the present northern range boundary of Neanderthals between 50-55° northern latitude is a result of preservation bias and re-depositional sediment history rather than a true artifact of past human dispersal. This is at the heart of our research in the NeanderEDGE project, where fieldwork and data-based approaches will help us understand these 'marginal' northern landscapes at the end of the Neanderthal world.

MAIN RESEARCH QUESTIONS
The main research questions I address in my research are; how far north did the Neanderthals disperse? What are the main drivers of Neanderthal range expansion and contraction? What are the adaptive responses and land-use strategies of northern Neanderthals compared to core southern populations, and do we see significant spatiotemporal variation?

FUTURE PLANS
My plan for the next years involves working in-depth with the above mentioned research questions within the frame of the NeanderEDGE project.

Photo: Lars Svankjær

KEY PAPERS

Hussain, S. T., Weiss, M., & **Nielsen, T.K.** 2022. Being-with other predators: Cultural negotiations of Neanderthal-carnivore relationships in Late Pleistocene Europe *Journal of Anthropological Archaeology* 66:101409.

Nielsen, T.K., Kristiansen, S.M., & Riede, R. 2019. Neanderthals at the frontier? Geological potential of southwestern South Scandinavia as archive of Pleistocene human occupation. *Quaternary Science Reviews* 221:105870.

Nielsen, T.K. & Riede, F. 2018. On research history and Neanderthal occupation at its northern margins *European Journal of Archaeology* 21:506–527.

Nielsen, T.K. 2017. Northern Neanderthals? A multi-perspective assessment of the potential of Pleistocene human occupation of southern Scandinavia. *Mitteilungen der Gesellschaft für Urgeschichte* 26:11-52.

Benito, B.M., Svenning, J.-C., **Nielsen, T.K.**, Riede, F., Gil-Romera, G., Mailund, T., Kjærgaard, P.C, Sandel, B. 2017. The ecological niche and distribution of Neanderthals during the Last Interglacial. *Journal of Biogeography* 44:51-61.

Nielsen, T.K., Benito, B.M., Svenning, J.-C., Sandel, B., McKerracher, L., Riede, F., Kjærgaard, P.C. 2017. Investigating Neanderthal dispersal above 55°N in Europe during the Last Interglacial Complex. *Quaternary International* 431:88-103.

Egeland, C.P, **Nielsen, T.K.**, Byø, M., Kjærgaard, P.C., Larsen, N.K., Riede, F. 2014. The taphonomy of fallow deer (Dama dama) skeletons from Denmark and its bearing on the pre-Weichselian occupation of northern Europe by humans. *Archaeological and Anthropological Sciences* 6:31-61.

RESEARCH HIGHLIGHTS

Full references for the publications mentioned in this chapter can be found under publications in section **Communication and Outreach**

The research highlights cover papers published between August 2020 to December 2021.

RESEARCH HIGHLIGHTS

THEME 1

Theme 1 focuses on fundamental biodiversity dynamics that are likely to characterize future ecosystems, including their capacity for biodiversity and their functioning. These include (i) transient dynamics driven by climate change and other anthropogenic global changes, (ii) assembly of novel ecosystems without historical precedent due to globalization and spread of anthropogenic environments, and (iii) strong changes to megafaunas through over-hunting and eradication in many areas, as well as increased protection and reintroductions in others. Since the last report, we have achieved important research progress in all three focal areas within theme 1. In the following, only a few out of many other insightful studies are highlighted.

One study, led by BIOCHANGE alumnus Koenraad van Meerbeek and involving Jens-Christian Svenning (JCS), synthesizes theoretical concepts related to ecosystem stability and resilience. These concepts are widely and increasingly used in ecology and beyond, reflecting their relevancy in the current situation of global change, but often with quite divergent meanings. In the new study, they provide a much-needed integrated framework and consistent terminology to help study ecosystem dynamics in a biosphere increasingly characterized by strong anthropogenic forcings (Van Meerbeek *et al.* 2021, *J. Ecol.*). Multiple studies involving BIOCHANGE researchers contribute to research showing how past climate change has caused long-lasting strong disequilibria in biodiversity and ecosystem patterns. A study, led by Xue Yin and involving JCS, analyzes species richness patterns in genera of vascular plants with disjunct distributions between environmentally similar regions of eastern Asia and eastern North America (Yin et al. 2021, *Glob. Ecol. Biogeogr.*). The study finds that these genera are more species-rich per 100 × 100 km grid cells in eastern Asia than in eastern North America, controlling for topography and climate. Hereby, the study showcases how large-scale diversity patterns are often in disequilibrium with the current climate and environment, commonly reflecting the influence of deep-time speciation, extinction, and migration patterns. Another study, led by US collaborators and involving JCS, further shows how current tree species in North America often fail to fill large parts of their climatically suitable range, a pattern that is especially strong for small-range species (Seliger *et al.* 2021, *J. Biogeogr.)*. These studies highlight that we must expect strong lags in biodiversity responses to future climate change, especially in terms of recolonizing or expansion into suitable climate space. In contrast, strong climate deterioration can remove extinction disequilibria, where populations have been persisting under

A key element in the global human-driven trophic downgrading is the widespread decimation of large herbivore faunas, Wild Przewalski horses – exterminated in the wild during the 20th century but reintroduced in multiple areas across the last decades – here in the Chornobyl nuclear disaster area in Ukraine. Photo: OrioleGin/Depositphotos.com.

suboptimal conditions, causing their further attrition or outright extirpation. A study led by María Á. Pérez-Navarro, coauthored by BIOCHANGE alumnus Pep Serra-Diaz and JCS, shows this for semi-arid shrubland in Spain, finding how an extreme drought increases community equilibrium with climate (Pérez-Navarro *et al.* 2021, *OIKOS*). This perspective is also supported by a study led by collaborators from the BIEN working group, to which JCS contributed, showing how evolutionary diversity of plants is particularly constrained by arid conditions, highlighting that future expansions of such conditions are likely to lead to strong diversity losses (Neves *et al.* 2021, *PNAS*).

We have also achieved important findings on novel ecosystems and the ecosystem effects of megafauna down- and upgrading. These include a study by Evan Fricke and JCS showing how introduced species fundamentally change the local and global network structure of frugivore-plant interactions and do so at an accelerating pace (Fricke & Svenning. 2020, *Nature*). Another BIOCHANGE-led study quantifies the global loss of large herbivores in the near past and the functional consequences as well as assesses the restoration potential (Schowanek *et al.* 2021, *Glob. Ecol. Biogeogr.*)

THEME 2

The alpine plant species *Aster alpinus* (Tatra Mountains, Poland) is associated to quite specific climate conditions. In theme 2, we aim to develop better predictions of how future climate change will impact biodiversity, e.g., with impacts on plant species distributions and diversity as a key focus. Photo Jens-Christian Svenning, BIOCHANGE.

The BIOCHANGE team and collaborators have contributed significant advances in our understanding of the effects on biodiversity of climate change, improving our ability to forecast these changes, and determining possible strategies to manage, mitigate or adapt to these changes. Hereunder only a select of the recent studies are highlighted.

A fundamental part of the work in theme 2 is to understand effects of climate change by mapping the risks it could impose on biodiversity. Alejandro Ordonez Gloria (AOG) and JCS contributed to a large multi-author work published in PNAS (Zohner *et al.* 2020, *PNAS*) mapping the changes in late-spring frost occurrences between 2015 and 2017. This work shows that over one-quarter of Europe's and Asia's forests are increasingly threatened by frost damage. Moreover, these increases do not match the phenological strategies that helped trees tolerate past frost frequencies.

Besides mapping the risk of climate change, work led by BIOCHANGE collaborators with contributions from AOG and JCS shows the implications of these changes on extinction risks. One of these studies was a cross-continental comparison of extinction drivers between eastern Asia and eastern North America (Song *et al.* 2021, *Glob. Change Biol.*). Here, they compare the range responses of species of genera shared between the two evaluated regions to determine if the same variables determine these responses. The results show that the main variables determining extinction risks differed between the two compared regions. Such findings show the context-specific nature of anthropogenic effects on biodiversity and the importance of making region-specific policies for conservation and restoration in response to the intensifying global changes.

The work of the BIOCHANGE team has also focused on showcasing the importance of critically assessing the benchmarks used to define restoration goals. On this front, BIOCHANGE work by Sophie Monsarrat and JCS shows that a focus on the recent past to define the purpose of megafauna restoration practices puts a higher burden for megafauna restoration on countries in the Global South (Monserrat & Svenning 2021, *Ecography*). This result is highly relevant in the context of equitability in addressing the challenges of climate change, as countries in this region have less capacity to support these restoration initiatives. This work also shows that when considering mid-Holocene and Pleistocene conditions to define restoration benchmarks, opportunities for restoration appear in the global north, where countries have the financial means to take on these challenges.

On the conceptual front, a study led by Jack Williams, AOG, and JCS (Williams *et al.* 2021, *Nat. Ecol. Evol.*) proposes a new way to think about ecological dynamics under climate change and how to manage them. The new framework presented propose a new way to study and manage climate-driven rates of ecological change. This new perspective focuses on placing environmental driven ecological changes in an abrupt-fast-slow continuum and addresses the ongoing calls for ecological management to focus on managing ecological rates of change instead of maintaining past states.

THEME 3

Examples of woody expansion of *Tarchonanthus camphoratus* near Aitong, Maasai Mara, Kenya, likely linked to overgrazing by livestock.
Photos: Jens-Christian Svenning, BIOCHANGE.

Big Data and machine-learning analyses of remote sensing data from satellites and drones are an integral part of many studies conducted within BIOCHANGE during the past year. The focus of theme 3 is to take advantage of informatics approaches and new technologies to gain deeper insights into current biodiversity and ecosystem dynamics and their drivers and consequences.

This emphasis on technology can be seen in BIOCHANGE's various studies making use of remote-based sensing data. For example, Wang Li (WL), BIOCHANGE alumnus Wenyong Guo, and JCS contributed to our understanding of forest dynamics by mapping the spatial heterogeneity of tree cover with 35-years' worth of global satellite imagery (Li *et al.* 2021, *Int. J. Appl. Earth Obs. Geoinf.*). This investigation captures forest degradation and recovery more fully by examining the relationships between heterogeneity, tree cover, climate, forest intactness and anthropogenic disturbances. Satellite imagery was also used to analyze highly complex interactions between greening, precipitation, climate change, and anthropogenic factors in Argentina. This study, from WL, Robert Buitenwerf (RB), Julia Mata (JM), and JCS, calls for careful consideration of greening trends over simplistic assumptions that greening always indicates ecosystem recovery; notably, 37% of the greening areas represented expansion of commercial tree plantations with strongly negative biodiversity effects (Li *et al.* 2020, *Geogr. Sustain.*). Further capitalization on satellite imagery took place in Kenya's Greater Maasai Mara Ecosystem (GMME) where WL, RB, Michael Munk, and JCS constructed a comprehensive vegetation map. Importantly, their deep-learning based mapping workflow provided evidence for widespread woody densification, of potential negative consequences for the region's socio-ecological system and which was linked to climate and local human influences (Li *et al.* 2020, *Remote Sens. Environ.*). These new insights highlight that factors challenging the maintenance of the GMME's rich megafauna and valuable local culture arise both within the system and through large-scale factors. In Argentina JM, RB, and JCS mobilized high-resolution satellite imagery, in combination with wildlife tracking, to implement a novel framework which measures the progress of rewilding efforts (Mata *et al.* 2020, *PLoS ONE*). This spatial analysis exemplifies how such integrated modelling of multiple data sources can be an important tool for

rewilding practitioners and policy-makers by measuring realized and potential areas occupied by reintroduced species. Marco Davoli, RB, Oskar Hansen, and JCS further contributed to this theme with the development of a computational model titled ENERSCAPE (led by BIOCHANGE alumnus Emilio Berti), which allows for the spatial mapping of the energetic costs of terrestrial animal movement considering factors such as elevation and body mass (Berti *et al.* 2021, *Methods in Ecol. Evol.*). ENERSCAPE acts as a tool for improving our understanding of where and why animals move throughout a landscape as well as for planning the spatial and functional design of conservation and rewilding areas.

BIOCHANGE has also supported and applied Big Data vital for climate analysis at a global scale. For example, JCS along with various other researchers across the globe contributed to sPlotOpen (Sabatini et al. 2020, Global Ecol. & Biogeogr.). This large open-access database provides data on all the vascular plant species present in 95,104 vegetation plots across the globe. Notably, sPlotOpen provides fine-grained data to monitor and study plant biodiversity at a macroecological level. JCS has also worked with a Big Data approach via his contribution to a global assessment on where land management can optimize biodiversity, carbon retention and water quality (Jung *et al.* 2021, *Nat. Ecol. Evol.*). The joint consideration of these three factors provides the spatial guidance on synergies required for large-scale international conservation goal setting and implementation.

THEME 4

The BIOCHANGE community continues its interdisciplinary journey and have made strong headway across a range of topics, resulting in a range of high-profile publications. One express goal of theme 4 is to enhance the collaboration with computer science in order to unfold the potential for Big Data studies on biodiversity and the global challenges. By integrating a wide range of data sets, JCS and collaborators have mapped global changes in land-use clearly demonstrating humans' extensive encroachment across ecosystems. Notably, as far back as 12,000 years ago nearly three quarters of Earth's land was inhabited and therefore shaped by human societies. The authors highlight that much of current loss of natural habitats does not reflect the loss of uninhabited wildlands, but destruction of biodiversity-rich ecosystems which have long sustained low levels of human use. Supporting the need to recognize indigenous people's contributions to nature conservation (Ellis *et al.* 2021, *PNAS*). Looking forward into the future a study with contribution from JCS, used deep historical data on human population densities to define suitability measures for human life on Earth, first under present conditions and then under future climate change. Worryingly, the results show that much of the planet risk of not being suitable for human habitation in the absence of climate action (Xu *et al*, *PNAS*).

Working within human health, a study led by Kristine Engemann (including JCS) shows how exposure to greenspace over folks' life-course can improve wellbeing and mental health (Engemann *et al.* 2021, *Health & Place*). This paper builds on and provides nuance to a line of research developed over multiple years with leading epidemiologists at Aarhus University. Another novel focus is soil macroecology. AOG and collaborators neatly demonstrate the necessity to

In theme 4, we focus on increasing our understanding about the human dependence on nature amongst other things. Here a local Maasai herding cattle among Plains Zebras, Blue Wildebeests, and Thomson's Gazelles in the Mara North Conservancy, Maasai Mara, Kenya, which is a mixed-use area of wildlife and human residency. Photo: Michael Munk, BIOCHANGE.

integrate soil-specific data, spatio-temporal biotic and abiotic considerations in all stages of research, from sampling design to statistical analyses. Such analyses are critical to ensure future soil health (White *et al.* 2020, *Global Ecol. Biogeogr.*). Similarly pushing research forward, a new study including JCS relating to rewilding – another one of BIOCHANGE's core interests – provides critical guidelines and consensus building for land management using rewilding principles (Carver *et al.* 2021, *Conserv. Biol.*). Other studies such as that by BIOCHANGE alumnus Simon Schowanek including Erick Lundgren, Rasmus Pedersen and JCS show the reintroduction of previously extirpated herbivores could at least partially reverse the late-Quaternary decline of large and grazing species, and thereby positively influence ecosystem functioning (Schovanek *et al.* 2021, *Global Ecol. Biogeogr.*). Likewise, Troiano *et al.* (including JCS) (2021, *Land*) promptly implement our best practice suggestions in the context of traditional free-ranging livestock farming as a management strategy for biological and cultural landscape diversity. Exemplifying the possibility of synergies between biological and cultural diversity. And apropos biological and cultural landscapes, the BIOCHANGE team has also lately pushed the conceptual envelope in terms of how to robustly integrate historical and archaeological thinking in research relating to biodiversity and the climate crisis. JCS has co-led a paper on why the combination of historical ecological and socio-cultural perspectives are not only valuable but essential in thinking about sustainable woodlands (Swanson *et al.* 2021, *One Earth*). Taking a similar argument deeper into time, Shumon Hussain and Felix Riede (Hussain and Riede 2020, *WIREs Clim. Change*) show how the perspectives of the so-called environmental humanities can be given a palaeo-twist - how thinking and writing about human evolution, climate and the environment together can contribute to a more balanced and productive appreciation of our current biodiversity and climate crisis.

RESEARCH

VILLUM INVESTIGATOR PROJECT:
BIODIVERSITY DYNAMICS IN A CHANGING WORLD

1 2 3 4

Principal investigator: Jens-Christian Svenning

Earth is a living planet and the thing that makes it not just a livable but a wonderful place to live is its rich biodiversity. This natural and biocultural heritage is now under massive pressure from human resource use and associated anthropogenic pressures, with a substantial risk that these pressures will become even stronger in the future. To safeguard Earth's biodiversity is one of the most pressing and difficult challenges facing humanity, e.g., as outlined in the global sustainable development goals (SDGs). The VILLUM Investigator project aims to improve our understanding and predictive capacity of the complex biodiversity dynamics under anthropogenic global change and their consequences for people and society. Based hereon, it aims to develop novel solutions to promote a biodiverse future.

The project has four linked themes, which are the same as for the BIOCHANGE center overall:
[1] Fundamental Biodiversity Dynamics
[2] Global Challenges
[3] Ecoinformatics and New Technologies
[4] Interdisciplinary Innovation

Within these we have key focus on:
(1) transient biodiversity dynamics, trophic changes (notably megafauna losses and comebacks), and novel ecosystems,
(2) developing next-generation predictive models in relation to current and future climate change,
(3) advancing the team's ecoinformatics capability and exploiting the rapidly rising potential for extremely high-resolution spatiotemporal analyses, and
(4) novel interdisciplinary work. For the latter, the focus will be on: (a) ecological Big Data, (b) human-nature inter-relations (notably the role of exposure to nature and biodiversity for human mental health and well-being), and (c) interdisciplinary landscape planning to safeguard biodiversity, ecosystem services and human well-being in the face of strong current and future human population growth, societal challenges, and climate change.

The project is funded by VILLUM FONDEN, with 39,987,212 DKK and runs 2017-2023.

Since the project started in 2017, we have achieved substantial progress, both organizationally and scientifically. Most importantly, the BIOCHANGE center, which was founded based around this project, has been established as a vibrant, collaborative, and ambitious research community, with a skilled set of senior scientists, many postdocs and PhD students, as well as MSc and BSc students, and numerous international collaborators working towards addressing the four research themes. Many important studies have already been published, with much more started and well underway. As a key development, the second of two tenure-track positions linked to the BIOCHANGE project has been filled by Elizabeth Le Roux, assistant professor in megafauna ecology & restoration.

KEY PAPERS

Van Meerbeek, K., Jucker, T., & **Svenning, J.-C**. 2021. Unifying the concepts of stability and resilience in ecology. *Journal of Ecology* 109:3114-3132.

Yue, K., Jarvie, **S.**, Senior, A.M., **Meerbeek, K.V.**, Peng, Y., Ni, X., Wu, F., & **Svenning, J.-C**. 2020. Changes in plant diversity and its relationship with productivity in response to nitrogen addition, warming, and increased rainfall. *Oikos* 129:939-952.

Conradi, T., **Van Meerbeek, K.**, **Ordonez, A.**, & **Svenning, J.-C.** 2020. Biogeographic historical legacies in the net primary productivity of Northern Hemisphere forests. *Ecology Letters* 23:800-810.

Fehr, V., **Buitenwerf, R.J.**, & **Svenning, J.-C.** 2020. Non-native palms (Arecaceae) as generators of novel ecosystems – a global assessment. *Diversity and Distributions* 26:1523-1538.

Perino, A., Pereira, H.M., Navarro, L.M., Fernández, N., Bullock, J.M., **Ceauşu, S.**, Cortés-Avizanda, A., van klink, R., Kuemmerle, T., Lomba, A., Pe'er, G., Plieninger, T., Rey Benayas, J.M., Sandom, C.J., **Svenning, J.-C.**, & Wheeler, H.C. 2019. Rewilding complex ecosystems. *Science* 364:eaav5570.

Meerbeek, K., Muys, B., **Schowanek, S.D.**, & **Svenning, J.-C**. 2019. Reconciling conflicting paradigms of biodiversity conservation: human intervention and rewilding. *BioScience* 69:997-1007.

Monsarrat, S., **Jarvie, S.**, & **Svenning, J.-C.** 2019. Anthropocene refugia: integrating history and predictive modelling to assess the space available for biodiversity in a human-dominated world. *Philosophical Transactions of the Royal Society B: Biological Sciences* 374:20190219.

MEGAPAST2FUTURE:

MEGAFAUNA ECOSYSTEM ECOLOGY FROM THE DEEP PREHISTORY TO A HUMAN-DOMINATED FUTURE

14

Principal investigator: Jens-Christian Svenning

Before the global expansion of *Homo sapiens*, ecosystems across the world teemed with large animals (megafauna). Elephants, for example, occurred from Patagonia to the British Isles and the Cape until just 10,000 years ago. Since then, megafaunas have declined dramatically, a decline that continues today, driven by land conversion to agriculture to feed growing human populations and unsustainable hunting. In some regions, however, declines have been replaced by comebacks (e.g., re-expansion of wolves in Europe). At the same time, evidence is emerging that megafaunas may be crucial for ecosystem function and may even affect Earth's climate and nutrient cycling. Reflecting this, it is increasingly, but controversially, argued that megafaunas should be reintroduced to restore their ecological functions (rewilding). Human impacts are now so pervasive that officially defining a new geological epoch (the Anthropocene, epoch of man) for the present is being considered. Given the intensifying human impacts on Earth's environment – with pronounced increases in the human population and likely substantial climate changes across the 21st century – we are now at a crossroads for Earth's megafauna. Do we let it become lost, or do we attempt to restore it together with its functional importance?

The project ended in 2020 but results from this work are still being published. The project was highly successful and has placed BIOCHANGE at the forefront of megafauna research worldwide. While the project is finished, we continue its four lines of research in other projects, including via a broad range of international collaborators. The project focused on developing a solid, synthetic understanding of megafauna ecosystem ecology and its potential role in developing a sustainable, biodiverse future. To this end, MegaPast2Future had four lines of research:

- Developing new theories on the role of megafauna in ecosystems [work package 1],
- providing a novel understanding of the evolutionary and biogeographic development of the world's megafaunas and their ecosystem importance [work package 2],
- field-based testing of key theory and hypotheses [work package 3], and
- assessing and improving the scope for human-megafauna coexistence in the Anthropocene [work package 4].

Given the complexity of the problem, the methodology was designed to be interdisciplinary, integrating macroecology, theoretical ecology, paleobiology, experimental ecology, geography, economics, and conservation. The project contributes to theme [1] Fundamental Biodiversity Dynamics and theme [4] Interdisciplinary Innovation of BIOCHANGE.

Core field sites have been established in Denmark, Argentina, Kenya, and South Africa with successful fieldwork in all areas, and we still work or plan to continue working in all areas. In 2020-2021, fieldwork in the project was quite constrained by the Covid19 pandemic, but we were able to successfully realize extensive fieldwork in both Denmark and Kenya through this period. Despite the pandemic, we have continually been very active in public outreach in relation to this project nationally and internationally, as well as continued our publication of project research at a high level. One key publication from the project in late 2020 and 2021 is a global assessment of the functional diversity reductions in large herbivore assemblages through the late-Quaternary and the potential for recovery through restoring native species ranges, published in *Global Ecology and Biogeography*. It shows that past species losses have selectively removed not just large but also grazing herbivores, leading to big functional changes in herbivore assemblages. It further shows that restoring still-surviving herbivores to their full native ranges would partially reverse these changes. However, due to the many global extinctions, many herbivore assemblages would remain somewhat down-sized and browser-dominated relative to pre-anthropogenic conditions. Another key paper, published in *Scientific Data,* is a data paper reporting an open-access database of key functional traits for all extant and extinct large-bodied mammal and bird herbivores from the Late Pleistocene to the present. It covers 545 species ≥10 kg body weight and provides a highly important data source for a broad range of megafauna studies.

The project was funded by the Carlsberg Foundation 'Semper Ardens' research project, with 13,777,082 DKK and ran 2016-2020.

CARLSBERG FOUNDATION

MegaPast2Future

Elephant and Thompson's gazelles in one of the world's remaining megafauna-rich ecosystems - Maasai Mara, Kenya: In MegaPast2Future our focus was on understanding the past, present and potential future ecological importance of megafauna. Photo: Jens-Christian Svenning, BIOCHANGE.

KEY PAPERS

Schowanek, S.D., **Davis, M.**, **Lundgren, E.J.**, Middleton, O., Rowan, J., **Pedersen, R.Ø.**, Ramp, D., Sandom, C.J., & **Svenning, J-C**. 2021. Reintroducing extirpated herbivores could partially reverse the late Quaternary decline of large and grazing species. *Global Ecology and Biogeography* 30:896-908.

Lundgren, E.J., **Schowanek, S.D.**, Rowan, J., Middleton, O., **Davis, M.**, Ramp, D., **Pedersen, R.Ø.**, Wallach, A.D., & **Svenning, J-C**. 2021. Functional traits of the world's late Quaternary large-bodied avian and mammalian herbivores. *Scientific Data* 8:17.

Berti, E. & **Svenning, J.-C**. 2020. Megafauna extinctions have reduced biotic connectivity worldwide. *Global Ecology and Biogeography* 29:2131-2142.

Lundgren, E.J., Ramp, D., Rowan, J., Middleton, O., **Schowanek, S.D.**, Sanisidro, O., Carroll, S.P., **Davis, M.**, Sandom, C.J., **Svenning, J.-C.**, & Wallach, A.D. 2020. Introduced herbivores restore Late Pleistocene ecological functions. *Proceedings of the National Academy of Science USA* 117:7871-7878.

Davis, M., Faurby, S., & **Svenning, J.-C**. 2018. Mammal diversity will take millions of years to recover from the current biodiversity crisis. *Proceedings of the National Academy of Science USA* 115:11262-11267.

Faurby, S., **Davis, M.**, **Pedersen, R.Ø.**, **Schowanek, S.D.**, Antonelli, A., & **Svenning, J.-C.** 2018. PHYLACINE 1.2: The Phylogenetic Atlas of Mammal Macroecology. *Ecology* 99:2626-2626.

TREECHANGE:

TREE DIVERSITY DYNAMICS UNDER CLIMATE CHANGE

2 3

Principal investigator: Jens-Christian Svenning

The big question that we address in TREECHANGE is: how will tree species diversity react to future global climate change? Forests are among the most important ecosystems on Earth, harboring a substantial proportion of biodiversity and providing vital ecosystem services such as carbon sequestration, climate regulation, erosion protection, and timber and non-timber forest products. The diversity of tree species play a central role in forest ecosystems and the subsistence of millions of people in rural communities worldwide. Part of the challenge in understanding drivers of tree diversity is that we do not have a complete picture of the current tree distribution and diversity of tree species worldwide.

To improve our understanding of global tree distributions, we have carried out a large effort to collect, integrate, and quality check data on distributions, traits, and phylogeny for about 65,000 identified tree species globally. We are now applying advanced modeling approaches to generate estimates of distributions and climate niches and to estimate missing trait values. For species with very few records, we use gap-filling approaches along with information on functional traits and phylogeny to provide insights on species climate niches. As a key outcome, we will use the results to project tree species ranges under different climate change scenarios to evaluate the impacts on tree diversity. Moreover, we are investigating the patterns of the global functional and phylogenetic diversities using the compiled comprehensive dataset and examining the effects of paleo- and current climate, among other factors, on these spatial patterns. The project contributes to theme [2] Global Challenges and theme [3] Ecoinformatics and New Technologies of BIOCHANGE.

Through the project, we have built a comprehensive, quality-checked database on Earth's tree species, covering about 500,000 tree species and including ca. 37 million species occurrence records and large amounts of data on functional traits and phylogeny. The project has already led to several publications, including a paper on the global patterns of tree-soil organism mutualisms in Nature (as coauthors and providing the journal's front-page photo), the latter reflecting our integration into a large global research community on forest ecosystems and biodiversity based on the TREECHANGE data effort. Other major papers, both led by TREECHANGE and others with us as collaborators, are in the works.

KEY PAPERS

Gatti, C., et al., **Svenning, J.-C., Serra-Diaz, J. M.**, et al. 2022. The number of tree species on Earth. *Proceedings of the National Academy of Science USA* 119:e2115329119.

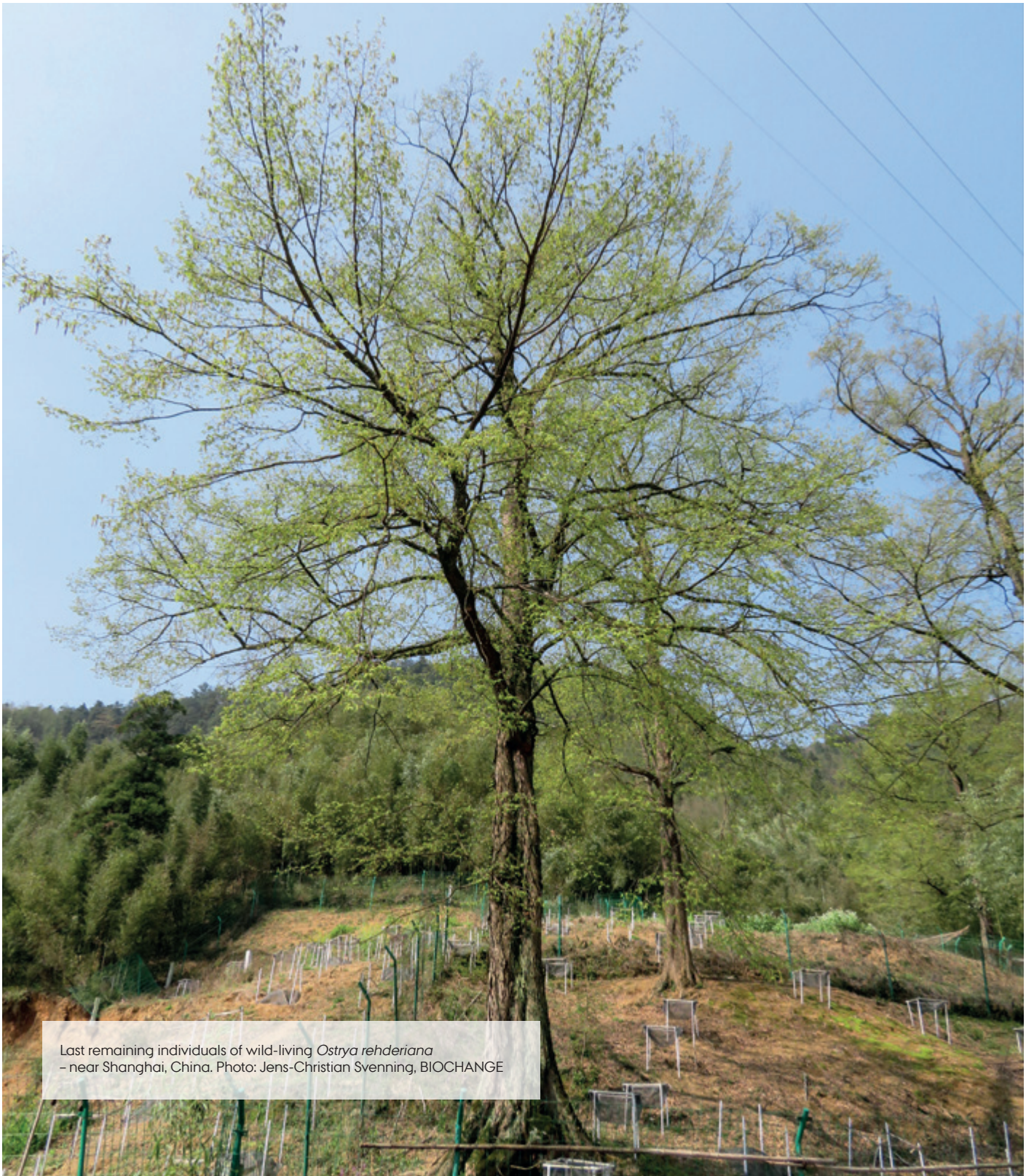
Wang, W.-t., **Guo, W.-Y., Jarvie, S., Serra-Diaz, J.M.,** & **Svenning, J.-C.** 2022. Anthropogenic climate change increases vulnerability of Magnolia species more in Asia than in the Americas. *Biological Conservation* 265:109425.

Steidinger, B.S., et al., **Svenning, J.-C.**, **Serra-Diaz, J. M.**, et al. 2019. Climatic controls of decomposition drive the global biogeography of forest-tree symbioses. *Nature* 569:404–408.

Serra-Diaz, J.M., Enquist, B.J., Maitner B., Merow, C., & **Svenning, J.C.** 2017. Big data of tree species distributions: how big and how good? *Forest Ecosystems* 4:30.

The project was initially funded by Danish Council for Independent Research | Natural Sciences with 2,587,678 DKK and ran from 2016-2019. We have continued TREECHANGE as part of the VILLUM Investigator project. It has currently one postdoc employed and is done in collaboration with BIOCHANGE alumnus Josep M. Serra-Diaz (assistant professor, AgroParisTech) and other international collaborators.

DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK



Last remaining individuals of wild-living *Ostrya rehderiana* – near Shanghai, China. Photo: Jens-Christian Svenning, BIOCHANGE

TERRANOVA:

14

THE EUROPEAN LANDSCAPE LEARNING INITIATIVE: PAST AND FUTURE ENVIRONMENTS AND ENERGY REGIMES SHAPING POLICY TOOLS

Principal investigator: Jens-Christian Svenning

TERRANOVA is a Marie Skłodowska-Curie Innovative Training Network. It aims to improve our long-term understanding of ecosystem and landscape histories and land-use strategies and impacts in Europe in the Holocene and Anthropocene. It takes special interest in developing the basis for mainstreaming rewilding into European landscape management. Previously identified socio-cultural transitions and the effects of natural forcings will be critically assessed. Regional and continental syntheses will be used to anchor a new generation of landscape and climate change models, which include the effects of past human actions and generate scenarios for landscape management and rewilding. Ultimately, this project aims to contribute research and training to the needed future transition to a low carbon society, addressing the joint current climate and biodiversity crises.

These efforts are realized through a new interdisciplinary arena created by the TERRANOVA project, constituted by its interdisciplinary and inter-sectoral consortium and 15 PhD positions. The TERRANOVA consortium consists of eight universities, three NGOs, and three companies. The non-academic beneficiaries include IUCN, the world's oldest and largest global environmental organization, and Rewilding Europe, currently working in 13 different European countries and connecting rewilding initiatives in more than 20 European countries. Together with the academic beneficiaries, they form an unprecedented inter-sectoral consortium for training the next generation of scientists, policy-makers, and entrepreneurs.

Two PhD projects – on natural ecosystem baselines and on megafauna dynamics – are localized in BIOCHANGE with Jens-Christian Svenning as the main supervisor and Signe Normand as local co-supervisor, with further two PhD projects at other institutions co-supervised by Jens-Christian Svenning. All four PhD candidates have progressed in good order, despite the challenges from the Covid19 pandemic for such a pan-European network, with emerging promising results, and both AU PhD students have passed their mid-term qualifying exams. This project contributes to theme [1] Fundamental Biodiversity Dynamics and theme [4] Interdisciplinary Innovation of BIOCHANGE.

The project is funded by European Commission Marie Skłodowska-Curie actions, Horizon 2020 with 4,090,952.52 EUR totally (with 522,844 EUR to Aarhus University).
Further reading: terranovaproject.eu

KEY PAPERS

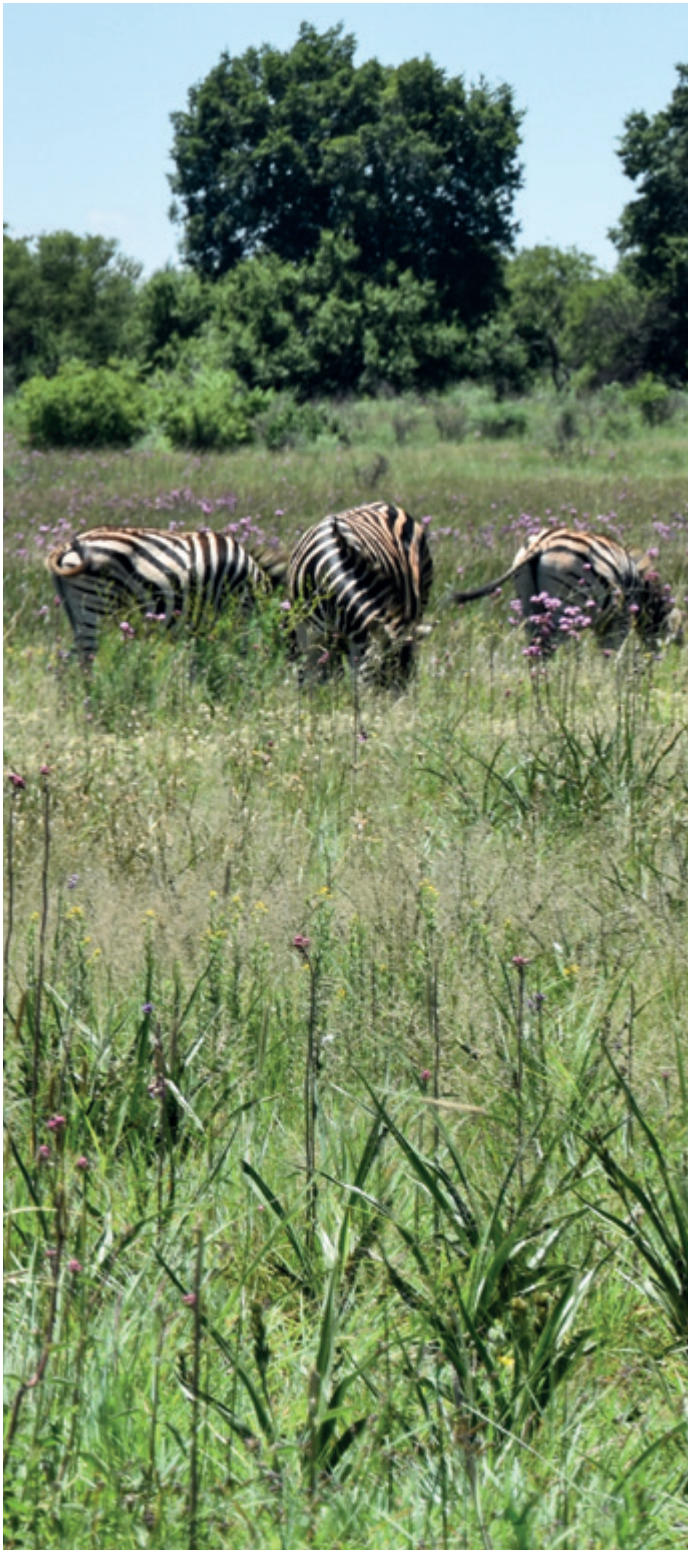
Nikulina, A., *et al.*, **Pearce, E., Davoli, M., Svenning, J.-C.**, *et al.* 2022. Tracking hunter-gatherer impact on interglacial vegetation in Last Interglacial and Holocene Europe: proxies and challenges. *Journal of Archaeological Method and Theory.* (e-pub ahead of print).

In TerraNova, one of our aims is to understand the natural structure of vegetation in Europe's temperate forest zone, re-analyzing large amounts of pollen data from the late Quaternary. Yew (*Taxus baccata*) represents a European tree species whose ecological niche in pre-human forests remain poorly understood and a particular focus of our work in BIOCHANGE (cf. Jensen, D. A. & Svenning, J. C. 2021. Population ecology and dynamics of a remnant natural population of European yew Taxus baccata in a lowland temperate forest – implications for use in reforestation. Nordic Journal of Botany 39: e03167). Photo: Jens-Christian Svenning, BIOCHANGE

MEGACOMPLEXITY:
MEGAFAUNA COMPLEXITY AS A GLOBAL DRIVER OF VEGETATION DIVERSITY

1 3

Principal investigator: Jens-Christian Svenning



What impact does big animals (megafauna) have on nature around the world? That is the question MegaComplexity seeks to answer. 80% of Earth's living biomass consists of plants, thereby making the basic structure of the natural ecosystem – especially on land. Traditionally, vegetation is thought to be primarily regulated by climate, soil, and water. However, the increasing evidence of megafauna's substantial shaping effects now challenges this view, but it remains poorly known how strong and general these megafauna effects are on vegetation. The project seeks to provide insight into that through Big Data analyses of satellite-imagery of vegetation and data on megafauna, climate, etc. The project further aims to discover if the complexity of megafauna (different types of herbi- and carnivores) increases the variation in vegetation and, thereby, the collective biodiversity of a landscape. The project will investigate three types of systems: 1) The global network of natural reserves, i.e., established nature and the backbone in nature conservation efforts. 2) The big areas in the world that each year are abandoned by agriculture production (one reason being that people move from rural to urban areas), i.e., young ecosystems that represent an important possibility for more space for nature. 3) Selected rewilding projects in Europe, North America, and Africa, where megafauna has been reintroduced in the last decades, often with restoration of megafauna-vegetation interactions as an explicit purpose. The project thereby gives not only fundamental insights into the role of top-down trophic effects in ecosystems, but also provides important background knowledge to how we best design nature restoration and manage the world's natural reserves and nature in general. In the last year, the project has begun satellite-based analyses of vegetation dynamics in natural areas, testing for links to large-herbivore presence and functional diversity as well as started remote-sensing-based analyses of vegetation dynamics in major trophic rewilding areas. Several analyses and resulting papers are close to finished and at this point are being considered for publication.

The project contributes to theme [1] Fundamental Biodiversity Dynamics and theme [3] Ecoinformatics and New Technologies of BIOCHANGE.

The project is funded by Danish Council for Independent Research | Natural Sciences from 2020 –2025 and has currently one postdoc and one PhD student employed.

DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK

In the MegaComplexity project, we aim to test the hypothesis that increasing megafauna complexity (functional diversity within and across trophic levels) increases vegetation diversity, based on both macroecological and field-based studies around the world. One key focus area is South Africa, where many megafauna reintroduction projects exist (here, one such area near Pretoria). Photo: Jens-Christian Svenning, BIOCHANGE.

GRIP:
INTEGRATIVE GREEN INFRASTRUCTURE PLANNING

3 4

Principal investigator: Jens-Christian Svenning

Rapidly expanding and disintegrated urban areas in developing economies are often presented with interrelated social, climatic, and ecological challenges. The design of green, health-promoting cities, particularly in low- and middle-income countries, has become a pressing matter. Zooming in on South Africa, the country is ranked as the third most biologically diverse in the world; yet ecological issues receive low priority in relation to pressing social issues, especially in the growing cityscapes. It is time to rethink urban development towards greater sustainability and social inclusion.

Green infrastructure offers a sustainable planning approach that integrates water-related benefits and socio-economic gains into cities' ecological fabric to improve the functioning of urban ecological systems and the quality of public spaces for greater health and well-being. In the face of climate change, biodiversity loss, and rapid urbanization, there is an increasing urgency to establish multifunctional green infrastructure in growing urban areas. Like many countries around the world, South Africa is becoming increasingly warmer and drier, with unpredictable precipitation patterns leading to increasing droughts and flooding events. Improved green infrastructure can not only alleviate damages from such events but also provide a range of ecological, social, cultural, and economic benefits to local communities and the broader society.

The GRIP project provides new knowledge and strengthens research capacities on urban green infrastructure in South Africa through an interdisciplinary research project in the national capital, the City of Tshwane (CoT, former Pretoria). GRIP is an independent research component working in parallel with a city-to-city collaboration between CoT and the City of Aarhus. It focuses on holistic urban planning, integrating social, economic, and cultural issues toward more sustainable cities. In collaboration with research partners from the University of Pretoria and private consultants from both countries, the GRIP project cross-fertilizes spatial ecology, environmental justice, and landscape design. It seeks to build capacities across disciplines, borders, and sectors. In practice, knowledge is co-created through reciprocal exchange of management experiences (e.g., organization and communication) and stronger technical capacities (high-resolution mapping and big data modeling of multifunctionality), and through integration of ecological knowledge (on species and habitats) and social gains (local identity, equity, justice and economic development, in particular). GRIP contributes to BIOCHANGE theme [3] Ecoinformatics and New Technologies and theme [4] Interdisciplinary Innovation.

During its first project year, the project has completed four interactive workshops and two fieldwork campaigns. During the latter, various data have been collected, e.g., through GIS mapping and ecological transects measuring green infrastructure multifunctionality, as well as through surveys and interviews with the local community applying an environmental justice lens (on benefit distribution, decision procedures, and social recognition). Landscape architect students from the University of Pretoria, under supervision of key project partner Ida Breed, have developed design proposals based on a socio-ecological assessment of the study sites and inputs from the researchers from GRIP. Together, and in on-going dialogue with the two municipalities, all research components will be synthesized into actionable green infrastructure management guidelines and recommendations.

Unmanaged waste, crime, and limited access are some of the main challenges at the Atteridgeville study site. This pedestrian bridge crossing a highway is one of the only formal access points to the 100 ha urban green area. Unfortunately, the bridge has been vandalized, as desperate people break off the poles and railing to sell the core metal parts. Photo: Maya Pasgaard, BIOCHANGE.

The project is funded by Ministry of Foreign Affairs of Denmark, DANIDA Fellowship with amount DKK 4,976,217 and runs 2021-2023.

MINISTRY OF FOREIGN AFFAIRS
OF DENMARK
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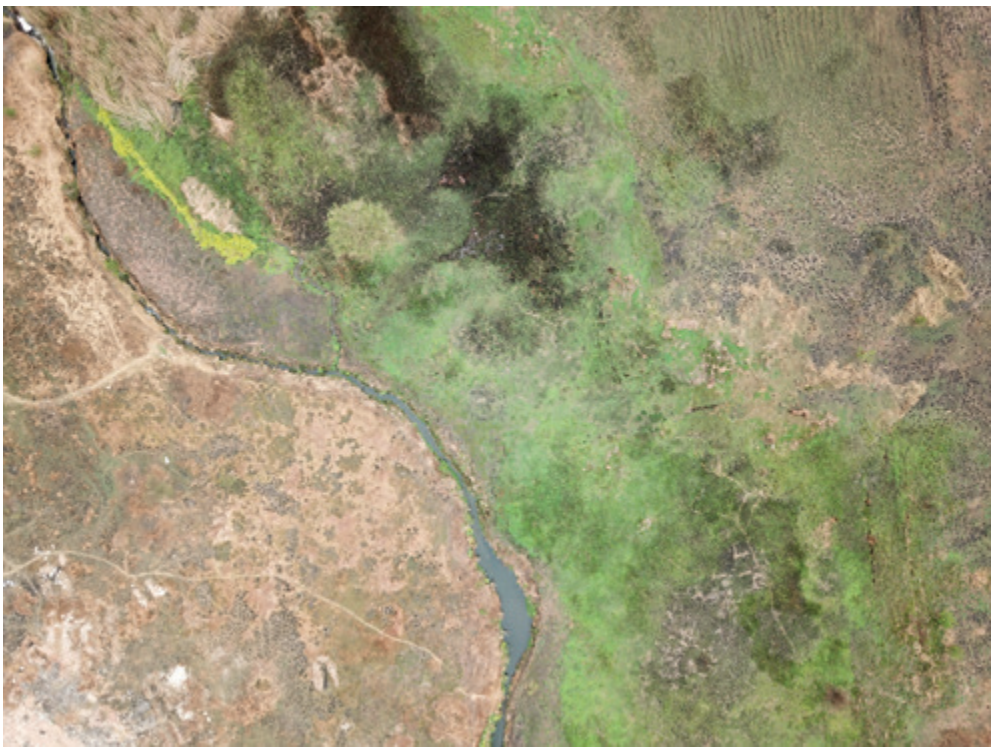


The Skinnerspruit River flows through the Atteridgeville study site, creating a green corridor that provides habitat for a multitude of native birds, reptiles, and insects, as well as water for urban agriculture by the local residents and mitigation of flooding and urban heat island effect. The site's ecological integrity and delivery of benefits is threatened by pollution and urban encroachment. Image: Siegwalt Kusel.

Maria runs a street kitchen with local food at the edge of the Mabopane urban green corridor framed by the impressive ODI stadium in the background. To sustain a living, Maria and her cooking team also work in their small urban gardens (where they grow vegetables for their own use) and collect bottles for recycling. Photo: Maya Pasgaard, BIOCHANGE.

FAIR:
FOREST TRANSITIONS IN THE ANTHROPOCENE AND THEIR IMPLICATIONS FOR RESTORATION VALUES – A GLOBAL ASSESSMENT BASED ON REMOTE SENSING

2 3

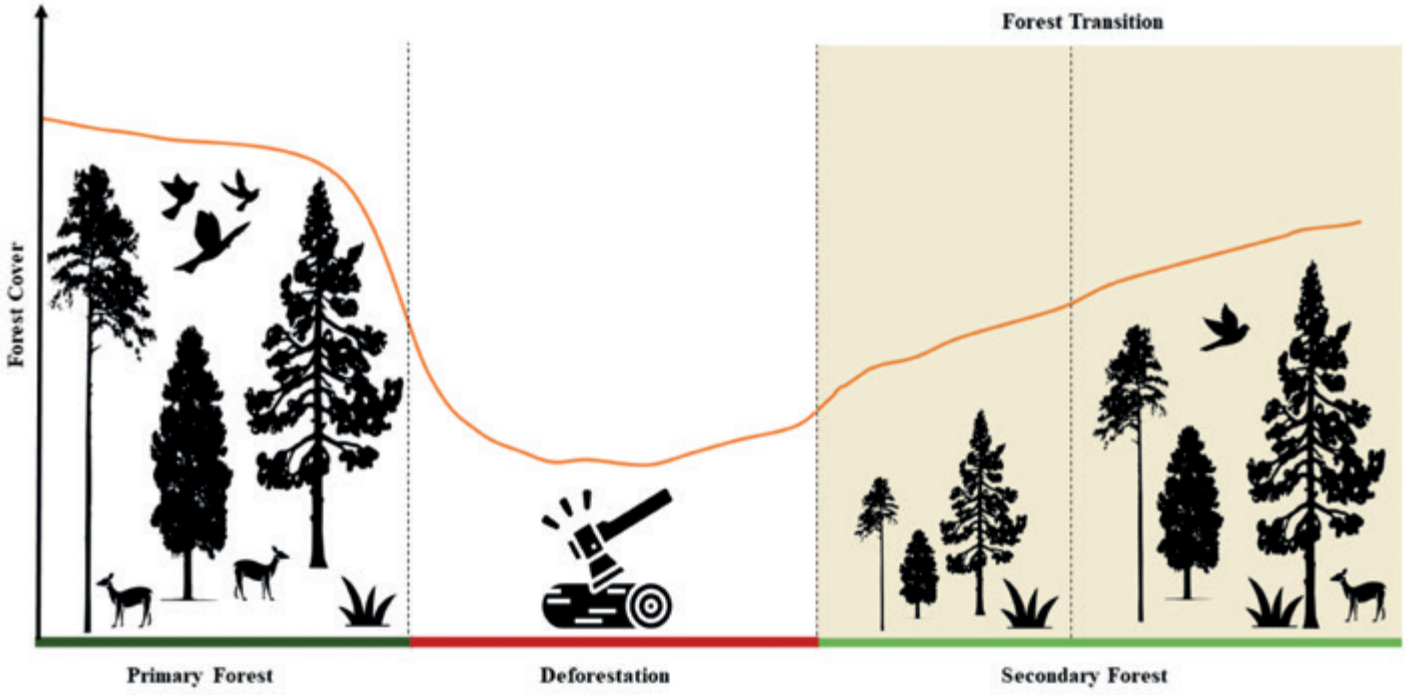
MSCA fellow: Wang Li
Supervisor: Jens-Christian Svenning

Forest degradation and biodiversity losses caused by land conversion and over-use have strongly increased since the mid-20th century. Today, only 22% of the global forest area remains as intact forest with little human activity or habitat fragmentation. Despite the exceptional value for global biodiversity conservation, ecosystem services, and human well-being, only 12% of the intact forests are protected. Moreover, many intact forests risk degradation from climate change and increasing human pressures. However, forest transitions - shifts from net deforestation to net reforestation - have occurred widely and rapidly in recent decades. These net increases in forest area are due to active afforestation, reforestation, and spontaneous reforestation following land abandonment. In addition to increases in forest area, reversals from forest degradation to net gains in tree cover and forest quality are also reported from degraded forests. Recent studies highlight that global forest restoration provides an important opportunity for climate change mitigation. However, the restoration of biodiversity and ecosystem processes often fails, e.g., when monocultures are planted, if the landscape is fragmented, or due to social, political, and economic pressures. The need to develop strategies for shaping forest transitions has been increasingly highlighted, with active restoration becoming a global priority with billions of dollars invested. The overall objective of FAIR is to link global forest transitions' dynamic trajectories, i.e., de- to re-forestation shifts and analogous shifts in intactness, to societal and climate change. FAIR will deliver the quantitative basis for developing sound forest restoration efforts globally by determining:

1) where and how forest transitions have occurred,
2) why they occur in some areas and not in others,
3) where and at which rate transitioning forests develop towards more intact states, and
4) how intensifying societal and climate changes of the Anthropocene affect forest transitions.

FAIR will rely strongly on remote sensing satellite data and contributes to BIOCHANGE theme [2] Global Challenges and theme [3] Ecoinformatics and New Technologies and has tremendous potential to map, quantify, and monitor forest change at a global scale.

The project is funded by European Commission, H2020 MGA MSCA IF grant with 207,312 EUR and runs 2020–2022.



Secondary forests are structurally recovering but under multi-source pressure from climate, human activities, and their combined influence – fire. Transitioning secondary forests, including both natural (naturally regrown) and planted forests established following deforestation and agriculture abandonment, might risk potential re-degradation under such pressure. Figure: Wang Li, BIOCHANGE.

CLIOARCH:

3 4

CLIODYNAMIC ARCHAEOLOGY: COMPUTATIONAL APPROACHES TO FINAL PALEOLITHIC/EARLIEST MESOLITHIC ARCHAEOLOGY AND CLIMATE CHANGE

Principal investigator: Felix Riede

Late Pleistocene/early Holocene Europe is said to be the ideal laboratory for the investigation of human responses to rapidly changing climates and environments, migration, and adaptation. Yet, pinpointing precisely how and why contemporaneous Final Palaeolithic/earliest Mesolithic (15,000-11,000 years BP) foragers migrated and which environmental or other factors they adapted to, or failed to, has remained remarkably elusive. At the core of CLIOARCH is the radical but (in light of research-historical insights) necessary hypothesis that the current archaeological cultural taxonomy for this iconic period of European prehistory is epistemologically flawed. The operationalizations and interpretations based on this traditional taxonomy are therefore problematic. Especially those that seek to relate observed changes in material culture and land use to contemporaneous climatic and environmental changes. Hence, novel approaches to crafting the taxonomic building blocks are required, as are novel analyses of human-environment relations in this period. CLIOARCH's premier ambition is to provide operational cultural taxonomies for the Final Palaeolithic/earliest Mesolithic of Europe and to couple these with interdisciplinary cultural evolutionary, quantitative ecological methods, and field archaeological investigations beyond the state-of-the-art to capture better such adaptations – almost certainly with major implications for the standard culture-historical narrative relating to this period. In so doing, the project will pioneer a fully transparent and replicable – and eminently transferable – methodology for studying the impacts of climate change and extreme environmental events in deep history. In turn, such a quantitative understanding of past adaptive dynamics will position archaeology more centrally in contemporary debates about climate change, environmental catastrophe, and their cultural dimensions.

Through five linked work packages (WPs), the project will explore the application of new technologies and techniques borrowed from ecoinformatics in order to understand human adaptations to past climate change and events better. Jens-Christian Svenning is involved in the project as senior advisor and co-supervisor of one of its PhD students. Indeed, BIOCHANGE is this exciting project's natural second home!

This grant will contribute to theme [3] Ecoinformatics and New Technologies and theme [4] Interdisciplinary Innovation of BIOCHANGE.

KEY PAPERS

Matzig, D.N., **Hussain, S.T.**, & **Riede, F.** 2021. Design space constraints and the cultural taxonomy of European final palaeolithic large tanged points: A comparison of typological, landmark-based and whole-outline geometric morphometric approaches. *Journal of Paleolithic Archaeology* 4:27.

Manninen, M.A., *et al.*, **Riede, F.**, & Persson, P. 2021. Using radiocarbon dates and tool design principles to assess the role of composite slotted bone tool technology at the intersection of adaptation and culture-history. *Journal of Archaeological Method and Theory* 28:845-870.

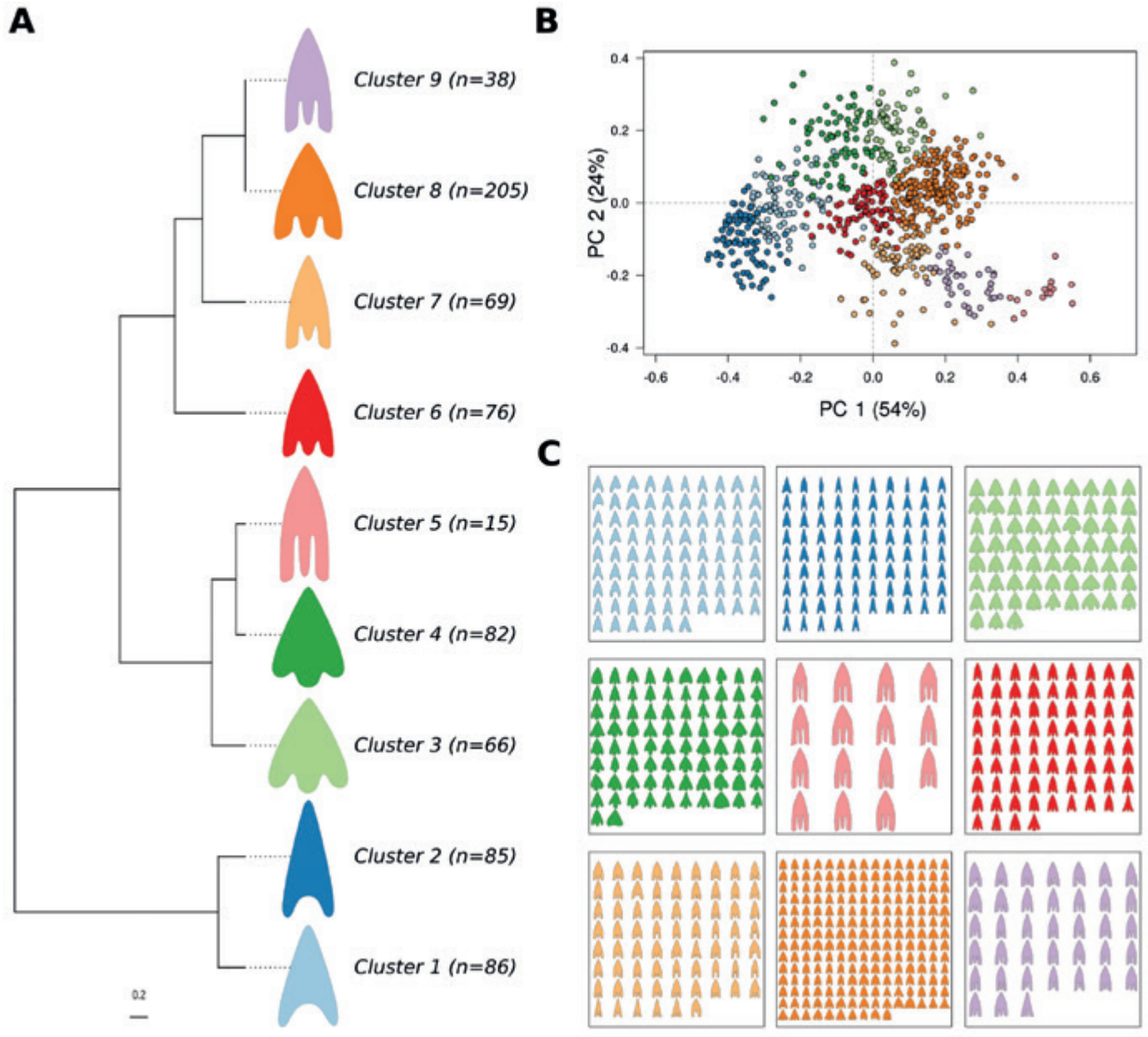
Hussain, S.T., **Matzig, D.N.**, *et al.*, **Riede, F.** 2021. Towards a collaborative meta-analysis of the Final Palaeolithic / earliest Mesolithic in Europe. Report on the 2nd CLIOARCH Workshop, 26th-27th November 2020. *Archäologische Informationen* 43:415-420.

Ivanovaitė, L., Serwatka, K., **Hoggard, C.S.**, **Sauer, F.**, & **Riede, F.** 2020. All these fantastic cultures? Research history and regionalization in the Late Palaeolithic tanged point cultures of Eastern Europe. *European Journal of Archaeology* 23: 162-185.

Riede, F., Araujo, A.G.M., Barton, M.C., Bergsvik, K.A., Groucutt, H.S., **Hussain, S.T.**, et al., **Sauer, F.**, Serwatka, K., Zander, A. 2020. Cultural taxonomies in the Paleolithic—Old questions, novel perspectives. *Evolutionary Anthropology: Issues, News, and Reviews* 29:49-52.

Riede, F., **Hussain, S.T.**, Timmreck, C., & **Svenning, J.-C**. 2020. CLIOdynamic ARCHaeology: computational approaches to Final Palaeolithic/Early Mesolithic archaeology and climate change. *Antiquity* 94:e13.

CLIOARCH is funded by the European Research Council through the Consolidator Grant grant agreement 817564 under the Horizon 2020 research and innovation program with 1,907,638 EUR and will run from 2019-2024.



With inspiration from palaeobioology, we developed a semi-automated protocol to recognize the outline shapes of ancient stone tools and to feed them into an analysis that sorts them into significant clusters. Using this method, we aim to construct transparently operational units for understanding the dynamics of cultural transmission and adaptation in ancient human societies. Figure: Felix Riede/David Matzig, BIOCHANGE.

PLAY|OBJECT|PLAY:
The role of early-age niche provisioning in technological innovation and adaptation

4

Principal investigator: Felix Riede

This project is funded by the Aarhus University Research Foundation's NOVA instrument and the Graduate School, Arts. Material culture is at the heart of human identity and ingenuity. The breadth and complexity of our toolkits have allowed us to adapt to diverse and challenging ecologies throughout our evolutionary history. By investigating the processes by which technology is modified and transmitted across generations, archaeologists are uniquely poised to inform how we may harness our species' innovative potential to thrive in the face of unprecedented environmental change.

P|O|P aims to challenge existing archaeological paradigms by developing an integrative child-centered model of material culture change. Both narrative and quantitative archaeological models aimed at explaining technological change have primarily focused on the role of adults as innovators and transmitters of tool manufacturing skills. Yet, this viewpoint is out of step with emerging psychological and anthropological understandings of the cognitive and cultural processes by which children develop their tool-making skills. Experimental research has shown that while children struggle to innovate individually, they easily invent aesthetic and practical objects with peers. During play, children learn the properties of materials through toy construction and develop the cognitive flexibility necessary for innovation while simulating real-world scenarios during pretense. Cultural variation in how adults transmit tool-making knowledge to their children may differentially constrain or encourage children's problem-solving skills.

Bringing these multidisciplinary perspectives into conversation, we have recently proposed the hypothesis that the temporal and geographic stochasticity in toolkit diversification throughout our evolutionary history may reflect cultural differences in cognitive priming for innovation via play, exploration, and opportunity provisioning. Since its publication in 2018, the paper outlining this hypothesis has been highly cited in psychology, anthropology, and archaeology, demonstrating the timeliness of considering children's agency in culture change. Yet, testing this hypothesis using archaeological data is challenging because many objects made for or by children were likely made from organic material, which is often not preserved. Moreover, archaeological signatures associated with learners are poorly characterized.
To overcome these challenges, we will identify the developmental processes which led to material culture conservation and diversification in the deep past by pioneering new statistical and analytical models derived from the anthropological and archaeological records.

By integrating a wide range of ethnographic, ethno historic, archaeological, and environmental data, P|O|P will investigate intra- and inter-cultural trends regarding tool types, use, manufacturing, and learning, and tool user age and sex, all placed within their ecological context. We will use these data to develop an agent-based model for how societal factors, including subsistence strategy, available natural material, and incipient cultural change, predict children's acquisition and innovation of tools. We will then test our models against the existing archaeological data from published and unpublished records to infer children's material culture contributions in the deep past.
This grant will contribute to theme [4] Interdisciplinary Innovation of BIOCHANGE.

KEY PAPERS

Riede, F. & **Meyer, M.V.** 2021.Book review: Growing up in the Ice Age. Fossil and archaeological evidence of the lived lives of Plio-Pleistocene children. *Childhood in the Past* 14:197-199.

Riede, F., Walsh, M.J., Nowell, A., Langley, M.C., & Johannsen, N.N. 2021. Children and innovation: play, play objects and object play in cultural evolution. *Evolutionary Human Sciences* 3:e11.

Nowell, A., Langley, M.C., & **Riede, F**. 2020. Children and innovation: A Wenner-Gren workshop. *Evolutionary Anthropology: Issues, News, and Reviews* 29:6-8.

The project is funded by Aarhus University Research Foundation's NOVA instrument with 2,000,000 DKK and further supported with a full Faculty PhD stipend by the Graduate School Arts.

Toys from traditional societies around the world. According to our survey, children across cultures tend to play with the same sorts of objects – those representing or mimicking nature (e.g., animals or humans) and those mimicking technology (e.g., weapons, cooking utensils, transport). Children and the way in which they innovate are essential for societal adaptation.

C2C CC:
COAST TO COAST CLIMATE CHALLENGE SUBPROJECT C24: CLIMATE HISTORY | CULTURE HISTORY

2 4

Principal investigator: Felix Riede

As part of a large EU Life funded project anchored in the Region of Central Denmark, this project aims to provide a historically informed and evidence-based dissemination platform for C2C Climate Challenge that facilitates citizen-near adaptation and long-term behavioral change. The project couples existing environmental and cultural-historical datasets together in order to provide evidence-based snapshots of past environmental conditions and human responses. With a focus on hydrological changes in inland (river, lake) and coastal contexts, C24 connects directly with other C2C CC projects and makes use of existing dissemination platforms (e.g., the Klimatorium and AquaGlobe) in order to showcase the overall project nationally. At the same time, this project reaches out to a wider international network through workshops and participation in international conferences. Finally, the project will add value to C2C CC overall by translating climate history into components useable for sustainable growth via tourism. The popular outreach portal danmarkshistorien.dk is co-opted in this project to present coupled cultural and climate history to the Danish-speaking public. Our collection of expert contributions can be seen here: Miljøhistorie – hvad er det? (danmarkshistorien.dk). We have also curated a small exhibition on environmental history in the Skanderborg area on display at the AquaGlobe. This project contributes to theme [2] Global Challenges and theme [4] Interdisciplinary Innovations of BIOCHANGE.

KEY PAPERS

Kerr, S., Krogh, U., & **Riede, F**. 2022. Experimental participatory methodology brings local pasts to contemporary climate action. *Climate Action* 1:5.

Allen, K., **Riede, F.**, Gouramanis, C., Keenan, B., Stoffel, M., Hu, A., & Ionita, M. 2022. Coupled insights from the palaeoenvironmental, historical and archaeological archives to support social-ecological resilience and the Sustainable Development Goals. *Environmental Research Letters* 17:055011.

The project is supported by the EU LIFE program with approximately 52 million DKK and has a total budget of ca. 90 million DKK.

A **B** **C**

Using historical maps together with projections of future climate change - here related to hydrology - we communicate the risks, costs, and opportunities related to such projections. In collaboration with municipal actors, planners, and local museum staff, we use local history and prehistory as a bridge between scientific knowledge, managerial concerns, and local stakeholder perspectives.
Image A and B credit: Agency for Data Supply and Efficiency.
Image C: Source: C2C CC (n.d.). Værdier og risici ved et ændret klima.
Figure retrieved from: Kerr, S., Krogh, U., and Riede, F. 2022. Experimental participatory methodology brings local pasts to contemporary climate action. *Climate* Action 1:5.

HUMAN COLONIZATION:

14

PATTERNS AND PROCESSES OF DISPERSAL, CULTURAL CHANGE AND DEMOGRAPHIC COLLAPSE IN THE EARLIEST HUMAN COLONIZATION OF PALAEARCTIC SOUTHERN SCANDINAVIA

Principal investigator: Felix Riede

This project focuses on the first presence of modern humans in southern Scandinavia during the Late Glacial (14,500-14,000 years ago), linked to the so-called Hamburgian culture. A reindeer-specialized hunter-gatherer culture is generally understood as reflecting a culture-historical epoch with an unbroken use of the recently deglaciated landscape. The Hamburgian culture is traditionally divided into an earlier, more eastern 'classic' and a later, more north-western 'Havelte' phase and ends abruptly at around 14,000 years ago. Rather than differing substantially in their lithic repertoire or subsistence economy, however, the two phases of the Hamburgian culture diverge only in their diagnostic projectile point forms. A chronological and spatial overlap is also observed, making the basis for, and meaning of, this division of phases somewhat problematic. Currently, no robust answer for this clear yet curious division exists.

The HUMAN COLONIZATION project takes its starting point in the excavation of the Krogsbølle site near Nakskov on Lolland. Here, tools from the Hamburgian culture were found alongside palaeoecological remains – including the remarkably well-preserved bones of Denmark's oldest gull. The project seeks novel explanations for the shift from 'classic' to 'Havelte' and the latter's sudden disappearance. The hypothesis of the project is that (i) the change from 'classic' to 'Havelte' was driven by a dispersal process linked to individual decision making, and that (ii) the disappearance of the 'Havelte' phase and with it the entire Hamburgian culture can plausibly be linked to a demographic collapse. The project aims to address these questions by:

- Using a mixed-method approach to identify the artefactual signatures of individuals in order to quantify and hence qualify the technological and morphological variability inherent in the Hamburgian culture;
- Deploying ethnographic data on hunter-gatherer demographic collapse as part of quantitative models that reconstruct past population dynamics;
- Using climate datasets of the Last Glacial Maximum with the archaeological data of the Hamburgian culture in order to evaluate the relationship between the archaeological record and climate conditions in time and space and, by doing so, construct distribution models for the Hamburgian culture.

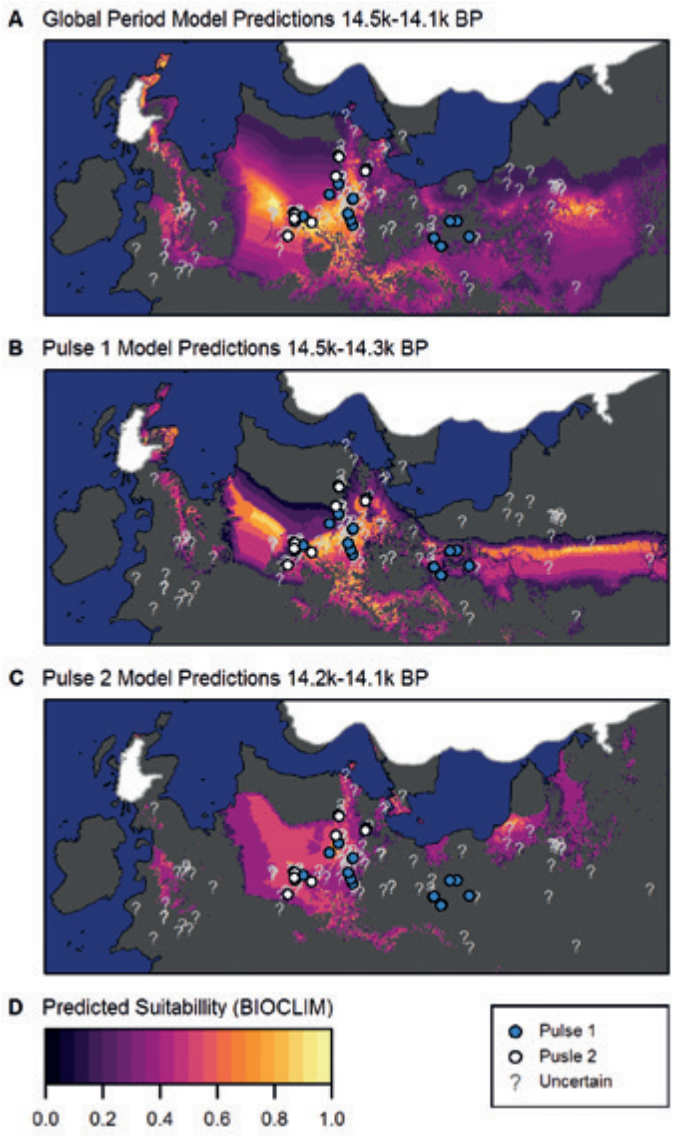
The aim of the project is, therefore, to generate new empirical data through these multi-scalar analytical tracks. If the hypothesis is correct, we will need to significantly rethink how we conceptualize Palaeolithic 'cultures' in general, how we see hunter-gatherers adapting to climate change, and how vulnerable such groups are to changing climates. This particular and iconic episode of the 'first immigration' of people into what is today Denmark may need to be substantially revised. The first papers arising from this project are being published. This project contributes to theme [1] Fundamen¬tal Biodiversity Dynamics and theme [4] Interdisciplinary Innovation of BIOCHANGE.

The project currently employs one PhD student supported by an AU Arts Faculty PhD Fellowship supervised by Felix Riede and co-supervised by Signe Normand from BIOCHANGE. BIOCHANGE alumnus Jakob Assmann is also very much involved in the project.

KEY PAPERS

Pedersen, J.B. 2021. Tidsrummet for Hamborgkulturens bosættelse ved Jelssøerne kommenteret gennem forsøg på flintsammensætning. *Arkæologi i Slesvig/Archäologie in Schleswig* 18:303-317.

Pedersen, J.B., Poulsen, M.E., & **Riede, F**. 2022. Jels 3, a New Late Palaeolithic Open-Air Site in Denmark, Sheds Light on the Pioneer Colonization of Northern Europe. *Journal of Field Archaeology* (e-pub ahead of print).



Climate niche models for the earliest peopling of northern Europe at the end of the Pleistocene, which took place through two discrete dispersal events. Note the different eco-cultural niche spaces during the two dispersals. The time-slice for the first event (Pulse 1) describes a broad climate space, reflecting a widening window of opportunity for human dispersal at a time of rapid climatic amelioration. The time-slice for the second event (Pulse 2) offers a contrasting picture, with the projected niche space being more fragmented and separated by larger gaps of marginal environments. Such a dramatic and rapid fragmentation of available niche space may have eventually inflicted significant social and demographic costs upon these pioneering groups, rendering this earliest attempt at settling the northern latitudes untenable and potentially leading to a cultural and/or biological collapse. Figure: Jesper Borre Pedersen, BIOCHANGE.

sDYN:
CROSS-SCALE INTEGRATION OF ARCTIC SHRUB DYNAMICS

1 2 3

Principal investigator: Signe Normand

Climate warming is expected to have pronounced effects on the functioning of Arctic ecosystems. However, evidence shows substantial and often unexplained variation in the response of woody plants to recent warming across research sites in the North. sDYN is providing new insights on Arctic shrub dynamics and their variation across space and time through innovative integration of satellite- and drone-based remote sensing, functional traits, dendroecology, and dynamic modeling.

The empirical basis for this project stems from data collected at multiple sites across the whole of Greenland during past field campaigns (2011-2019) (Fig.1). The data set represents a unique combination of growth, recruitment, cover, and functional trait data collected simultaneously with drone-based surveys at multiple sites across large-scale climatic gradients in Greenland. Key to the sDYN project is a combination of stratified random sampling campaigns of vegetation cover and composition, in-depth ecological field observations, and the deployment of top-of-the-range drone and microclimate logger technologies. Fused with high- and moderate-resolution images from satellites, the data from the field sites allows for cross- and landscape-scale mapping of vegetation dynamics and their geophysical drivers.

Recent outcomes from the working group have provided additional insight into the underlying drivers of shrub community composition and contributed to global predictions of soil temperature. An abundance of species and functional groups of shrubs had highly individualistic trends with variation in both abiotic and biotic variables such as annual temperature variability, functional community composition, and graminoid abundance (Fig. 2). Therefore, integrating community theory and functional trait concepts represents a promising pathway to predict biotic interactions better. Ultimately, it will also improve the predictions of dominant shrub vegetation's responses to rapid environmental changes across the Arctic tundra biome. Furthermore, detailed measurements of microclimate across a tundra landscape have been used to develop gridded layers of soil temperature and bioclimatic variables at a global extent, a key component of terrestrial ecosystems. Ongoing investigations address vegetation feedback to microclimate and relationships of shrub growth with local as well as large-scale climate dynamics across Greenland. In particular, to improve quantification of the magnitude and extent of current shrub community responses, a synergetic approach combining a comprehensive and community-based sampling design, quantitative wood anatomical analyses, and satellite-based and in-situ data describing trends and events of multiple drivers has been identified.

Overall, sDYN provides the scientific basis for an improved understanding and prediction of ongoing and future vegetation dynamics in the Arctic. This project contributes to theme [1] Fundamental Biodiversity Dynamics, theme [2] Global Challenges, and theme [3] Ecoinformatics and New Technologies of BIOCHANGE.

KEY PAPERS

Prendin, A.L., M. Carrer, M. Karami, J. Hollesen, N.B. Pedersen, M. Pividori, **U.A. Treier**, A. Westergaard-Nielsen, B. Elberling, and **S. Normand**. 2019. Immediate and carry-over effects of insect outbreaks on vegetation growth in West Greenland assessed from cells to satellite. *Journal of Biogeography* 47:87-100.

Prendin, A.L., S. Normand, M. Carrer, Pedersen, N.B., Matthiesen, H., Westergaard-Nielsen, B. Elberling, **U.A. Treier** & J. Hollesen. 2022. Influences of summer warming and nutrient availability on Salix glauca L. growth in Greenland along an ice to sea gradient. *Scientific Reports* 12:3077.

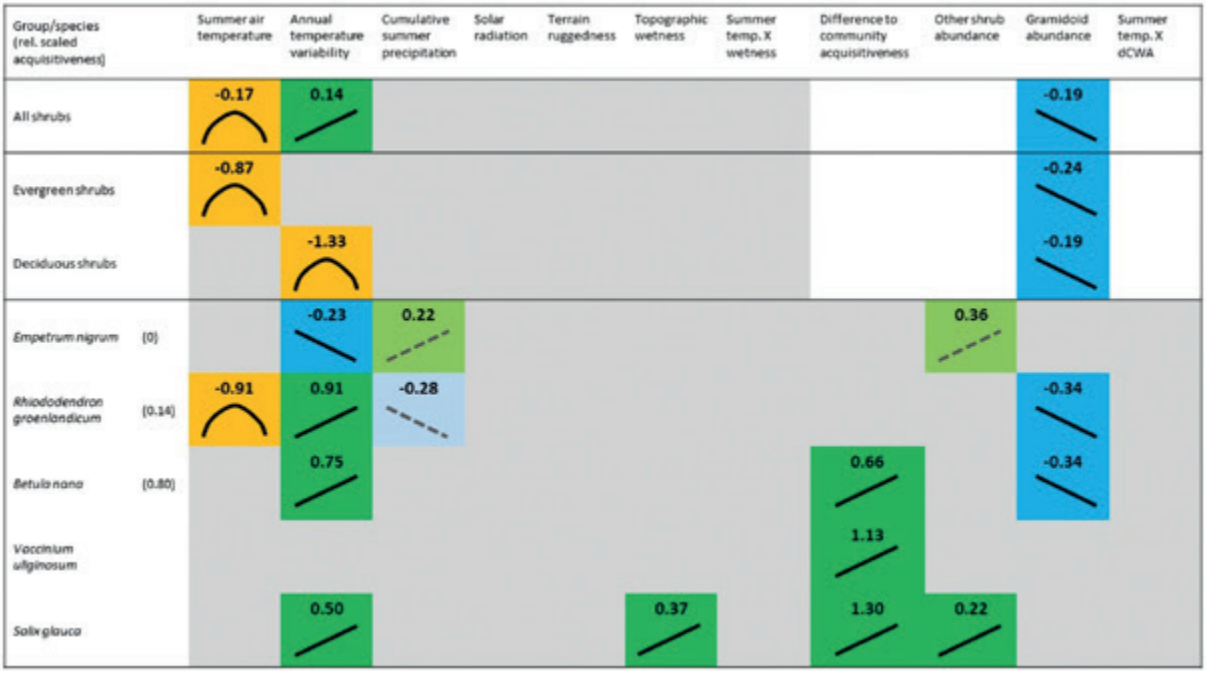
von Oppen J., Normand S., Bjorkman A.D., **Blach-Overgaard A.**, **Assmann J.J.**, Forchhammer M., Guéguen M., & Nabe-Nielsen J. 2021. Annual air temperature variability and biotic interactions explain tundra shrub species abundance. *Journal of Vegetation Science* 32:e13009.

Figure 2: Schematic overview of how an abundance of shrub functional groups and species was related to climatic, topographic, and biotic variables, as obtained from individual hierarchical Bayesian models, with Topographic Wetness Index (TWI) as the wetness variable. Colors and sketched trend lines indicate relationships as positive (green, ascending line), unimodal (orange, curved line), or negative (light blue, descending line). Color saturation and line appearance indicate 95% (saturated, solid lines) or 90% (half- saturated, dotted lines) credible intervals of coefficient posterior distributions not overlapping zero. Grey fields indicate relationships with credible intervals overlapping zero. Difference in community- weighted mean (CWM) acquisitiveness and shrub cover were not included in functional group models as they are species- specific estimates. Species are arranged according to their ecological strategy, from resource-conservative (*Empetrum nigrum*) to – acquisitive (*Salix glauca*). Figure modified from von Oppen *et al.*, 2021. Figure: Jonathan von Oppen, BIOCHANGE.

The project is funded by the Sapere Aude Research leader grant, Danish Council for Independent Research, from 2018-2022. One postdoc and two PhD students are currently employed in this project, which closely collaborates with several national and international collaborators as well as MSCA postdoc Angela Luisa Prendin.

DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK

Figure 1: Topography, soil cover and vegetation variability of the research area in the Disko Island. Photo: Angela L. Prendin, BIOCHANGE.



BoRiS:
Uncovering the anatomical archive of annual rings to understand abiotic and biotic drivers of shrub growth at the range border

MSCA fellow: Angela Luisa Prendin
Supervisor: Signe Normand

Climate change is observed and predicted to affect Arctic and Alpine ecosystems profoundly. These ecosystems, at the border of woody plant growth, change at a faster rate than the global average. Growth responses of Arctic-Alpine shrubs to climate change are variable and influenced by different abiotic and biotic factors. A key to understanding the plasticity of responses to climate change is a detailed analysis of growth at the intra-individual to the community level. Currently, we lack knowledge on the intra-individual, intraspecific, and interspecific variation in growth and wood anatomical traits across environmental gradients. BoRiS aims to uncover the information archived in annual rings to gain fundamental insight on how the responses scale from individuals to communities. Insight into past dynamics opens a valuable window to the future and provides the basis for predicting future range dynamics of Arctic-Alpine shrubs. BoRiS is possible due to a unique data set of > 1000 individual shrubs sampled (Fig. 1) in Arctic and Alpine areas and innovative integration of state-of-the-art quantitative wood anatomical analyses, classical dendrochronology, a newly proposed community-based dendroecology framework, range dynamic modeling, and remote sensing observations.

An increase in the terrestrial carbon (C) sink in the Arctic due to enhanced plant growth caused by recent climate change is a potentially important feedback mechanism on the global C cycle. Preliminary results based on willow species from 20 sites across ice-free Greenland demonstrate that warming leads to different magnitudes of growth and biomass change depending on local and regional environmental variation unrelated to temperature differences per se. Biotic disturbances, such as insect outbreaks, could also lead to direct and lagged effects on C investment. Outbreak years with narrower rings and thinner fibre cell walls results accompanied by a change in the content of cell-wall polymers finalized to possibly maintain an efficient hydraulic system and guarantee growth (Fig. 2). BoRiS is also assessing the role of nutrient enrichment in promoting promote plants growth. Recent outcomes show that higher nutrient availability due to past human activities plays a role in Arctic vegetation growth. This should, therefore, be considered when assessing both the future impact of plants and the general greening of landscapes with contrasting nutrient availability.

BoRiS perfectly integrates into sDYN and contributes to improving the understanding of ongoing and future vegetation productivity and dynamics in the Arctic and contributes to theme [1] Fundamental Biodiversity Dynamics, theme [2] Global Challenges, and theme [3] Ecoinformatics and New Technologies of BIOCHANGE.

KEY PAPER

Prendin, A. L., Carrer M., Bjerregaard Pedersen N., **Normand S.**, Hollesen J., **Treier U.A.**, Pividori M., & Garbrecht Thygesen L.. 2021. Chemical signature of *Eurois occulta L.* outbreaks in the xylem cell wall of *Salix glauca L.* in Greenland. *Science of the Total Environment* 764:144607.

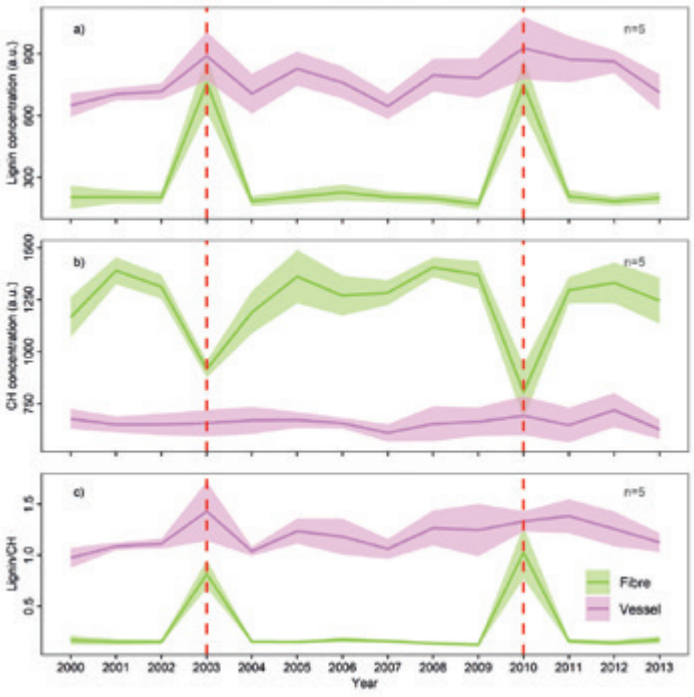


Figure 2: Time series of chemical cell wall components of *Salix glauca L.* from Iffiartarfik in the Nuuk Fjord (West Greenland) based on two multiset Multivariate Curve Resolution – Alternating Least Squares (MCR-ALS) models, one for vessels, one for fibers. The MCR-ALS resolved concentration (arbitrary unit) of lignin, carbohydrates (CH), and their ratios were derived from these two models. Data are means ± SE (Standard Error). Dashed lines indicate the years of the outbreak events. Figure modified from Prendin *et al.*, 2021.

The project is funded by the European Commission, H2020 MGA MSCA IF grant and runs from 2020-2022

Figure 1: Selective sampling of *Juniperus communis* L. in Nuuk, Greenland. Photo: Angela L. Prendin, BIOCHANGE.

BIORATES:
RATES OF BIODIVERSITY CHANGE DUE TO HUMAN INDUCED GLOBAL ENVIRONMENTAL SHIFTS

1 2

Principal investigator: Alejandro Ordonez Gloria

Earth's environmental and biological setup is changing due to human activities, a transformation that is leaving lasting impacts on biodiversity. These changes are often described in terms of accelerated species extinctions and shifts in species' geographical ranges. Consequently, conservation efforts have focused on species at risk (endangered) instead of considering variations in species assemblage composition. BIORATES aims to define how much change we can expect in biodiversity composition and interaction structure due to the current ongoing transformation of the biosphere. Using trees as a study system, BIORATES evaluates how much β-diversity (variation in composition) changes in space in three different ecological dimensions (species, functional traits, and phylogenetic relations; Fig. 1), and the role of present and past climate as a driver of these changes. BIORATES also assesses how the association networks between individuals within the same trophic level would change as a consequence of climatically driven non-random extinctions. This project contributes to theme [1] Fundamental Biodiversity Dynamics and theme [2] Global Challenges of BIOCHANGE.

KEY PAPERS

Fricke, E.C., **Ordonez, A.**, Rogers, H. S., & **Svenning, J.C**. 2022. The effects of defaunation on plants' capacity to track climate change. *Science* 375:210-214.

Conradi, T., **Van Meerbeek**, **K. Ordonez, A.**, & **Svenning, J.C.** 2020. Biogeographic historical legacies in the net primary productivity of Northern Hemisphere forests. *Ecology Letters* 23:800-810.

Ordonez, A. 2020. Points of view matter when assessing biodiversity vulnerability to environmental changes. *Global Change Biology* 26:2734-2736.

The project is funded by the Aarhus University Research Foundation with 1,900,000 DKK and runs from 2018-2022. It is currently employing one PhD student.

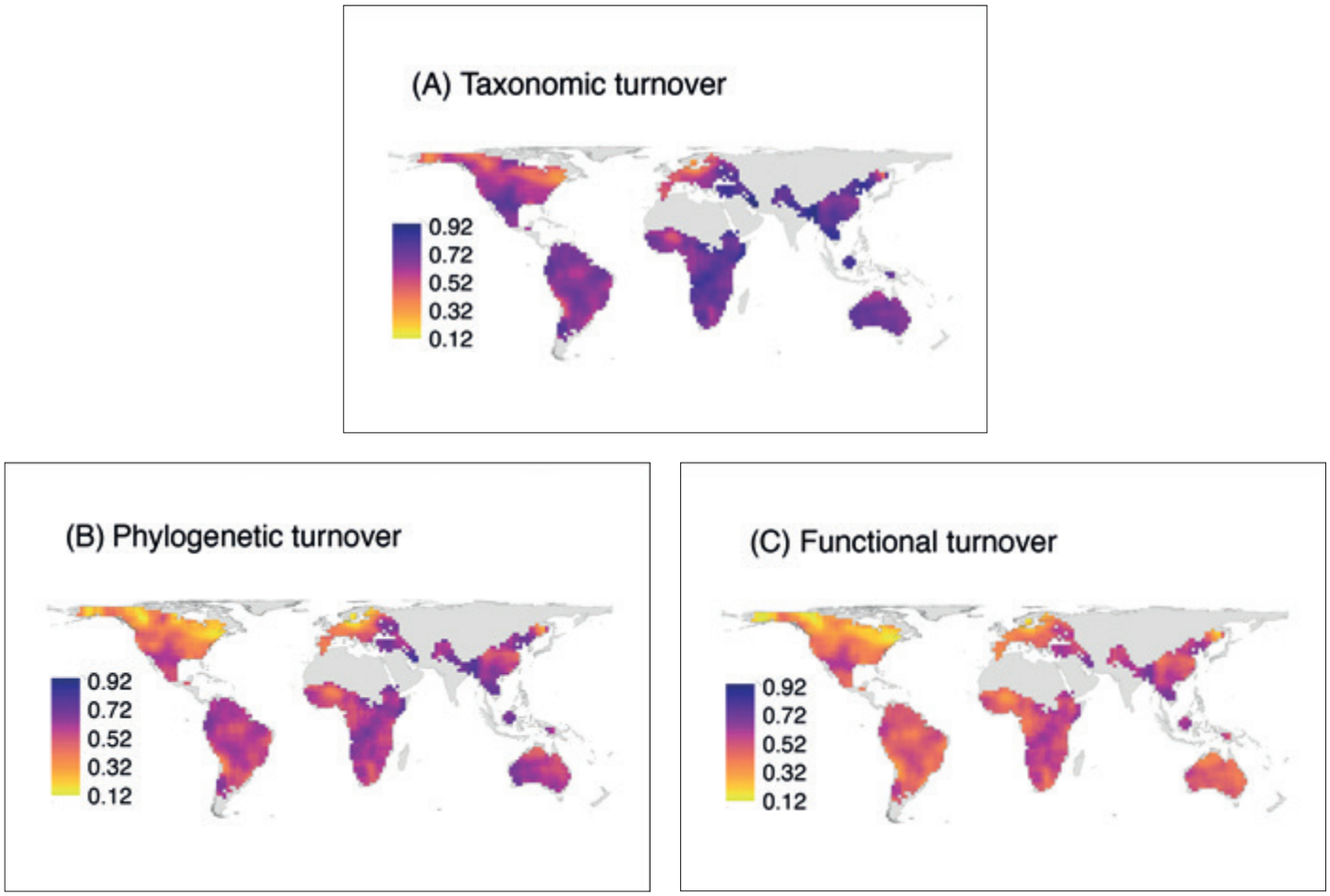


Figure 1. Global patterns of taxonomic (A), phylogenetic (B), and functional (C) turnover of angiosperm trees. Figure: Wubing Xu, BIOCHANGE.

MEGAHERBIVORES' FUNCTION IN EARTH SYSTEM PROCESSES:

1 2

Moving carbon from flammable to inflammable pools

Principal Investigator: Elizabeth le Roux

Grazing animals have the capacity to change fire dynamics by lowering fuel loads. Essentially, grazing animals and fire compete for the same resource. The larger the grazing animal, the better it can compete with fire because large animals consume more grass biomass and lower quality grass (lower quality grass is often also more flammable).

It has also been suggested that grazing may enhance belowground carbon build-up through an accumulation of root material. However, it is still uncertain which factors control these long-term effects of grazing on belowground biomass. One pattern that has been identified is that C4 grasslands (such as those occurring in tropical and subtropical savannas) seem to be accumulating soil carbon under the impact of grazing, whereas C3 grasslands do not. Yet the mechanisms responsible for this pattern are unknown.

African savannas are understudied in this regard, despite being one of the last remaining ecosystems that retain high densities of mega grazing mammals such as white rhino and hippopotamus. These mega grazers could be hugely influential agents, and studying these systems could provide mechanistic insights into how and when grazing stimulates belowground growth. To investigate these questions, we turned to a South African savanna system called Hluhluwe-iMfolozi Park. This protected area and its surrounds offer convenient contrasts in grazing history and intensity, among which we can investigate the differences in the aboveground to belowground ratios of the grass layer. The reserve is one of the only places where the white rhino did not go locally extinct and has housed high densities of rhinos for at least the past 70 years. This contrasts with the surrounding grasslands, where cattle are the largest (and often only) grazing animals. A third contrast is provided by a recent expansion of the protected area allowing access to white rhinos and other wild grazing mammals to a region which, up until four years ago, had been only grazed by cattle.

Using this natural experiment, we are currently quantifying the differences in grassland structure and species composition among these three contrasts. We are measuring long-term species compositional shifts and whether grass species that dominate in the mega grazer-dominated grasslands have larger root structures. We will also experimentally look at the direct effects of simulated grazing on the allocation of carbon to root growth in individual plants.

This project contributes to theme [1] Fundamental Biodiversity Dynamics and theme [2] Global Challenges.

Root box or rhizotron used to study the development of root structure of dominant grass species in mega grazer-dominated grasslands.
Photo: Célesté Maré, BIOCHANGE.

The project is funded by the Aarhus University Research Foundation with 2,100,000 DKK and runs from 2021-2025. The project employs one PhD student

Grazing animals – Impala and Blue Wildebeest on a grazing lawn in the Hluhluwe-iMfolozi Park, South Africa
Photo: Célesté Maré, BIOCHANGE.

THE CHEMICAL LANDSCAPES OF DANISH REWILDED ECOSYSTEMS

1 2

Principal Investigator: Elizabeth le Roux

Nutrient dynamics is a pivotal part to ecosystem functioning and amongst the most highly valued ecosystem services. Nutrient and elemental availability is essential for plant growth and thus supports the growth and development of all heterotrophic organisms that rely on plants as food source.

In highly human modified landscapes, where animal impact is minimal, nutrient distributions are determined by abiotic and anthropogenically influenced processes such as agricultural runoff and atmospheric deposition. These anthropogenically driven impacts often occur at large scales and may lead to elevated and relatively even distribution of nutrients. Moreover, in landscapes with agricultural histories, practices such as tilling would further have homogenized nutrient distributions.

In this project, we aim to evaluate the extent to which trophic rewilding reshapes these nutrient landscapes. Large animals consume, transport and redistribute nutrients and mineral elements across landscapes. Because animals are selective in where they eat, what they eat, and where they walk and rest (and thus defecate), they have the capacity to change the distribution of elements, change where elements accumulate and where they become depleted, and change the ratios in which elements occur in the landscape.

In this project, we will investigate the possible reconnection between the trophic impact of large animals and the fine-scale nutrient landscape in Danish rewilding sites. We will assess whether animals are able to recreate fine-scale patterning in elemental landscapes and diversify elemental geographies. We also plan to evaluate whether such changes in elemental landscapes lead to changes in plant species diversity and community composition.
Since nutrients are fundamental to the structure and function of ecosystems and underpin all biological systems, developing an understanding of how trophic rewilding could shape elemental landscapes may be the most straightforward way to track the impact of trophic rewilding across multiple trophic levels and across different ecosystems.

This project contributes to theme [1] Fundamental Biodiversity Dynamics and theme [2] Global Challenges.

This project is funded by the Inge Lehman program by the Independent Research Foundation Denmark with 2,879,548 DKK and runs from 2022-2024. The project will employ one Postdoc between 2023-2024.



Galloway cattle, Exmoor pony, and Roe deer dung at Geding-Kasted Mose, Denmark. Photos: Elizabeth Le Roux, BIOCHANGE.

Exmoor ponies at Geding-Kasted Mose rewilding site in December 2020. Photo: Anne Blach Overgaard, BIOCHANGE.

WildSoil:
REWILDING AS A TOOL FOR SOIL CARBON CAPTURE

2

Co-Principal Investigator: Elizabeth le Roux

The ways in which large animals impact ecosystems can influence the climate in many ways. Thus, the conservation and restoration of large animal communities could potentially form part of climate mitigation strategies.

One of the mechanisms through which animals may impact climate is through their influence on soil carbon stocks. However, this impact varies greatly between different biomes and over different timescales. There are several mechanisms through which animal impact may facilitate the build-up of soil carbon over the long-term. For example, soil carbon may accumulate when animals enhance nutrient availability or feed selectively on good quality vegetation, leaving behind the vegetation that is lower in quality and slower to decompose. Animals may also shift plant community composition to grazing-tolerant species that may allocate more carbon to belowground storage organs to be able to compensate for the feeding damage caused by the herbivores.

In WildSoil, we will assess whether the restoration of large animals within Danish rewilding sites contributes to soil carbon capture and greenhouse gas mitigation. This project will combine controlled experimental work, aimed at exploring the mechanisms through which animals impact soil carbon dynamics and greenhouse gas release, with larger-scale ecosystem-level monitoring of soil properties. This information will eventually be integrated into mechanistic models to predict, at climate-relevant timescales (decades), how animal impact would alter soil carbon and greenhouse gas dynamics. The outcome of this project will help to highlight when and how ecosystem restoration efforts could achieve positive synergy with climate mitigation goals.

This project contributes to BIOCHANGE theme **[2]** Global Challenges.

This project is funded by the Independent Research Foundation Denmark to Principal Investigator Lars Vesterdal at Copenhagen University with 3,329,369 DKK allocated to Aarhus University. The project runs from 2022-2026 and will employ one postdoc between 2024-2026.

Trampling effects at the rewilding site in the foreground vs. crop field in the background. Geding-Kasted Mose, Denmark. Photo: Elizabeth Le Roux, BIOCHANGE.

Trampled soil at Geding-Kasted Mose, Denmark. Photo: Elizabeth le Roux, BIOCHANGE.

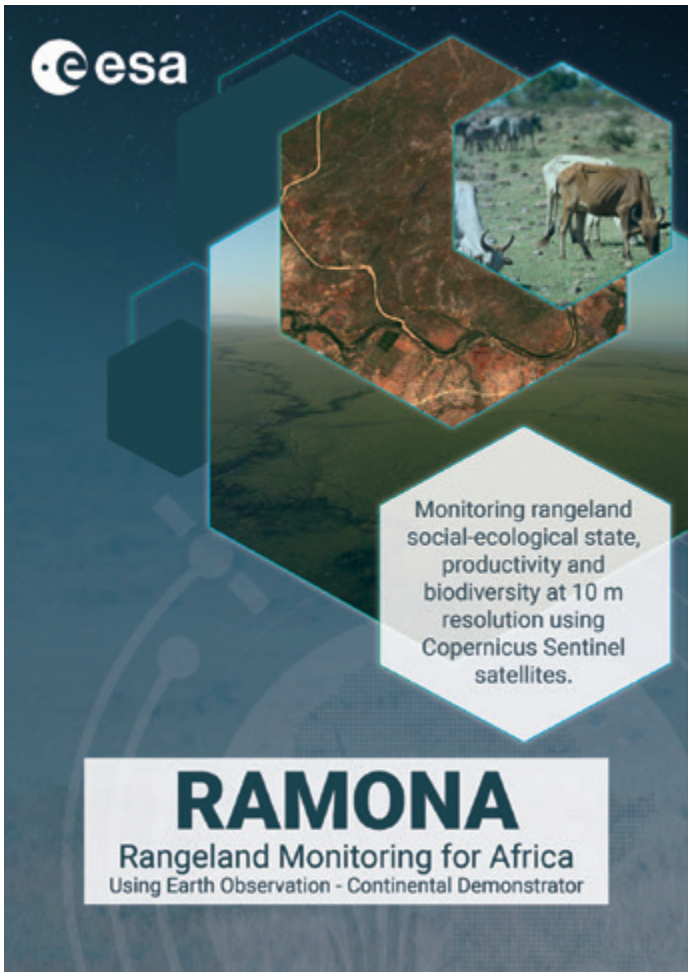
RAMONA:
RANGELAND MONITORING IN AFRICA USING EARTH OBSERVATION – CONTINENTAL DEMONSTRATOR

2 3

Principal Investigator: Robert Buitenwerf

The primary objective of the RAMONA project is to develop and implement a prototype Earth observation based rangeland monitoring system at a continental scale for Africa.

Sub-Saharan rangelands alone are inhabited by 348 million people amounting to >40% of the total population in 2015. Rangelands are thus a crucial resource for livelihoods in Africa. We broadly define rangelands as all vegetated land that is not cropped or closed-canopy forest, including areas used for livestock production, wildlife conservation, and alternative land uses. The increased capacity that RAMONA will provide in evaluating and responding to spatiotemporal fluctuations in forage biomass availability and quality will therefore aid livelihood decisions and strategies and thus human wellbeing. Similarly, it will help conservation managers and organizations to anticipate and respond to impacts from environmental shocks such as drought and the effects of long-term environmental and ecological changes, e.g., the ongoing thickening of woody vegetation at the cost of grass-based resources.



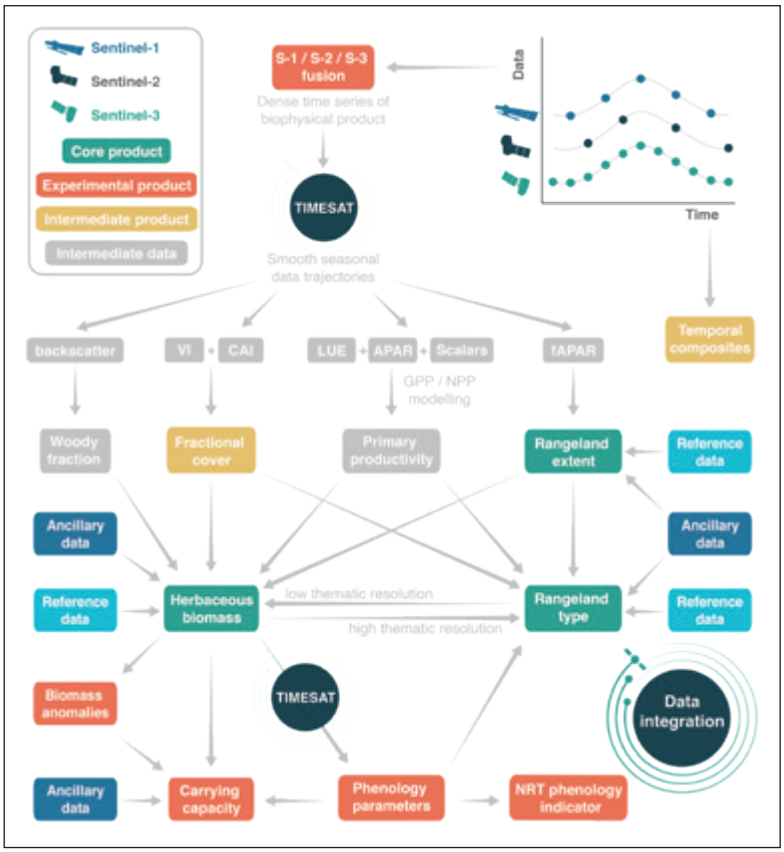
A functional and effective monitoring system should provide timely and reliable information on key rangeland variables in a form that is accessible and interpretable to users. In RAMONA, we, therefore, harness the combined power of Europe's Sentinel satellites (1, 2, and 3) to produce knowledge and high-resolution maps (10 m) on the extent and type of rangeland, herbaceous biomass, vegetation phenology, and the performance of rangeland ecosystems, defined as the juxtaposition of ecosystem integrity and human-consumable productivity in terms of livestock, tourism revenue, etc.

The project consortium consists of Aarhus University and Lund University as well as remote sensing companies, DHI in Denmark and GeoVille in Austria.

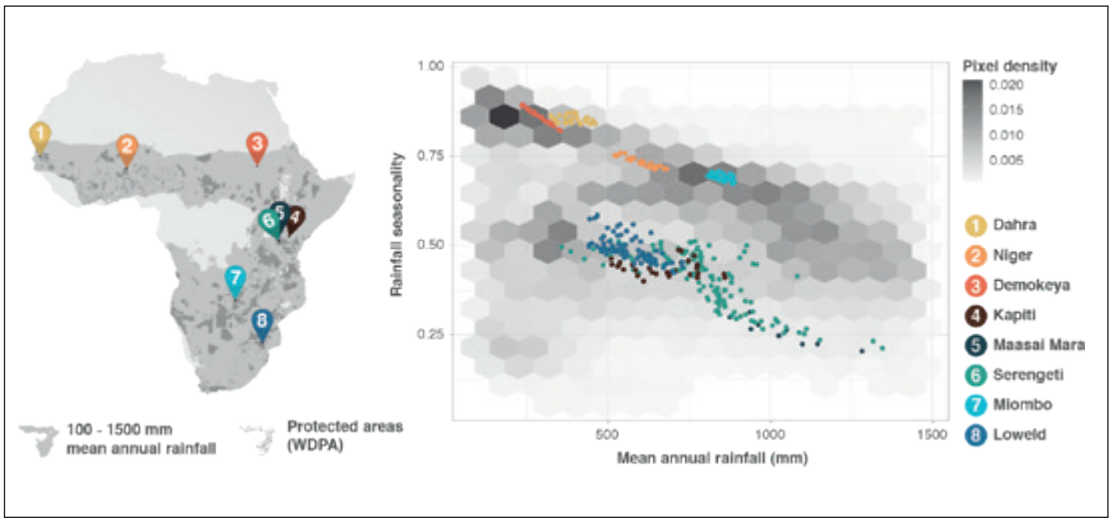
This project links to BIOCHANGE theme [2] Global Challenges and theme [3] Ecoinformatics and New Technologies.

This project is funded by the European Space Agency (ESA) with 1.2 million EUR and runs from 2022-2023.
The project will employ two postdocs.

RAMONA core and experiment products. Dependencies are shown with arrows.
Image: Michael Munk, DHI.



Location of proposed pilot areas along the major bioclimatic and land-use gradients.
Pilot areas were selected to: 1) cover the major bioclimatic and land-use gradients, 2) well-established relations to local stakeholders and in-situ data and 3) geographic spread.
The map shows pilot areas on top of the potential rangeland distribution (100 - 1500 mm annual rainfall) in medium grey, and protected areas in dark grey (source: WDPA).
Bioclimatic graph with coverage of selected pilot sites.
Image: Michael Munk, DHI.



OMRH:
ONE MARA RESEARCH HUB

1 2 4

Advisory Council: Robert Buitenwerf

The mission of the One Mara Research Hub is to strengthen and enhance conservation efforts across the Greater Mara Ecosystem (GME) by creating opportunities, mechanisms, and systems for coordination and collaboration of researchers, scientists, and relevant stakeholders. We aim to further or leverage this collaboration, influence policymakers at the conservancy, local government, and national government levels, and to influence donors on funding decisions.

OMRH objectives are:
- To facilitate multi-lateral information exchange and foster positive collaborations with respect to research and conservation in the Greater Mara Ecosystem
- To promote and strengthen evidence-based decision making
- To promote collaboration and connect groups, policy & research, and conservation activities
- To provide stakeholders with one voice/direction with respect to research outputs

The initiative was founded in 2019 as a response to the urgent need for better coordination of research activities in the Mara, especially around the communication of research findings to local, regional, and national governments and organizations that hold decision power over land and resource management in the Mara. OMRH is a growing partnership, currently including representatives from 16 Kenyan and international organizations.

This initiative links to theme [2] Global Challenges and theme [4] Interdisciplinary Innovations of BIOCHANGE.

Further reading: https://onemararesearchhub.org

Photo: Michael Munk, BIOCHANGE.

MMSDI:
MAASAI MARA SCIENCE AND DEVELOPMENT INITIATIVE

1 2 4

Maasai Mara
Science and Development Initiative

Chair: Jens-Christian Svenning

The Greater Mara Ecosystem in Kenya is facing a multitude of interconnected, complex challenges, which can be divided into four main categories: (1) land use and climate challenges, (2) ecosystem challenges, (3) political and economic challenges, and (4) human and cultural challenges. The Maasai Mara Science and Development Initiative (MMSDI) is an African-European cooperation between the University of Nairobi, Aarhus University, Kenya Wildlife Trust, Karen Blixen Camp Trust, and the local Mararianta Community in Maasai Mara, Kenya, initiated to address these challenges through interdisciplinary research and development activities. Therefore, the MMSDI operates as a multi-stakeholder platform with representatives from academia, businesses, organizations, and local citizens as members of the core structure of the initiative. The overall aim of the partnership is to develop initiatives with a clear goal: to contribute to conserving the Greater Mara ecosystem with its rich wildlife and culture through interdisciplinary research and development initiatives. It is the hope that intense knowledge exchange with the many stakeholders of the Maasai Mara will give valuable input to the research about core challenges and research questions and provide data for the research projects. In return, research outputs can support decision-makers in developing sustainable solutions.

The initiative was founded in 2014 as a response to the urgent need for action in the area. It is funded by the individual members conducting research in the area supported by the Karen Blixen Camp in Mara North. Center director Jens-Christian Svenning is chair of MMSDI, and several members of BIOCHANGE are involved in the initiative. This project contributes to theme [1] Fundamental Biodiversity Dynamics, theme [2] Global Challenges, and theme [4] Interdisciplinary Innovations of BIOCHANGE.

Further reading: mgmt.au.dk/maasaimarascience

KEY PAPERS

Li, W., Buitenwerf, R., Munk, M., Bøcher, P.K., & **Svenning, J.-C.** 2020. Deep-learning based high-resolution mapping shows woody vegetation densification in Greater Maasai Mara Ecosystem. *Remote Sensing of Environment* 247:111953.

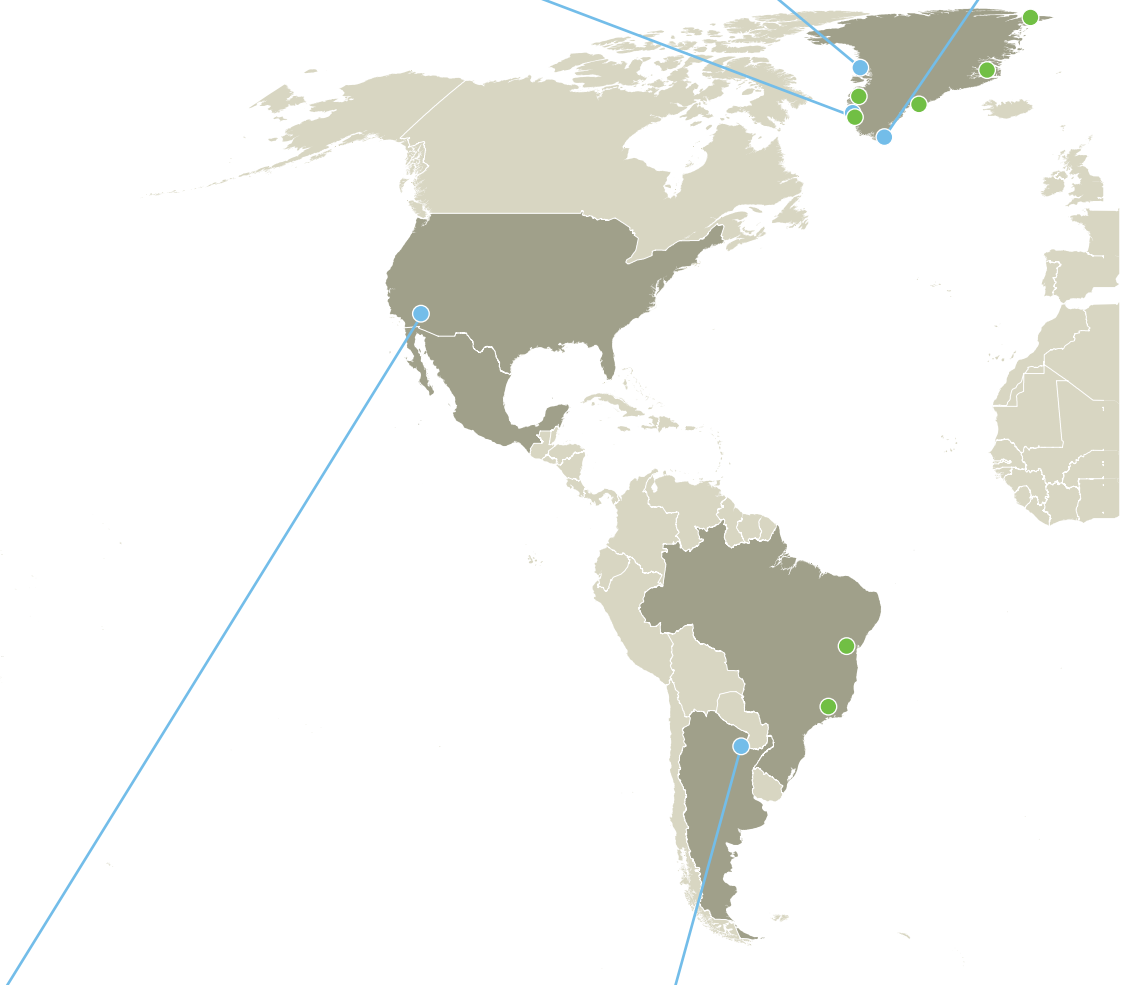
Li, W., Buitenwerf, R., & **Svenning, J.-C.** 2020. Accelerating savanna degradation threatens the Maasai Mara socio-ecological system. *Global Environmental Change* 60:102030.

Løvschal, M., **Bøcher, P.K.**, Pilgaard, J., Amoke, I., Odingo, A., Thuo, A., & **Svenning, J.-C.** 2017. Fencing bodes a rapid collapse of the unique Greater Mara ecosystem. *Scientific Reports* 7:41450.

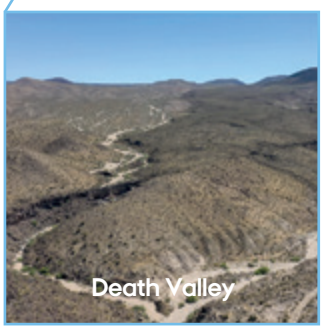
FIELD CAMPAIGNS

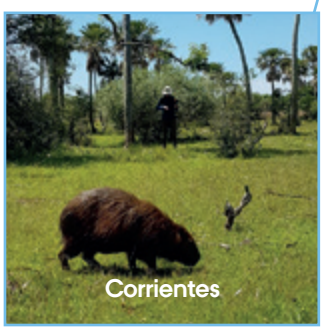
BIOCHANGE FIELD SITES

ON THE FOLLOWING PAGES, WE DESCRIBE A SELECT OF CURRENT FIELD CAMPAIGNS CONDUCTED IN 2020-2021.

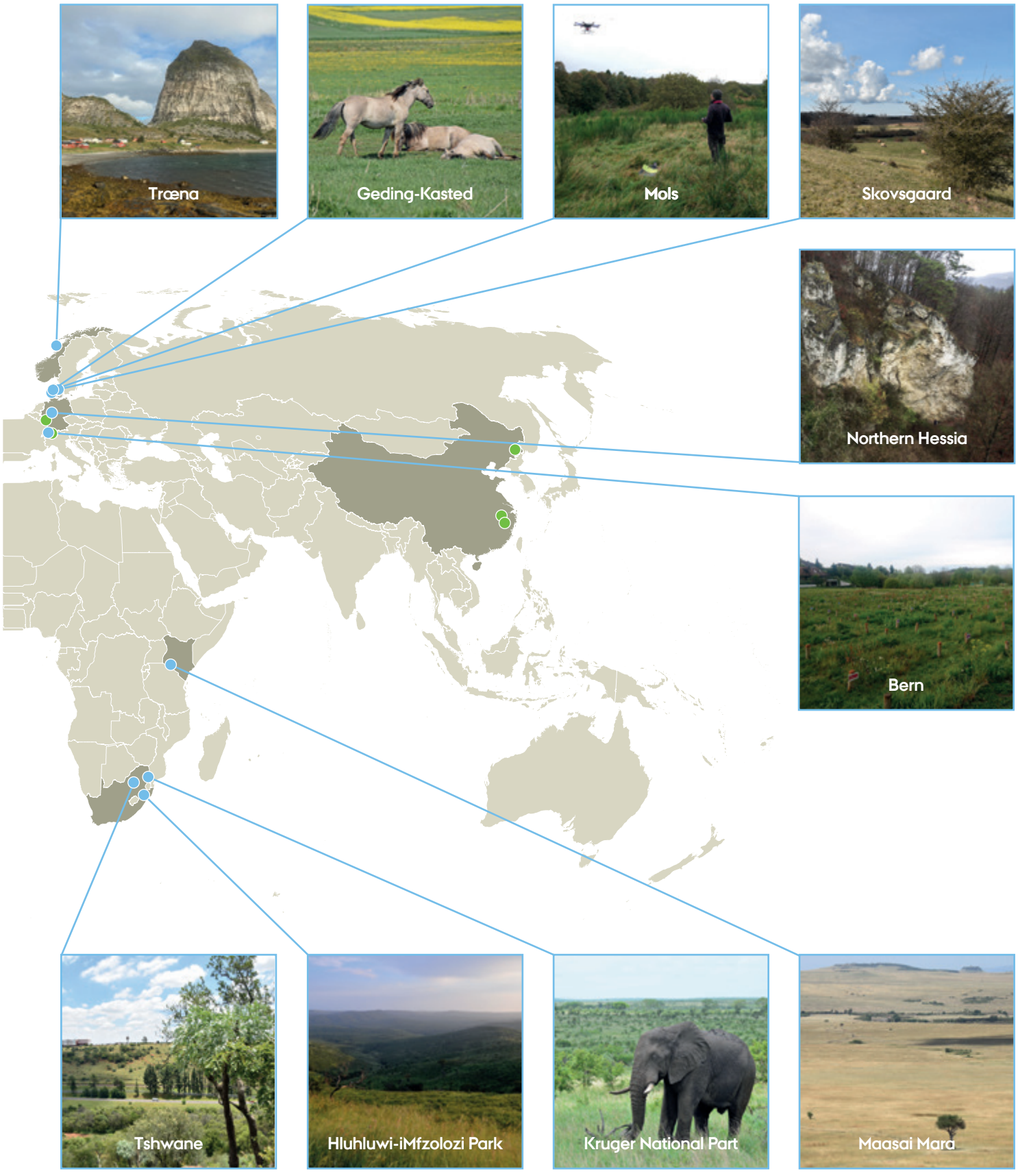


Map of the distribution of current (●) and past (●) field sites across the World. BIOCHANGE conducts research in many parts of the World spanning the Arctic to the Tropics.





Insert photos by:
Bjarke Madsen
Erick Lundgren
Urs Treier
Simon Schowanek
Florian Rudolf Sauer
Anne Blach Overgaard
Felix Riede
Jens-Christian Svenning,
BIOCHANGE


Trœna
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Skovsgaard
Northern Hessia
Bern
Tshwane
Hluhluwi-iMfzolozi Park
Kruger National Part
Maasai Mara

MAASAI MARA – A WORLD-FAMOUS NATURAL HERITAGE SITE UNDER PRESSURE

MAASAI MARA, KENYA

The Maasai Mara in Kenya is one of the World's most famous natural areas due to its rich savanna wildlife including its million-plus migration of wildebeests, zebras and gazelles. However, the Mara savanna ecosystem is under increasing pressure. Wildlife numbers are declining, and local pastoralist populations are strongly growing and undergoing great societal changes. The traditional pastoral lifestyle is changing, livestock numbers are increasing, and private land plots are increasingly fenced, hindering the movement of larger animals competing with increasing numbers of livestock.

Our research aim is to better understand the Mara socio-ecological dynamics. This includes the roles of its wild megafauna and the Maasai and their livestock in shaping biodiversity, ecosystem structure, processes, and services, such as fire spread, carbon sequestration, erosion control, and the availability and quality of grass. It is our goal to provide a scientific basis for sustainable management of this key natural heritage site.

As described in our previous report, just before the COVID-19 pandemic hit (January-March 2020), we collected information across the Maasai Mara on how willing Maasais were to live with elephants, rhinos, and their attitude towards conservation and the conservancies in particular. As the pandemic had a high impact on the communities and their income from tourism, it became very important to repeat this measurement to see if these results would severely change. Therefore, with strong efforts on both our and our Masaai collaborators side, we repeated the survey (following local regulations and safety measures) and added questions on the impact of COVID-19 on people's lives and their perspective towards conservation and the conservancies. Interestingly, we found that while people's general attitudes did not change overall, those involved in tourism and (usually) receiving benefits from tourism increased their willingness to coexist with elephants compared to those that did not.

Once COVID-19 travel restrictions lifted, we revisited Maasai Mara to continue our fieldwork on human-wildlife coexistence. During this visit the focus was on strengthening ties with local NGOs, Maasai collaborators, tourism companies, conservancies management and government bodies, but also starting up a new line of research in Maasai pastoral and agricultural decision-making that influences (wildlife) conservation. For this purpose, a pilot was conducted, translating ethnographic interview protocols, and conducting around 40 interviews to construct ethnographic decision models on these topics. Interviewers were also trained in the methods behind conducting these interviews, and during the following three months four interviewers collected 160 interviews across the Mara conservancies that allowed testing the ethnographic decision models.

Besides these surveys, we also managed to across the Maasai Mara to organise research dissemination meetings for the different communities our interviewers visited. For this purpose, we created a plain English summary with figures, tailored to information based on the conservancies, and trained our interviewers to organize dissemination meetings and explain (in Maa) the information from the booklet. We also asked them to report on feedback from those attending or report what questions they were asked by participants.

In late 2020, we also had two MSc students in the area, studying landscape use by the region's various large-herbivore species, notably in relation to the livestock management in the area. This is part of a long-term effort to understand the trade-offs and synergies between livestock and the wild fauna in this shared landscape. We see Maasai Mara as an interesting model for human-megafauna coexistence in a world with a rising human population.

Purity Take, David Noosaron, and Susanne Vogel (now BIOCHANGE alumna) from BIOCHANGE, who train and lead the interview team together.
Photo: Jonathan Noosaron.

Maasai cattle herders participating in the Living with elephants focus group game, led by Purity Take, Susanne Vogel, David Noosaron, and Jonathan Noosaron. Photo: Susanne Vogel, BIOCHANGE.

Purity Take, David Noosaron, and Susanne Vogel from BIOCHANGE , who train and lead the interview team together.
Photo: Jonathan Noosaron.

TROPHIC REWILDING IN THE GLOBAL SOUTH

CORRIENTES, ARGENTINA

In this project, we study megafauna effects on vegetation – including as part of trophic rewilding – in a key understudied biome, namely the South American subtropical savanna region. South America formerly harbored a very rich megafauna but was depleted of most of it as humans colonized the continent at the end of the Pleistocene (± 12,000 years ago), with further losses continuing up through history to the present day. Surviving species persist only at low densities, often in small refugia or on unproductive land. The loss of megafauna resulted in the loss of ecological functions. However, the large-scale ecological consequences of losing most of the megafauna remain understudied as do potential recovery through trophic rewilding, hampering planning, restoration, and management toward a biodiverse future.

Figure 1: Field site in Rincon del Socorro. Photo: Julia C. Mata, BIOCHANGE.

Our field site, Rincon del Socorro (Fig. 1) is a reserve that was recently donated to National Parks of Argentina (proyectoibera.org/en). It has an active rewilding program where locally extinct species such as jaguar, pampas deer, and collared peccary are reintroduced, while non-extirpated megafauna species such as capybara and marsh deer have recovered to high abundances due to strong protection. To assess impacts of megafauna, we characterize vegetation structure and biodiversity using remote sensing and traditional vegetation plots and we study herbivore diet by genetic barcodes of plant DNA from dung collected in the field. We established an experiment in May 2018 where we measure herbivore impact on vegetation by excluding megafauna such as capybaras from small, fenced areas (Fig. 2) and set up camera traps to assess which species visit these plots (Fig. 3). In October 2019, a field expedition collected data for the third re-measurement of the herbivore exclosures. The data show a clear effect of capybara grazing for short and medium-tall grasslands, as vegetation inside the exclosure plots was significantly taller and had more biomass than outside the plots, where capybaras graze the vegetation short. Through this experiment we showed that species richness decreased the longer herbivores were excluded from the plots. Furthermore, we found a shift in species composition, where control plots became more dissimilar from fenced plots through time. To gain a better understanding of how different herbivore species affect the vegetation, we quantify diet composition using DNA meta-barcoding on fecal material from all major herbivores in the system. We have extracted the DNA of 580 fecal samples and 34 plant samples collected in the 2018 fieldtrips, and we analysed them in the lab during 2019 and 2020. In this study we found that reintroduced native herbivore species expanded the dietary breath of the site, whereas the non-native species diets did not.

After an extended absence from our fieldsites in Argentina during 2020 and 2021 due to Covid-19 lockdowns, we will return in 2022 for two field campaigns in April and October. We will replace the fences from our herbivore exclosure experiment, as these were damaged in recent wildfires, and continue collecting data on herbivore impact on vegetation structure and composition within our experiment as well as record the effects of the wildfire on vegetation.

Figure 2: Exclosure plot set up in 2018 to measure the impact of herbivores on the vegetation. Photo: Julia C. Mata, BIOCHANGE.

Figure 3: Capybaras captured in one of the many camera traps set up in the field site. Photo. Julia C. Mata, BIOCHANGE.

GREEN INFRASTRUCTURE - CITY OF TSHWANE

TSHWANE (PRETORIA), SOUTH AFRICA

Our two study sites in the City of Tshwane are Atteridgeville, a township area experiencing backlogs in terms of basic infrastructure and green infrastructure, exacerbated by rapid inward migration and uncontrolled urbanization, and Mabopane, a peri-urban area with a scarcity of well-developed mixed-use, recreational spaces and green infrastructure. Both sites have high green space development potential, and the wetlands on the river have great ecological value. Unfortunately, the areas face massive green infrastructure challenges, including hydrological impacts associated with urbanization, new formal and informal settlements encroaching into open green space, illegal waste dumping, sewer and stormwater pollution, and lack of maintenance and safety.

In the first year of the GRIP project, two fieldwork campaigns have been jointly conducted with the University of Pretoria (researchers and students) and private partners.

In the residential zones bordering the green space, a community survey with 100 residents at each site has been conducted, capturing – among other aspects – people's spatial practices, perceived benefits and risks, community engagement, decision making, values and wellbeing, social identity, and sense of belonging. All tied to the green space. Within the study sites, linear transects for each 200m (40 in total) have been used to register and spatially map ecological, social and climate change adaptation benefits and safety, pollution, and degradation challenges (Fig. 1 & 2). A design studio and four Master students from University of Pretoria have worked on the sites, as have four Danish MSc students investigating informal settlement, ownership, access, and justice at deeper levels. Supported by an additional grant from the Danish Ministry of Foreign Affairs, two students are running a "photo-voice" research project in Mabopane, engaging the local community in photography workshops, walks inside and along the edges of the green space, and focus group discussions on photos taken during these walks. This all culminated in a public outdoor exhibition of posters with photos taken by the community reflecting how the "see" and feel their green space (Fig. 3).

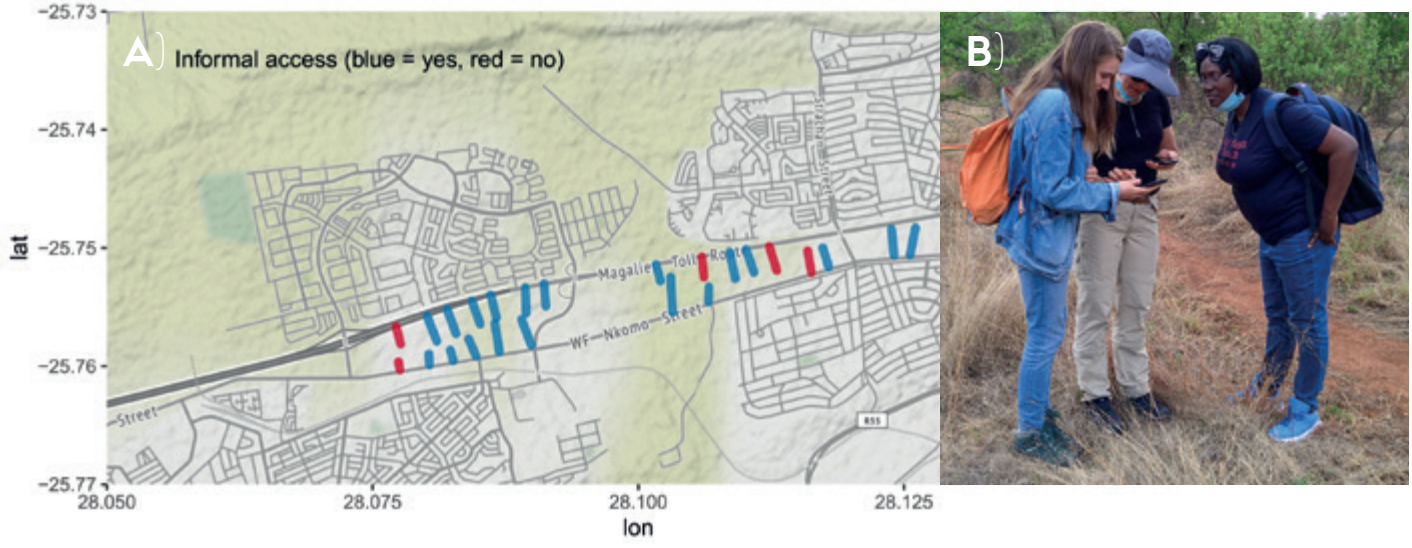


Figure 1: A) Map of ecological transects for the Atteridgevile study site and the resulting mapping of informal access. Map: Kristine Engemann, BIOCHANGE. B) Piloting the transects through joint fieldwork with GRIP researchers. Photo Maya Pasgaard, BIOCHANGE

Figure 2: Investigating a heavily polluted stream at the Mabopane study site together with private partners (Habitat Architects [South Africa], NIRAS [Denmark]), and students from both countries. An upstream sewage leak into the freshwater stream limits the local use of the water source for fishing, swimming (after heavy rain), and spiritual cleansing. Photo: Maya Pasgaard, BIOCHANGE.

Figure 3: University of Copenhagen and University of Pretoria researchers present the fundamentals of photography to the first 'My Mabopane' photo-voice participants at Odi Stadium. These fundamental are aimed to inspire participants to make photographs which communicate both what they value and find problematic in the space they use to work out in every Friday. Photo: Maria Heines, BIOCHANGE.

TROPHIC REWILDING IN DENMARK

BIOCHANGE studies the ecological dynamics in multiple trophic rewilding projects in Denmark, here Skovsgaard on Langeland (left) and Geding-Kasted Mose at the outskirts of Aarhus (right). Photos: Jens-Christian Svenning, BIOCHANGE.

Trophic rewilding is increasingly being implemented in Denmark and across Europe. It is defined as an ecological restoration strategy that uses species introductions to restore top-down trophic interactions and associated trophic cascades to promote self-regulating biodiverse ecosystems. In BIOCHANGE we study the functioning and development of multiple trophic rewilding sites: 1) as experiment-like cases of the ecosystem effects of trophic upgrading (BIOCHANGE research theme [1]) and 2) to improve the scientific evidence-base on the socio-ecological dynamics and outcomes of this promising restoration approach (BIOCHANGE research theme [4]).

One key study site is the Rewilding Mols project in Mols Bjerge National Park in eastern Jutland. The Natural History Museum, Aarhus, started the project in 2016 by introducing feral horses and feral cattle as wild-living populations into the area, a well-known biodiversity-rich site in highly heterogenous terrain and varied, clayed to sandy soils. Since then, the Natural History Museum Aarhus, BIOCHANGE, and other colleagues have studied the impact of trophic rewilding at the site, including running an exclosure experiment, which was designed to study the impact of the large grazers by fencing them out of small areas. The monitoring program focusses on how large herbivores drive changes in ecosystems and how those changes affect resource and habitat availability for other organisms, including plants, insects, and other arthropods. Through the exclosure experiment, changes through time can be linked to the trophic and non-trophic effects of large herbivores. In the past years, the site has been studied through many BSc, MSc, and PhD projects and actively used for development and testing of new field methods, including animal monitoring via GPS collars, camera traps for arthropods, and drone-surveys for vegetation data. The drones have been equipped with basic RGB cameras and advanced multispectral and LiDAR sensors, which potentially provide new perspectives in the way we monitor vegetation. We have since 2021 been developing a large analysis of the first years of dynamics at this rewilding site and expect to finalize this work in 2022.

Another focus area is the Geding-Kasted Mose, which is a peri-urban rewilding area on the outskirts of Aarhus, owned and managed by the City of Aarhus, also in eastern Jutland. The area is a mixture of marshland, former improved grasslands used for livestock, and former cropland areas. To prevent the

vegetation from developing into forest, three semi-feral large herbivore species were introduced in 2016, namely cattle, horse, and water buffalo. Since 2017, we have tracked the landscape use and behavior of these animals, to identify areas of high and low usage. Simultaneously, we have conducted studies on the vegetation, to assess its development. Like in the Mols project, many BSc and MSc students have been involved in this work. So far, these studies have shown interesting differences among the three herbivore species in space use and considerable temporal change in the vegetation structure and composition, with an increase in the heterogeneity of vegetation structure, suggesting that the large herbivores are transforming the area from a homogeneous starting point into an increasingly diverse ecosystem. In 2021, the rewilding area was expanded, and a new study objective is to understand how these newly abandoned cropland areas develop under trophic rewilding.

In August 2021, we started a project on third trophic rewilding area in Denmark, namely the manor of Skovsgaard on Langeland in southern Denmark. The site is owned and managed by the Danish Society for Nature Conservation, Denmark's largest nature NGO. In early 2021, rewilding with feral horses and cattle replaced traditional nature management and organic agriculture. The area is adjacent to the coast and covers a strong, but less rugged topographic gradient and richer soils as compared to the Mols Rewilding area. The focus of our field-based study there is to follow the effect of trophic rewilding on plant diversity, vegetation structure, and soil in the years to come. In 2021, we established a network of sample-sites and recorded baseline vegetation diversity and structure as well as collected soil samples and prepared these for analysis. In early 2022, we will monitor the impact of the animals though the winter and continue to monitor the transects as well as establish with 20 herbivore exclosures in the area.

Finally, BIOCHANGE has hosted a joint PhD student (under the so-called Industrial PhD program) with the Danish Nature Agency to improve the evidence base for the 15 "nature national parks", large trophic rewilding areas that are being established on state-owned land across Denmark from 2021 onwards. In 2021, focus of the PhD study was on developing a spatial analysis to inform site selection for the nature national parks, and the result was provided as input to this selection process.

ECOLOGICAL ROLES OF FERAL EQUIDS IN NORTH AMERICAN ECOSYSTEMS

DEATH VALLEY NATIONAL PARK, USA

Human beings have influenced ecosystems for millennia, both by causing extinctions and by introducing species from distant lands. These twin forces of extinction and introduction raise important questions in ecology and conservation, such as the importance of coevolutionary history in ecological communities and how to optimally conserve biodiversity in an age of mass extinction. In the summer of 2021, we returned to fieldwork sites in the deserts of western North America. This landscape is huge, diverse, and provides a perfect laboratory to test these questions. In particular, we focused on the ecologies of introduced feral donkeys and feral horses. These animals, once an essential labor force in expansionist colonial economies, are now the dominant wild herbivore in many landscapes and are considered 'invasive' pests in dominant conservation narratives. However, these animals have ancient precedent: until the arrival of humans, 3–5 species of equid roamed North America. Their extinction was most likely driven by prehistoric human hunting and landscape modification.

We are interested in studying the effects of these animals in the context of Earth's history. In the summer of 2021, we conducted research in Death Valley National Park, a massive, protected area in eastern California. Popular visions of Death Valley include endless wastelands and brutal heat. But rising above the salt streams of the desert plains are snow-capped mountain peaks and canyon upon canyon, each with flowing streams, riparian forests, and geologic marvels. There are also feral donkeys here, an animal the National Park Service considers an 'invasive pest' and in need of eradication. Indeed, their eradication program is well into its 4th year, providing an opportunity to experimentally document the influences of these lost and then returned megafauna.

Over the summer of 2021 we focused on how donkeys influence desert wetlands, critical lifegiving resources and homes to unique plants and animals. These springs can be heavily modified by feral donkeys, who cut trails through vegetation and dig open pools of water. In the absence of feral donkeys, these springs often become dominated by a couple species of competitively dominant plant species, such as giant cane and clonal willows. To document these changes, we spent the summer hiking to every spring we could find in Death Valley, in temperatures breaching 50°C. We conducted vegetation surveys and we measured water quality and availability.

Our preliminary analyses indicate that springs with donkeys have significantly higher vegetation heterogeneity, higher species richness, and dramatic reductions in dead vegetation cover. Moreover, nearly 95% of the springs without donkeys lacked available surface water, with water often buried by up to 2 m of dead vegetation. Finally, we are in the process of analyzing bioacoustic data, to test how these changes in ecosystem structure and water availability affect birds and bats. This research ties into several years of data on how feral donkeys relate to other species and sets the stage for new considerations of the ancient ecologies unfolding in modern ecosystems.

Study area in Death Valley National Park. Wild donkeys appear to play an important role in maintaining open water availability at ecologically important desert wetlands in this hyper arid landscape.
Photos: Erick Lundgren, BIOCHANGE and Michael Alfuso.

OTHER FIELD SITES

NORTHERN HESSIA: ELLERSTEIN AND KUPFERBACH

In the autumn of 2019, we continued our efforts to locate sites with combined archaeological and palaeoecological remains in the northern part of the German Federal State of Hessia. This time around, we targeted the sites of Ellerstein and a small cave along the so-called Kupferbach. At Ellerstein, previous - illegal - excavations had apparently yielded some ceramics and bones but. Sadly, our investigations did not produce significant results. This means back to the digital drawing board! We are recalculating our predictive model using newly obtained high-resolution landscape models. We intersect these with geological maps for the region, allowing us – hopefully – to locate areas in the landscape with shallow caves and the right background rocks to facilitate good preservation.

Photo: Felix Riede, BIOCHANGE.

DEAD-ICE LAKES IN EASTERN JUTLAND AND MICRO-ECOLOGICAL DIFFERENCES UNDER RAPID CLIMATE CHANGE

Just before Christmas 2020, a massive reindeer antler found near Mårslet just outside of Aarhus came to our attention. It was radiocarbon-dated to the early part of the Late Glacial: a period of rapid climate transition from glacial to interglacial conditions around 14.000 years ago. In August 2021, we followed up with a small excavation to collect palaeoecological samples to be analyzed for pollen, volcanic ash, and traces of human activity nearby (e.g., charcoal). Together with a parallel analysis of similar sites from elsewhere in Eastern Jutland, such analyses will allow us to capture micro-ecological differences along a transect from southern to northern Jutland and evaluate contemporaneous ecosystem services and human settlement.

Photo: Felix Riede, BIOCHANGE.

Photo: Felix Riede, BIOCHANGE.

MARINE ENVIRONMENTS, FISHING, AND HUMAN IMPACTS IN NORTHERN NORWAY

Led by colleagues from NIKU North, Felix Riede and his team are re-excavating the magnificent Kirkehelleran- Cathedral Cave - located on the offshore island of Træna in Northern Norway. The excavation includes extensive palaeoecological work, ancient DNA analysis as well as traditional archaeological investigations. The aim is to better understand the changing marine environment, how it was exploited by humans, and how contemporary climate change impacts the preservation of the coupled natural and cultural heritage at this locale.

RESEARCH TRAINING AND EDUCATION

RESEARCH TRAINING

One of the objectives of BIOCHANGE is to be a platform for excellent research training. In collaboration with Section for Ecoinformatics and Biodiversity (ECOINF), Department of Biology and Graduate School of Natural Science (GSNS), BIOCHANGE usually offers advanced research training for PhD students, aimed at those at the center and section, but open to and attended by students from Aarhus University more broadly, as well as from other universities from Denmark and beyond. Due to the Covid-19 pandemic we unfortunately had to cancel our annual PhD course on Megafauna Ecology in 2020 and 2021, but we will resume this course in 2022. Core group member, Felix Riede has run a course in reproducible quantitative research in Archaeology.

BIOCHANGE and ECOINF host weekly journal clubs for all postdocs and PhD students in the group as well as periodical discussion groups on specific research topics organized by assistant professors, postdocs and Core group members of BIOCHANGE. All PhD students are offered to participate in international workshops and conferences and are on research exchange stays abroad at international institutions during their PhD program. BIOCHANGE PhD students are actively involved in BSc and MSc courses at Aarhus University, as teaching assistants, or do other outreach work in special cases.

PHD COURSES

REPRODUCIBLE QUANTITATIVE RESEARCH IN ARCHAEOLOGY. DOING OPEN SCIENCE ARCHAEOLOGY (USING R)
Led by Felix Riede, this course situates itself at the confluence of two trends in archaeology. First, like many Humanities disciplines, archaeology is swept along in a data deluge toward new digital shores. Second, a reproducibility crisis is looming, with many disciplines losing credibility because results of studies cannot, or only with great difficulties, be reproduced. Many funders, including the ERC, are beginning to take rigorous stances on issues of Open Science, a term that effectively encapsulates the notion of methodological and empirical transparency. Not least because of archaeology's disciplinary background and grounding in and recruitment from the Humanities, these trends amount to a double challenge: We must become better able to handle small and large data volumes – be they counts, frequencies, measurements, dates, or coordinates – and we must conduct and present our research in findable, accessible, interoperable, and reusable (FAIR: www.go-fair.org/fair-principles/) ways.

JOURNAL CLUB

BIOCHANGE hosts a weekly journal club jointly with ECOINF. The journal club is open to all ECOINF & BIOCHANGE postdocs and PhD students (including visitors). The journal club is led by Jens-Christian Svenning jointly with 1-3 early-career scientists, which circulates among group members. Each person takes a turn presenting an important, exciting or thought-provoking recent paper (preferably published in the last two months of a meeting) from his or her field (in a broad sense). The aims of the journal club are to create an active and stimulating environment in which ideas and methods are discussed, as well to improve communication skills and critical sense towards scientific works, and to broadening the attendants' perspective on different topics beyond their specific field of study. General thematic areas covered are: Ecology/Conservation/Restoration/Remote sensing/Geography/Human ecology. In the journal club, we aim to create interactive discussions about the papers from the different points of view of all the participants. The group discusses the scientific value of the paper, methodological procedures, impact on its specific field, and implication for the projects of the group.

Photo: Dennis Pedersen, BIOCHANGE

METHOD WORKSHOPS

At BIOCHANGE (jointly with ECOINF), we have a tradition of organizing method workshops open to all interested in our group. It is taught by BIOCHANGE PhD students and postdocs to promote knowledge and skills sharing. The past year, these workshops were held online due to covid. However, with the organization of PhD student Erik Kusch, this new format opened the possibility for international researchers to facilitate the workshops. In 2020/21, we had workshops on:

- *Online biodiversity resources* facilitated by Dr. Sophie Monsarrat (BIOCHANGE)
- *Building phylogenetic trees* facilitated by Dr. Fenjuan Rose Schmidt Hu (AU, Denmark)
- *KrigR – Downscaling State-of-the-Art Climate Data for Macroecologists* facilitated by Erik Kusch and Dr. Richard Davy (Nansen Environmental and Remote Sensing Center, Norway)
- *Effective Communication of Scientific Innovation* facilitated by Prof. Karin Pittman (University of Bergen, Norway)
- *Demographic Resilience* facilitated by Associate Prof. Rob Salguero-Gómez (University of Oxford, United Kingdom).

DISCUSSION GROUPS

Different weekly or bi-weekly discussion groups, led by BIOCHANGE core group leaders, assistant professors or postdocs and open to all in the group, have covered the following overall topics in the past year:

- Megafauna
- Remote sensing
- Socio-ecological systems

EDUCATIONAL ACTIVITIES

Photo: Anne Blach Overgaard, BIOCHANGE

BSC AND MSC COURSES

The senior members of BIOCHANGE are responsible for and involved in the teaching of several BSc and MSc courses and in the supervision of project-BSc and MSc students.

BSC AND MSC COURSES
Biogeography & Macroecology
(Aarhus University, 10 ECTS)
Climate Change - Cross-disciplinary Challenges and Solutions summer school
(Aarhus University, 5 ECTS)
Cultural-Historical Overview
(Aarhus University, 10 ECTS)
Danish Flora and Vegetation
(Aarhus University, 10 ECTS)
Geographic Information System (GIS)
(Aarhus University, 5 ECTS)
Statistical and Geospatial Modelling
(Aarhus University, 10 ECTS)
Ecology
(Aarhus University, 10 ECTS)
Tropical Ecology
(Aarhus University, 10 ECTS)

BACHELOR STUDENTS

- **Amanda Bjerregaard Krog** (BSc)
  Supervisors: Signe Normand, Candice Power, and Angela Prendin
- **Birgitte Hyldahl Ptak** (BSc)
  Supervisor: Signe Normand
- **Caroline Sophie Jessen** (BSc)
  Supervisor: Alejandro Ordonez
- **Esben Hørby Brandt** (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning
- **Eva Christoffersen** (BSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Jens Holmslykke Rat**h (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning
- **Johanne Meldgaard Petersen** (BSc)
  Supervisor: Signe Normand
- **Josephine Andersen** (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning
- **Lasse Lukas Platz Herskind** (BA)
  Supervisor: Felix Riede
- **Lise Hykkelbjerg** (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning
- **Martin Sloth** (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning
- **Matilde Mikkeline Stoltze** (BSc)
  Supervisor: Signe Normand
- **Niels Baunbæk** (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning

- **Nina Degn** (BSc)
  Supervisor: Signe Normand
- **Pernille Sørensen** (BSc)
  Supervisor: Signe Normand
- **Robert Skak Hansen** (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning
- **Sandy Somenzi** (BSc)
  Supervisor: Robert Buitenwerf
- **Sarah Ladegaard Kyneb** (BSc)
  Supervisors: Robert Buitenwerf + co-supervisor
- **Sean Birk Bek** (BSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Silas Tanderup** (BSc)
  Supervisor: Robert Buitenwerf
- **Simon Jensen** (BSc)
  Supervisors: Signe Normand + co-supervisors
- **Skjold Alsted** Søndergaard (BSc)
  Supervisors: Robert Buitenwerf and Jens-Christian Svenning
- **Sofie Folsach Hellerøe** (BA)
  Supervisor: Felix Riede

Photo: Bjarke Madsen, BIOCHANGE

MASTER STUDENTS

- **Aleksandrina Leonidova Mitseva** (MSc)
  Supervisors: Jens-Christian Svenning and Susanne Vogel
- **Amanda Bjerregaard Krog** (MSc)
  Supervisors: Signe Normand and Angela Prendin
- **Anja Dam Lisby** (MSc)
  Supervisor: Robert Buitenwerf
- **Ask Herrik** (MSc)
  Supervisors: Robert Buitenwerf and
  Jens-Christian Svenning
- **Astrid Holm Andersen** (MSc)
  Supervisors: Signe Normand + co-supervisors
- **Astrid Sahl Andersen** (MSc)
  Supervisor: Signe Normand
- **Astrid Vieth Vad** (MSc)
  Supervisors: Jens-Christian Svenning and
  Robert Buitenwerf
- **Brittany Wooldridge** (MSc)
  Supervisors: Jens-Christian Svenning + co-supervisor
- **Camilla Kjær** (MSc)
  Supervisors: Robert Buitenwerf + co-supervisor
- **Cecilie Kristensen** (MSc)
  Supervisor: Signe Normand
- **Emma Estrup Løw** (MSc)
  Supervisor: Signe Normand
- **Eske Skafsgaard Hjort** (MSc)
  Supervisors: Signe Normand + co-supervisor
- **Helena Johansen** (MSc)
  Supervisors: Jens-Christian Svenning and
  Robert Buitenwerf
- **Henrik Christensen** (MSc)
  Supervisors: Robert Buitenwerf and
  Jens-Christian Svenning
- **Jeppe Therkildsen Mads**en (MSc)
  Supervisors: Wolf Eiserhardt (ECOINF)
  and Signe Normand
- **Joanne Fournier** (MSc)
  Supervisors: Jens-Christian Svenning + co-supervisor
- **Johannes Nybro Udsen** (MSc)
  Supervisors: Signe Normand + co-supervisor
- **Julie Balslev Pristed** (MSc)
  Supervisor: Signe Normand
- **Julie Sander Lehnert** (MSc)
  Supervisors: Signe Normand + co-supervisor
- **Karoline Vibeke Dohrmann** (MSc)
  Supervisor: Jens-Christian Svenning
- **Kathrine Andreasen** (MA)
  Supervisor: Felix Riede
- **Line Larsdatter Andersen** (MSc)
  Supervisor: Signe Normand
- **Line Ochelka** (MSc)
  Supervisors: Jens-Christian Svenning
  and Robert Buitenwerf
- **Malene Kure Otte** (MSc)
  Supervisor: Signe Normand
- **Nikolaj Rauff Poulsen** (MSc)
  Supervisor: Jens-Christian Svenning
- **Nina Maria Lykke Christensen** (MA)
  Supervisor: Felix Riede
- **Pelle Kledal** (MSc)
  Supervisor: Signe Normand
- R**asmus Attrup** (MSc)
  Supervisors: Robert Buitenwerf and Kristine Engemann
- **Rebecca Lyhne** (MSc)
  Supervisors: Jens-Christian Svenning + co-supervisors
- **Sarah le Berre** (MSc)
  Supervisor: Jens-Christian Svenning
- **Sofie Amund Kjeldgaard** (MSc)
  Supervisors: Jens-Christian Svenning + co-supervisors
- **Sofie Lumby Vesterdal** (MSc)
  Supervisors: Jens-Christian Svenning
  and Robert Buitenwerf
- **Ugo Bisson** (MSc)
  Supervisors: Signe Normand, Elena Pearce,
  and Jens-Christian Svenning

COMMUNICATION AND OUTREACH

COMMUNICATION AND OUTREACH

INVITED AND CONTRIBUTED TALKS

AUGUST 2020
David Matzig, Shumon Hussain & Felix Riede: Re-assessing the lithic variability and cultural geography of final palaeolithic and early Mesolithic Europe. European Archaeologists' Association conference, Budapest, Hungary.

Felix Riede & Niels Johannsen: Constructing the niches of/for learning and expertise. The role of play objects and object play in social transmission. European Archaeologists' Association conference, Budapest, Hungary.

SEPTEMBER 2020
Alejandro Ordonez: A Humboldtian perspective to global change Research: connecting biodiversity, environment and society. Humbolt Day.

Felix Riede: After the apocalypse. Videnskaben bag udstillingen. Moesgård Museum, Højbjerg, Denmark.

Jens-Christian Svenning: A macroecological perspective on long-term human ecodynamics – the megafauna case. IMSET Bournemouth University.

Jens-Christian Svenning: Fremtidens Natur. Akadamiet for Talentfulde Unge Øst.

OCTOBER 2020
Felix Riede: Past 'Cultures' at the Macro-Scale. An archaeological perspective on culture and culture change. Cultures at the Macro-Scale: Boundaries, Barriers, and Endogenous Change, Cambridge, UK.

Felix Riede: From communities of practice to networks and cultural phylogenies. Scalar perspectives on cultural evolution in prehistoric hunter-gatherers. Social Networks and Cultural Evolution in Prehistoric Hunter-gatherers, University of Alicante, Spain.

NOVEMBER 2020
Jens-Christian Svenning: Naturens reaktioner på klimaforandringerne. Folkeuniversitetet, Aarhus Universitet.

Jens-Christian Svenning: Macroecological perspectives on plant diversity in a changing world. Swedish Phytogeographical Society Autumn meeting, online.

DECEMBER 2020
Jens-Christian Svenning: Restoring the role of megafauna in European ecosystems. Connecting Rewilding Science and Practice, Wageningen University & Research, Netherlands Institute of Ecology & Rewilding Europe, Wageningen/online.

JANUARY 2021
Felix Riede: After the Apocalypse! The impact of the Laacher See eruption (~13ka BP) on Final Palaeolithic foragers in Europe. Groningen University, Netherlands.

FEBRUARY 2021
Alejandro Ordonez: Rising Novelty in Ecosystems and Climates. EEE seminar series, Latrobe Univeristy, Melbourne.

Felix Riede: After the Apocalypse! Understanding and exhibiting the human impact of the Laacher See volcanic eruption (13,000 cal BP), University of Louvain, Belgium.

Jens-Christian Svenning: Late-Quaternary megafauna extinctions – the onset of human transformation of the biosphere. Max Planck Institute, virtual lecture.

MARCH 2021
Alejandro Ordonez & Felix Riede: Changes in limiting factors of forager population dynamics in Europe between the Last Glacial Maximum and 8ka BP. Cross Disciplinary Approaches to Prehistoric Demography – CROSSDEM, Aarhus, Denmark .

APRIL 2021
Felix Riede: Apocalypse then! Apocalypse now? Using the Laacher See eruption (13ka BP) for Realistic Disaster Scenario design, European Geosciences Union conference, Vienna, Austria*.

Felix Riede: The mandate of the Anthropocene and the collapse of disciplinary boundaries in education, Futures of Education – Learning to Become 2021, Aarhus, Denmark.

MAY 2021
Felix Riede: Roadmaps to resilience. Cultural evolution and the relevance of the past for the future, From past to future: Deep-time patterns of sustainability and resilience in socio-ecological systems, KU Leuven, Belgium.

Jens-Christian Svenning: Rewilding: What are the benefits and drawbacks of bringing back wild nature? Scientists for Extinction Rebellion, online.

JUNE 2021
Elizabeth le Roux: Herbivores' role in shaping the local nutrient environment – The mediating effects of trophic interaction and community complexity. LiveSciences International Lecture Series - Gottingen University.

Elizabeth le Roux: Predator control over nutrient landscapes. Mammal Research Institute, Polish Academy of Science, PhD Summer School.

Elizabeth le Roux: Herbivores' role in shaping the local nutrient environment – The mediating effects of trophic interaction, community complexity and body size. University of Potsdam seminar series.

Jens-Christian Svenning: Rewilding i et internationalt perspektiv. Konference om Naturnationalparker, Danish Ministry of Environment.

JULY 2021
Elizabeth le Roux: Tropical Zoogeochemistry: Alchemists of the wild. Annual Meeting for the Association for Tropical Biology and Conservation.

AUGUST 2021
Jens-Christian Svenning: Integrated macroecological-paleoecological perspectives on large-herbivore effects on ecosystems – implications for conservation and restoration. Annual Meeting of the Ecological Society of America (ESA), online.

SEPTEMBER 2021
Alejandro Ordonez: Mirar al pasado para comprender el presente:Legados de cambio climático pasado en patrones de diversidad funcional actual. Biologia Javeriana - tras la ruta de la diaspora.

David Matzig, Shumon Hussain & Felix Riede: Style, function and variability in the final palaeolithic large tanged points in Europe revisited. European Archaeologists' Association conference, Kiel, Germany .

Jens-Christian Svenning: Integrating paleobiology and macroecology to inform current and future megafauna-based rewilding (keynote). 2nd Crossing the Palaeontological-Ecological Gap (CPEG), Berlin (online).

Jens-Christian Svenning: What is the most pressing issue we face to bridge the Paleontology-ecology gap? CPEG conference, Berlin (online), September 8, 2021.

Jesper Pedersen, Jakob Assmann, Dirk Karger, Signe Normand, Felix Riede: Climate niche modelling reveals the fate of pioneering late Pleistocene populations in Northern Europe. European Archaeologists' Association conference, Kiel, Germany.

Kathrine Andreasen & Felix Riede: Convergent catastrophe? The combined human impacts of the 8.2ka event and the Storegga tsunami on Mesolithic foragers in Western Denmark. European Archaeologists' Association conference, Kiel, Germany.

Kristine Engemann Jensen: Natur og sundhed – en byparks sundhedsfremmende potentialer. Folkeuniversitetet Aarhus.

OCTOBER 2021
Alejandro Ordonez: Using GIS to predict the consequences of a no-analogue future. Aarhus University GIS days.

Elizabeth le Roux: Consumer-driven nutrient impact in savannas and the role of species diversity. Séminaires d'Écologie et d'Évolution de Montpellier.

NOVEMBER 2021
Felix Riede: After the Apocalypse. Experiencing the Laacher See eruption and its post-eruptive effects at some distance. Zentrum für interdisziplinäre Forschung – cooperation group: Vulcanoes, climate, and history. Bielefeld, Germany.

Jens-Christian Svenning: Hvorfor holder vi store dyr i naturen for naturens skyld? ViD-konference: Hold af dyr i naturen, Aarhus University.

Jens-Christian Svenning: Naturen i "Danmark" i fortid, nutid og fremtid. Vild Med Viljes fødselsdagsarrangement.

Jens-Christian Svenning: 'Genforvildning og naturgenopretning – begrebsudvikling og vidensgrundlag' and 'Vildere natur i Danmark – behov, viden og erfaringer'. Danmarks Naturfredningsforening.

Kristine Engemann Jensen: Naturens sundhedsfremmende potentiale. Folkeuniversitetet Aarhus.

DECEMBER 2021
Jens-Christian Svenning: Integrated macroecological- palaeoecological perspectives on large-herbivore effects on ecosystems: implications for conservation and restoration. Ecology Across Borders 2021.

MEDIA / DEBATES / NEWS

JUNE 2020
Jens-Christian Svenning: How to dramatically curb extinction (article). Scientific American. June 1, 2020

Jens-Christian Svenning: Farvel til kæmpeskildpadder og næsehorn: Hundredvis af arter kan snart forsvinde for altid (article). DR. June 5, 2020

Jens-Christian Svenning: Dansk natur kan rumme 10 gange så mange dyr som i dag (feature article). Kristeligt Dagblad p. 1-3. June 12, 2020

Jens-Christian Svenning: Dumpekarakter: Danmark passer ikke godt nok på de store dyr (article). Videnskab.dk. June 12, 2020

Jens-Christian Svenning: Genopretning af biodiversitet og økosystemer (expert opinion). IPBES i Danmark. June 24, 2020

JULY 2020
Jens-Christian Svenning: Dræb for Danmark (radio interview). DR P1. July 2, 2020

Jens-Christian Svenning: Menneskets tidsalder og massedød (radio interview). DR P1. July 23, 2020

Jens-Christian Svenning: Rewilding hitter: Her er fire steder i Danmark, hvor du kan se store, vilde dyr (article). DR. July 23, 2020

AUGUST 2020
Jens-Christian Svenning: Jægere dræber tusindvis af mårhunde i Danmark: Men er de overhovedet skadelige? (article). DR. August 9, 2020

Jens-Christian Svenning: Aarhus-professor: Er mårhunden overhovedet et problem? (article). Jaegerforbundet.dk. August 10, 2020

SEPTEMBER 2020
Jens-Christian Svenning: Globalisering gør også naturen ensartet (press release). Ritzau. September 9, 2020

Jens-Christian Svenning: Findes nu i alle verdenshjørner (article). Weekendavisen. September 11, 2020

Jens-Christian Svenning: Næsehorns unikke fodaftryk kan blive deres redning fra krybskytter (article). Videnskab.dk. September 18, 2020

Jens-Christian Svenning: Forskere: Sådan kan Danmark modvirke den sjette masseuddøen (article). Videnskab.dk. September 23, 2020.

OCTOBER 2020
Jens-Christian Svenning: Research and policy may need to prioritise in efforts to protect biodiversity, research finds (article). Science for Environment Policy. October 19, 2020

Jens-Christian Svenning: 10 years to transform the future for humanity – or destabalize the planet (video). Ted Talk. October 22, 2020

NOVEMBER 2020
Jens-Christian Svenning: Why South America's ancient mammals may have lost out to northern counterparts (article). Science News. November 4, 2020

Jens-Christian Svenning: Ejrnæs m.fl.: Vildere natur er ikke en trussel mod naturen (opinion). Altinget.dk. November 17, 2020

Kristine Engemann Jensen: Grøn barndom (radio contribution). Kraniebrud, RADIO4. November 24, 2020

DECEMBER 2020
Jens-Christian Svenning: Menneskeskabte materialer vejer nu mere end al levende natur (article). Videnskab.dk. December 9, 2020

Jens-Christian Svenning: Studie: Store skovbrande truer med at udrydde 4.400 arter verden over (article). Videnskab.dk. December 30, 2020

JANUARY 2021
Felix Riede: Historien omskrives: Vortesvin er verdens ældste figurative hulemaleri, mener forskere (article). Videnskab.dk. January 14, 2021

Jens-Christian Svenning: Energy and biodiversity – two researchers, one climate (article). The Velux Foundations. January 22, 2021

Jens-Christian Svenning: Jens-Christian Svenning receives Villum Kann Rasmussen Annual Award (press release). Faculty of Natural Science, Aarhus University. January 25, 2021

Alejandro Ordonez & Jens-Christian Svenning: Loss of seed-hauling animals spells trouble for plants in warming world (article). Science Magazine. January 30, 2021

FEBRUARY 2021
Jens-Christian Svenning: 701 forskere i opråb: Politikerne bør behandle klimakrisen med samme alvor som covid-19 (article). Politiken. February 5, 2021

Jens-Christian Svenning: Internationale topforskere advarer mod biomasse (press release). Ritzau. February 11, 2021

Jens-Christian Svenning: Mod Vildere Bjerge (interview). Radio4 Morgen. February 27, 2021

MARCH 2021
Jens-Christian Svenning: An exchange following Prof Svenning's lecture with Dr Matthew Stewart (debate). The past present and future of the Human Niche, Max Planck Institute conference. March 3, 2021

Jens-Christian Svenning: Bestiariet (radio interview). Radio4 Vildspor. March 13, 2021

Jens-Christian Svenning: Biolog Jens-Christian Svenning om sin yndlings plante, taks – Europas redwood (interview). Bloom. March 18, 2021

Jens-Christian Svenning: Are we overestimating climate change's threat to rare plants? (article). Sierraclub. March 27, 2021

APRIL 2021
Jens-Christian Svenning: "Nordens giraf" og andre spændende dyr på vej i Danmarks første naturnationalparker (article). Naturstyrelsen nyheder. April 29, 2021

MAY 2021
Felix Riede: Afrikas ældste grav er fundet: 3-årige Mtoto blev begravet for 78.000 år siden (article). Videnskab.dk. May 5, 2021

Jens-Christian Svenning: En ræv på rov jagede skestorkene op og lærte os en masse om Jordens liv (article) Information. May 5, 2021

Jens-Christian Svenning: Computeren knuste biologernes myter, og nu ved vi, at det er sindssygt almindeligt at være ufattelig sjælden (feature article). Information. May 8, 2021

Jens-Christian Svenning: Bisonen tygger sig tilbage til Europa (article). Verdens Bedste Nyheder. May 9, 2021

JUNE 2021
Jens-Christian Svenning: Skovbandende byboer: Naturen er min fly-mode i hverdagen (article). Politiken. June 7, 2021
Jens-Christian Svenning: Istidsdyrenes forsvinden (debate). Bloom Festival. June 20, 2021

Felix Riede: Dragemennesket: Nyopdaget forhistorisk menneskeart kan være vores nærmeste slægtning (article and video). Videnskab.dk.
June 25, 2021

JULY 2021
Jens-Christian Svenning: Gürteltiere so groß wie Autos: So sähe die Erde ohne den Menschen aus (feature article) GEOplus. July 27, 2021

Jens-Christian Svenning: Er havets giganter ved at uddø? Jens Christian Svenning (podcast). Undervandsitetet. July 28, 2021

AUGUST 2021
Jens-Christian Svenning: Hvad er vigtigst at redde? Naturen eller klimaet? (feature article). Zetland. August 5, 2021

Elena Pearce: Nature's Reaction to Shifting Baseline Syndrome (interview). Heritage Tribune. August 24, 2021

SEPTEMBER 2021
Jens-Christian Svenning: Studie: Dyr skifter form på grund af klimaet (article). Kristeligt Dagblad. September 14, 2021

Felix Riede: Frühe Kulturen im Klimastress und ihre Antworten auf Hitze, Dürre und Kälte (Radio interview). SWR2. September 17, 2021

Felix Riede: Arkæologer har gjort opsigtsvækkende fund af 23.000 år gamle fodspor i Amerika (article). Videnskab.dk. September 23, 2021

Jens-Christian Svenning: Efter bundkarakter til dansk natur: Her er tre områder, der faktisk går frem (article). DR. September 23, 2021

OCTOBER 2021
Jens-Christian Svenning: Vi opdager ikke naturens nedgang, fordi vi har glemt, hvordan den engang så ud (article). Videnskab.dk. October 11, 2021

Signe Nordmand & Jens-Christian Svenning: »Den helt store udfordring er, at der simpelthen ikke er nok plads til naturen« (article). Politiken. October 25, 2021

Jens-Christian Svenning: Spektakulært fund af vildheste-knogler kan bringe ny viden til debatten om vild natur (article). Kristeligt Dagblad. October 29, 2021

NOVEMBER 2021
Kristine Engemann Jensen: Træ er sundt for sjælen (interview). Viden om Træ, nr. 2. November, 2021

Jens-Christian Svenning: Kampen om urskoven (article). Weekendavisen. November 5, 2021

Jens-Christian Svenning: Naturnationalpark splitter borgere: Naturens redning – eller halsløst eksperiment? (article). Kristeligt Dagblad. November 10, 2021

Jens-Christian Svenning & Jeppe Aagaard: Climate change: how elephants help pump planet-warming carbon underground (article). The Conversation. November 18, 2021

Jens-Christian Svenning: From ambition to biodiversity action: Time to hold actors accountable (article). iDiv. November 23, 2021

Felix Riede: Oldtidsmennesket (radio interview). Kraniebrud, Radio4. November 26, 2021

Jens-Christian Svenning: 55 danske forskere er blandt verdens mest citerede (article). Sciencereport.dk. November 29, 2021

DECEMBER 2021
Kristine Engemann Jensen: Træbyggeri øger trivslen (interview). Træ i byggeriet. December 7, 2021

Jens-Christian Svenning: There Is No Such Thing as Pristine Nature (article). Science the Wire. December 6, 2021

Jens-Christian Svenning: Tiden i Amazonas er nok det vildeste, jeg har oplevet i mit efterhånden lange arbejdsliv (portrait). Retrospekt 2021 – Carlsbergfondet. December 15, 2021

Jens-Christian Svenning: Her er 10 vigtige budskaber, som 10 førende forskere gerne vil fortælle dig (article). DR. December 19, 2021

OTHER
Elizabeth le Roux: Tropical Zoogeochemistry: Alchemists of the wild (organizer of a Special Conference Session). Annual Meeting for the Association for Tropical Biology and Conservation. July 23, 2021

Jens-Christian Svenning: Dr. Jens C. Svenning talks about Dr. Margaret Davis (Youtube video). AEET outreach, February 11, 2021

Jens-Christian Svenning: Prof Jens-Christian Svenning discusses the onset of human transformation of the biosphere (video of invited talk). The past present and future of the Human Niche, Max Planck Institute conference.

Felix Riede: After the Apocalypse - special exhibition at Moesgård Museum, Sept. 2020 – May 2021

*Felix Riede's talk: 'Apocalypse then! Apocalypse now? Using the Laacher See eruption (13ka BP) for Realistic Disaster Scenario' design at the European Geosciences Union conference in Vienna, Austria was turned into a LEGO model. Photo: Stacy Phillips.

Apokalypse then! Apocalypse now?
Using the Laacher See eruption (13ka BP)
for Realisic Disaster scenario design

Felix Riede
Laboratory for Past Disaster Sciece,
Aarhus University, Denmark

EVENTS

BIOCHANGE E-RETREAT 2021

Graphics by Rikke Cilja/ProcessInk

Skanderborg Lake, 25 km south of Aarhus, was once again the planned destination for the BIOCHANGE center retreat in 2021. However, the Covid-19 lockdown did not allow this to happen. Instead, we arranged our very first BIOCHANGE e-retreat. On April 21, Jens-Christian Svenning bid welcome to the BIOCHANGE community as we initiated the first of two e-retreat days. The program was lined up to leave the participants inspired and with new inputs. Our core group members (Jens-Christian Svenning, Signe Normand, Alejandro Ordonez Gloria, and Felix Riede) each provided an update on the four research themes of BIOCHANGE, and Jens-Christian further offered his take on the vision for BIOCHANGE.

In 2019, at our first center retreat, we arranged a workshop on LEGO Serious Play - using LEGO to present our research projects. This year, we organized a workshop on graphic facilitation, a drawing technique to convey complex subjects in a simple manner. All participants were taught the basics of simple drawing techniques, and the team developed icons for our field of research. We subsequently used the drawing techniques and created icons to start a poster drawing on each participant's research projects. We had a follow-up session to this workshop on May 27, 2021.

The first day ended with discussions on selected topics in smaller groups with questions posted on Slido. Subsequently, the four core members of BIOCHANGE brought up the most upvoted questions in a panel discussion.

On day 2, we were very pleased to have Robert Buitenwerf, Kristine Engemann/Maya Pasgaard, Elizabeth Le Roux, and Trine Kellberg Nielsen give four very interesting talks about their research projects and future plans. Day 2 ended with a final group work session allowing all participants to reflect on the center retreat, the workshop, the main take-homes, and their research plans for the next two years.

HUMBOLDT DAY EVENT

On September 18, 2020, BIOCHANGE hosted one of the many Humboldt Day events announced across the globe during the week of 12-19 September 2020 to mark the 250th anniversary of the birth of Alexander von Humboldt and to celebrate his legacy and research.

We had a number of great speakers lined up for a live event on Zoom, where our speakers, Jens-Christian Svenning, Vincent Fehr, Erik Kusch, Wubing Xu, and Alejandro Ordonez Gloria, presented their research under the title: Biodiversity Dynamics in a Changing World – From Humboldt to Big Data and Novel ecosystems.

Photo: IBS and Jens-Christian Svenning, BIOCHANGE.

VILLUM KANN RASMUSSEN ANNUAL AWARD

On January 22, 2021, Jens-Christian Svenning was presented with the Villum Kann Rasmussen Annual Award in Science and Technology from VILLUM FONDEN, which comes with an award of DKK 5 million – the largest individual Danish research award. In relation to the award ceremony, the foundation made a movie about Jens-Christian's research:
> VILLUM FONDEN video.
(with English sub-titles):

An associated portrait about Jens-Christian can be found here:

veluxfoundations.dk/en/jens-christian-svenning-finding-solutions-biodiversity-crisis

Professor Jens-Christian Svenning and Chair of VILLUM FONDEN Jens Kann-Rasmussen.
Photo: Thomas Frandsen.

BIOCHANGE SEMINAR SERIES

In 2020, the Core group of BIOCHANGE initiated the BIOCHANGE seminar series, where we invite top international researchers to give a talk on a topic falling within one of the four research themes of BIOCHANGE. Due to the Covid-19 pandemic this initiative was started as online webinars followed by Q/A sessions and open for all to attend. This seminar series has been continued in 2022 with many excellent speakers lined up.

01: September 7, 2020
Professor Marten Scheffer
(Wageningen University, The Netherlands)
Title: Critical Transitions in Nature and Society

02: October 5, 2020
Professor Melodie McGeoch
(LaTrobe University, Australia)
Title: Insights on the science-policy interface from monitoring invasive species

03: October 28, 2020
Professor Ariane Burke
(Universite de Montreal, Canada)
Title: The impact of habitat suitability on the structure of human populations during the Last Glacial Maximum (LGM) in Western Europe

04: December 7, 2020
Professor Andrew Gonzales
(McGill University, Canada)
Title: Integrative biodiversity science for the Anthropocene

05: March 17, 2021
Professor Vigdis Vandvik
(University of Bergen, Norway)
Title: The Power of Experimental Macroecology in Disentangling Global Change Impacts on Plants, Vegetation, & Ecosystems

06: April 4, 2021
Professor Stephen T. Jackson
(University of Arizona, USA)
Title: Reinventing conservation for a post-normal world

07: June 4, 2021
Professor Duccio Rocchini
(Alma Mater Studiorum University of Bologna)
Title: A Critique of the spectral species concept: are satellites diamonds in the sky?

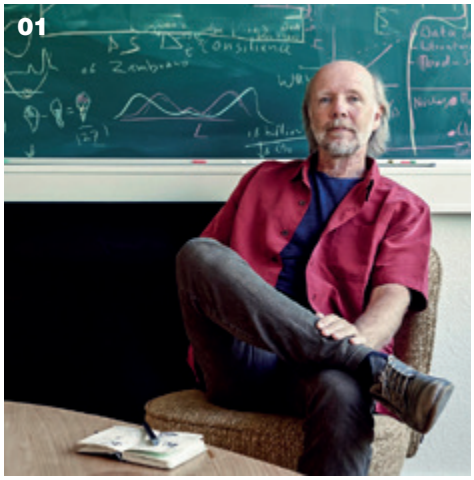
08: July 1, 2021
Dr. Philip Riris
(Bournemouth University, UK)
Title: Archaeological approaches to resilience from the perspective of ancient demography

09: October 27, 2021
Professor Wim van der Putten
(Netherlands Institute of Ecology (NIOO-KNAW))
Title: Responses of terrestrial ecological communities to climate change: range shifts, altered community interactions, and ecosystem functioning

10: November 8, 2021
Dr. Jonathan Lenoir
(Jules Verne University of Picardie, France)
Title: The stay-or-go paradox of plants in a warming world

11: December 7, 2021
Dr. Stefani A. Crabtree
(Utah State University and the Santa Fe Institute, USA)
Title: Archaeoecology: Using the archaeological past to understand our present and future

Photo 9: NIOO
Photo 10: Anibal Pauchard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PHD DEFENSES

This year we have celebrated several successful PhD defenses in BIOCHANGE.

On June 16, 2020, MegaPast2Future PhD student **Emilio Berti**, supervised by Professor Jens-Christian Svenning and BIOCHANGE alumnus Dr. Scott Jarvie, defended his thesis, 'Megafauna extinctions, allometric scaling and biotic interactions: ecological effects and restoration opportunities through rewilding'. Members of the assessment committee consisted of Associate Professor Anna Eklöf (Linköping University, Sweden), Senior Researcher Michael Harfoot (UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), United Kingdom), and Chair Professor Signe Normand (Aarhus University).

On June 30, 2020, PhD student **Oskar L. P. Hansen**, supervised by Professor Jens-Christian Svenning, Dr. Kent Olsen (Natural History Museum, Aarhus), and Professor Toke T. Høye (Ecoscience, Aarhus University), defended his thesis, 'Towards deep learning powered monitoring of biodiversity in rewilding projects'. Members of the assessment committee consisted of Professor Stefan Kremer (University of Guelph, Canada), Associate Professor Chris Smit (University of Groningen, Netherlands), and Chair Professor Henrik Balslev (Aarhus University).

On December 17, 2020, PhD student **Bjarke Madsen**, supervised by Professor Signe Normand, Associate Professor Arko Lucieer (University of Tasmania, Australia), and Professor Eric Allan (Bern University, Switzerland), defended his thesis, 'Drone ecology - Understanding grassland plant diversity dynamics using close-range remote sensing'. Members of the assessment committee consisted of Dr. Florian Zellweger (University of Cambridge, United Kingdom), Professor Rasmus Fensholt, (University of Copenhagen, Denmark), and Chair Professor Henrik Balslev (Aarhus University).

On May 19, 2021, PhD student **Julia C. Mata**, supervised by Professor Jens-Christian and Assistant Professor Robert Buitenwerf, defended her thesis, 'Ecological effects of megafauna and rewilding in a neotropical savanna ecosystem'. Members of the assessment committee consisted of Principal Researcher Mario S. Di Bitetti (Instituto de Biología Subtropical (IBS), CONICET-UNaM, Facultad de Ciencias Forestales, UNaM, Argentina), Professor Frank van Langevelde (Wageningen University & Research, Netherlands), and Chair Associate Professor Wolf Eiserhardt (Aarhus University).

On June 3, 2021, PhD student **Vincent Fehr,** supervised by Professor Jens-Christian and Assistant Professor Robert Buitenwerf, defended his thesis, 'Non-native palms as generators of novel ecosystems'. Members of the assessment committee consisted of Professor Melodie A McGeoch (School of Life Sciences La Trobe University, Australia), Lecturer Fred Stauffer (CJBG – Conservatoire et Jardin bontaniques, Switzerland), and Chair Associate Professor Wolf Eiserhardt, (Aarhus University).

On September 17, 2021, PhD student **Ditte Arp Jensen**, supervised by Professor Jens-Christian Svenning and Professor Keping Ma (Chinese Academy of Sciences, China), defended her thesis, 'Gymnosperm Ecology in the Anthropocene - Prospects and challenges in a changing world'. Members of the assessment committee consisted of Professor Dorota Dobrowolska (Forest Research Institute, Poland), Professor Dov Sax, (Brown University, USA), and Chair Associate Professor Wolf Eiserhardt (Aarhus University).

In 2020/2021, we have celebrated five successful defended qualifying exams by BIOCHANGE PhD students:
Jonathan van Oppen – August 13, 2020
Candice Casandra Power – August 25, 2020
Marco Davoli – March 25, 2021
Elena Pearce – June 22, 2021
Erik Kusch – July 5, 2021

PUBLICATIONS

Below BIOCHANGE-related publications published from June 2020 and to December 2021 are listed. We have highlighted BIOCHANGE members (present and past) and associates in bold font. Author lists abbreviated for publications with more than five authors (BIOCHANGE authors highlighted in brackets).

Abbott, P.M., et al. 2021. Volcanic climate forcing preceding the inception of the Younger Dryas: Implications for tracing the Laacher See eruption. *Quaternary Science Reviews* 2:107260. **(F. Riede)**.

Abraham, A. J., et al. 2021. Large predators can mitigate nutrient losses associated with off-site removal of animals from a wildlife reserve. *Journal of Applied Ecology* 58:1360-1369. **(E. le Roux)**.

Ahmadi, K., et al., 2020. The potential impact of future climate on the distribution of European yew (Taxus baccata L.) in the Hyrcanian Forest region (Iran). *International Journal of Biometeorology* 64:1451-1462. **(J. M. Serra-Diaz, J.-C. Svenning)**.

Ahmadi, K., et al., 2020. Patterns of density and structure of natural populations of Taxus baccata in the Hyrcanian forests of Iran. Nordic Journal of Botany 38. **(J. M. Serra-Diaz, J.-C. Svenning)**.

Ahmed, D., **Ammar, E.**, **Svenning, J.-C.**, El-Beheiry, M., & Shaltout, K. 2020. Wild plant species in Egyptian gardens of the Nile Region: Conservation *Viewpoint. Egyptian Journal of Botany* 60:719-732.

Ammar, E. E. S., Shaltout, K., **Svenning, J.-C.**, El-Beheiry, M., & Ahmed, D. A. E.-A. 2020. Assessment of the wild plants in the Egyptian botanic gardens; Nile region. *African Journal of Ecology* 58: 874-878. **(J.C. Svenning)**.

Axmanová, I., et al. 2021. Neophyte invasions in European grasslands. *Journal of Vegetation Science* 32:e12994. **(J.-C. Svenning)**.

Berti, E., Monsarrat, S., Munk, M., Jarvie, S., & **Svenning, J.-C.** 2020. Body size is a good proxy for vertebrate charisma. *Biological Conservation* 251:108790.

Berti, E. & **Svenning, J.-C.** 2020. Megafauna extinctions have reduced biotic connectivity worldwide. *Global Ecology and Biogeography* 29: 2131-2142.

Bjorkman, A. D., et al. 2020. Status and trends in Arctic vegetation: Evidence from experimental warming and long-term monitoring. *AMBIO* 49:678-692. **(S. Normand)**.

Brunbjerg, A. K., et al. 2020. Multi-taxon inventory reveals highly consistent biodiversity responses to ecospace variation. *Oikos* 129: 1381-1392. **(J.-C. Svenning, O. L. P. Hansen)**.

Cai, Q., et al. 2021. The relationship between niche breadth and range size of beech (Fagus) species worldwide. Journal of Biogeography 48:1240-1253. **(J.-C. Svenning)**.

Cao, K., et al. 2021. Species packing and the latitudinal gradient in beta-diversity. *Proceedings of the Royal Society B: Biological Sciences* 288:20203045. **(J.-C. Svenning)**.

Cao, K., et al. 2021. Undersampling correction methods to control gamma-dependence for comparing beta-diversity between regions. *Ecology* 102:e03448. **(J.-C. Svenning)**.

Capitán, J. A., Cuenda, S., **Ordonez, A.**, & Alonso, D. 2021. A signal of competitive dominance in mid-latitude herbaceous plant communities. *Royal Society open science* 8:201361.

Carver, S., et al. 2021. Guiding principles for rewilding. *Conservation Biology* 35:1882-1893. **(J.-C. Svenning)**.

Chacón-Labella, J., et al. 2020. From a crisis to an opportunity: Eight insights for doing science in the Covid-19 era and beyond. *Ecology and Evolution* 11:3588-3596 **(J. von Oppen)**.

Conradi, T., Henriksen, M. V. J., & **Svenning, J.-C.** 2021. Global change, novel ecosystems and the ecological restoration of post-industrial areas: The case of a former brown coal mine in Søby, Denmark. *Applied Vegetation Science* 24:e12605.

Couvreur, T. L. P., et al. 2021. Tectonics, climate and the diversification of the tropical African terrestrial flora and fauna. *Biological Reviews* 96:16-51. **(A. Blach-Overgaard, J.-C. Svenning)**.

Ellis, E. C., et al. 2021. People have shaped most of terrestrial nature for at least 12,000 years. *Proceedings of the National Academy of Sciences USA* 118:e2023483118. **(J.-C. Svenning)**.

Eggers-Kaas, T., Hoggard, C.S., & **Riede, F.** 2020. Flygtige Federmesser. Betragninger om at skelne mellem senpalæolitiske Federmesser og tidlig mesolitiske lancetspidser. *Tings Tale* 2:29–39.

Engemann, K., et al. 2020. Associations between growing up in natural environments and subsequent psychiatric disorders in Denmark. *Environmental Research* 188:109788. **(J.-C. Svenning)**.

Engemann, K., et al. 2021. A life course approach to understanding associations between natural environments and mental well-being for the Danish blood donor cohort. *Health & Place* 72:102678. **(J.-C. Svenning)**.

Escobar, S., et al. 2020. Pleistocene climatic fluctuations promoted alternative evolutionary histories in Phytelephas aequatorialis, an endemic palm from western Ecuador. *Journal of Biogeography* 48:1023-1037. **(S. Jarvie)**.

Fehr, V., Buitenwerf, R., & **Svenning, J.-C.** 2020. Non-native palms (Arecaceae) as generators of novel ecosystems: A global assessment. *Diversity and Distributions* 26:523-1538.

Feng, G., Zhang, J., Girardello, M., Pellissier, V., & **Svenning, J.-C.** 2020. Forest canopy height co-determines taxonomic and functional richness, but not functional dispersion of mammals and birds globally. *Global Ecology and Biogeography* 29:1350-1359.

Fløjgaard, C., **Pedersen, P. B. M.**, Sandom, C. J., **Svenning, J.-C.**, & Ejrnæs, R. 2021. Exploring a natural baseline for large-herbivore biomass in ecological restoration. *Journal of Applied Ecology* 59:18-24.

Fricke, E. C. & **Svenning, J.-C.** 2020. Accelerating homogenization of the global plant–frugivore meta-network. Nature 585:74-78.

Fristoe, T. S., et al. 2021. Dimensions of invasiveness: Links between local abundance, geographic range size, and habitat breadth in Europe's alien and native floras. *Proceedings of the National Academy of Sciences USA* 118:e2021173118. **(J.-C. Svenning)**.

Gaisberger, H., et al. 2021. Tropical and subtropical Asia's valued tree species under threat. *Conservation Biology*: e13873. **(J.-C. Svenning)**.

Geange, S. R., et al. 2020. Next-generation field courses: Integrating Open Science and online learning. *Ecology and Evolution* 11:3577-3587 (**J. von Oppen**).

Gordon, C. E., Lerm, R. E., Allin, P., Greve, M., & **Svenning, J.-C.** 2021. Elephant rewilding indirectly affects the abundance of an arboreal but not generalist savanna lizard. *Biodiversity and Conservation* 30:1277-1291.

Hess, T. & **Riede, F.** 2021. The use of lithic raw materials at the Early Mesolithic open-air site Feuersteinacker (Vogelsbergkreis, Germany). *Geoarchaeology* 36:252–265.

Hoeks, S., et al. 2020. Mechanistic insights into the role of large carnivores for ecosystem structure and functioning. *Ecography* 43:1752-1763. (**J.-C. Svenning**).

Hoggard, C.S., Birch, T., Stade, C.M., Janin, K.G., & **Riede, F.**, 2021. Evaluating the suitability of lithic illustrations in morphometric analyses. *Lithics.*

Hussain, S.T., **Matzig, D.N.**, et al. 2021. Towards a collaborative meta-analysis of the Final Palaeolithic / earliest Mesolithic in Europe. Report on the 2nd CLIOARCH Workshop, 26th-27th November 2020. *Archäologische Informationen* 43:415–420. (**F. Riede**).

Hussain, S.T., **Matzig, D.N.**, & **Riede, F.** 2021. Review of: Gillings, M., Hacıgüzeller, P. & Lock, G. (eds) (2019). Re-Mapping Archaeology. Critical Perspectives, Alternative Mappings. London: Routledge. *Archäologische Informationen* 43: 541–546.

Hussain, S.T. & **Riede, F.** 2020. Paleoenvironmental humanities: Challenges and prospects of writing deep environmental histories. *WIREs Climate Change* 11:e667.

Hyvarinen, O., et al. 2021. Megaherbivore impacts on ecosystem and Earth system functioning: the current state of the science. *Ecography* 44:1579-1594. (**E. le Roux**).

Jensen, D. A., Ma, K., & **Svenning, J.-C.** 2020. Steep topography buffers threatened gymnosperm species against anthropogenic pressures in China. *Ecology and Evolution* 10:1838-1855.

Jensen, D. A., et al. 2021. The potential for using rare, native species in reforestation– A case study of yews (Taxaceae) in China. *Forest Ecology and Management* 482:118816. (**J.-C. Svenning**).

Jensen, D. A. & **Svenning, J. C.** 2021. Population ecology and dynamics of a remnant natural population of European yew Taxus baccata in a lowland temperate forest – implications for use in reforestation. *Nordic Journal of Botany* 39: e03167.

Jung, M., et al. 2021. Areas of global importance for conserving terrestrial biodiversity, carbon and water. *Nature Ecology & Evolution.* (**J.-C. Svenning**).

Klynge, D., **Svenning, J.-C.**, & Skov, F. 2020. Floristic changes in the understory vegetation of a managed forest in Denmark over a period of 23 years – Possible drivers of change and implications for nature and biodiversity conservation. *Forest Ecology and Management* 466:118128.

Kristensen, J. A., **Svenning, J.-C.**, Georgiou, K., & Malhi, Y. 2021. Can large herbivores enhance ecosystem carbon persistence? *Trends in Ecology & Evolution* 37:117-128.

Li, C., et al. 2021. Decomposing multiple β-diversity reveals non-random assembly of the waterbird communities across anthropogenic subsidence wetlands. *Diversity and Distributions.* (e-pub ahead of print) (**J.-C. Svenning**).

Li, W., et al. 2020. Complex causes and consequences of rangeland greening in South America – multiple interacting natural and anthropogenic drivers and simultaneous ecosystem degradation and recovery trends. *Geography and Sustainability* 1:304-316. (**J. Mata, J.C. Svenning, R. Buitenwerf**).

Li, W., Buitenwerf, **R.**, **Munk, M.**, **Bøcher, P. K.**, & **Svenning, J.-C.** 2020. Deep-learning based high-resolution mapping shows woody vegetation densification in greater Maasai Mara ecosystem. *Remote Sensing of Environment* 247:111953.

Li, W., **Guo, W.,** Qin, Y., Wang, L., Niu, Z., & **Svenning, J.-C.** 2021. Mapping spatio-temporal patterns in global tree cover heterogeneity: Links with forest degradation and recovery. *International Journal of Applied Earth Observation and Geoinformation* 104:102583.

Li, W., et al. 2020. High-resolution mapping of forest canopy height using machine learning by coupling ICESat-2 LiDAR with Sentinel-1, Sentinel-2 and Landsat-8 data. *International Journal of Applied Earth Observation and Geoinformation* 92:102163.

Li, Y., et al. 2020. Effects of diversity, climate and litter on soil organic carbon storage in subtropical forests. *Forest Ecology and Management* 476:118479. (**W. Xu**).

Lim, J. Y., **Svenning, J.-C.**, Göldel, B., Faurby, S., & Kissling, W. D. 2020. Frugivore-fruit size relationships between palms and mammals reveal past and future defaunation impacts. *Nature Communications* 11:4904.

Liu, Q., et al. 2020. Ecological restoration is the dominant driver of the recent reversal of desertification in the Mu Us Desert (China). *Journal of Cleaner Production* 268:122241. (**J.-C. Svenning, K. Yue, S. Jarvie**).

Liu, Q., et al. 2021. Ecosystem restoration through aerial seeding: Interacting plant–soil microbiome effects on soil multifunctionality. *Land Degradation & Development* 32:5334-5347. (**J.-C. Svenning**).

Lundgren, E. J., et al. 2021. Functional traits of the world's late Quaternary large-bodied avian and mammalian herbivores. *Scientific Data* 8:17. (**J.-C. Svenning, R. Pedersen**).

Lundström, V., Peters, R., & **Riede, F.** 2021. Demographic estimates from the Palaeolithic–Mesolithic boundary in Scandinavia: comparative benchmarks and novel insights. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376:20200037.

Luo, M., et al. 2021. The use of Global Biodiversity Information Facility (GBIF)-mediated data in publications written in Chinese. *Global Ecology and Conservation* 25: e01406. (**W. Xu**).

Madsen, B., **Treier, U. A.**, Zlinszky, A., Lucieer, A., & **Normand, S.** 2020. Detecting shrub encroachment in seminatural grasslands using UAS LiDAR. *Ecology and Evolution* 10:4876-4902.

Manninen, M.A., et al. 2021. Using Radiocarbon Dates and Tool Design Principles to Assess the Role of Composite Slotted Bone Tool Technology at the Intersection of Adaptation and Culture-History. *Journal of Archaeological Method and Theory* 28:845–870. (**F. Riede**).

Mata, J. C., Buitenwerf, R., & **Svenning, J.-C.** 2021. Enhancing monitoring of rewilding progress through wildlife tracking and remote sensing. *PLOS ONE* 16:e0253148.

Matzig, D.N., **Hussain, S.T.**, & **Riede, F.** 2021. Design Space Constraints and the Cultural Taxonomy of European Final Palaeolithic Large Tanged Points: A Comparison of Typological, Landmark-Based and Whole-Outline Geometric Morphometric *Approaches. Journal of Paleolithic Archaeology* 4: 27.

Mi, X., et al. 2021. The global significance of biodiversity science in China: an overview. **National Science Review** 8:nwab032. (**J.-C. Svenning**).

Moleon, M., et al. 2020. Rethinking megafauna. *Proceedings of the Royal Society B: Biological Sciences* 287:20192643. (**J.-C. Svenning**).

Monnet, A.-C., Vorontsova, M. S., Govaerts, R. H. A., **Svenning, J.-C.**, & Sandel, B. 2020. Historical legacies and ecological determinants of grass naturalizations worldwide. *Ecography* 43:1373-1385.

Monsarrat, S., Hansen, **O. L. P.**, & **Svenning, J.-C.** 2020. Highly variable impacts of feral horses on ecosystems worldwide. *Biological Conservation* 247:108616.

Monsarrat, S. & **Svenning, J.-C.** 2021. Using recent baselines as benchmarks for megafauna restoration places an unfair burden on the *Global South. Ecography* 2022 -special issue:e06354.

Muscarella, R., et al. 2020. The global abundance of tree palms. *Global Ecology and Biogeography* 29:1495-1514. (**J.-C. Svenning**).

Myers-Smith, I. H., et al. 2020. Complexity revealed in the greening of the Arctic. *Nature Climate Change* 10:106-117. (**J. J. Assmann**, **S. Normand**).

Nagy-Reis, M., et al. 2020. NEOTROPICAL CARNIVORES: a data set on carnivore distribution in the Neotropics. *Ecology* 101:e03128.
(**J. Mata**, **J.-C. Svenning**, **R. Buitenwerf**).

Neves, D. M., et al. 2021. The adaptive challenge of extreme conditions shapes evolutionary diversity of plant assemblages at continental scales. *Proceedings of the National Academy of Sciences USA* 118:e2021132118. (**J.-C. Svenning**).

Nielsen, M., Sørensen, A.H., & **Riede, F.**, 2021. Islands of Time. Unsettling Linearity Across Deep History. *Ethnos* 86:943–962.

Niemeier, U., **Riede, F.**, & Timmreck, C., 2021. Simulation of ash clouds after a Laacher See-type eruption. *Climate of the Past* 17:633–652.

Padullés Cubino, J., et al. 2021. Phylogenetic structure of European forest vegetation. *Journal of Biogeography* 48:903-916. (**J.-C. Svenning**).

Pasgaard, M., Fold, N., Meilby, H., & Kalvig, P. 2021. Reviewing tourism and natural resource research in the Arctic: towards a local understanding of sustainable tourism in the case of South Greenland. *Geografisk Tidsskrift-Danish Journal of Geography* 121:1–15.

Pérez-Navarro, M. Á., et al. 2021. Extreme drought reduces climatic disequilibrium in dryland plant communities. *Oikos* 130:680-690. (**J.-C. Svenning**).

Perino, A., et al. 2021. Biodiversity post-2020: Closing the gap between global targets and national-level implementation. *Conservation Letters:e12*848. (**J.-C. Svenning**).

Pouteau, R., et al. 2021. Potential alien ranges of European plants will shrink in the future, but less so for already naturalized than for not yet naturalized species. *Diversity and Distributions* 27:2063-2076. (**J.-C. Svenning**).

Pouteau, R., et al. 2021. Climate and socio-economic factors explain differences between observed and expected naturalization patterns of European plants around the world. *Global Ecology and Biogeography* 30:1514-1531. (**J.-C. Svenning**).

Prendin, A. L., et al. 2021. Chemical signature of Eurois occulta L. outbreaks in the xylem cell wall of Salix glauca L. in Greenland. *The Science of the Total Environment* 764:144607. (**S. Normand, U. A. Treie**r).

Rech, A. R., et al. 2021. Population-level plant pollination mode is influenced by Quaternary climate and pollinators. *Biotropica* 53:632-642. (**J.-C. Svenning**).

Reichstein, M., **Riede, F.**, & Frank, D. 2021. More floods, fires and cyclones – plan for domino effects on sustainability goals. *Nature* 592:347–349.

Reinig, F., et al. 2020. Towards a dendrochronologically refined date of the Laacher See eruption around 13,000 years ago. *Quaternary Science Reviews* 229:106128. (**F. Riede**).

Riede, F. 2020. Felix Riede, in: Timbrell, L. (Ed.), Conversations in Human Evolution, Access Archaeology. *Archaeopress*. 9–14.

Riede, F., et al. 2020a. Cultural taxonomies in the Paleolithic – Old questions, novel perspectives. *Evolutionary Anthropology: Issues, News, and Reviews* 29:49–52. (**S. T. Hussain**)

Riede, F., et al. 2020b. Prospects and pitfalls in integrating volcanology and archaeology: A review. *Journal of Volcanology and Geothermal Research* 401:106977.

Riede, F. & Jackson, R.C. 2020. Do Deep-Time Disasters Hold Lessons for Contemporary Understandings of Resilience and Vulnerability?, in: Riede, F., Sheets, P. (Eds.), Going Forward by Looking Back: Archaeological Perspectives on Socio-Ecological Crisis, Response, and Collapse, Catastrophes in Context. *Berghahn Books*, New York, NY. 35–73.

Riede, F. & Meyer, M.V. 2021. Book review: Growing Up in the Ice Age. Fossil and Archaeological Evidence of the Lived Lives of Plio-Pleistocene Children. *Childhood in the Past* 14:197–199.

Riede, F. & Sauer, F. 2021. Steinzeit und Vulkanasche - Survey und Sondagegrabungen zum Spätpaläolithikum in Hessen. *Hessen Archäologie* 2020:52–56.

Riede, F. & Sheets, P. (Eds.), 2020a. Going Forward by Looking Back: Archaeological Perspectives on Socio-Ecological Crisis, Response, and Collapse, Catastrophes in Context. *Berghahn Books*, New York, NY.

Riede, F. & Sheets, P. 2020b. Introduction. Framing Catastrophes Archaeologically, in: Riede, F., Sheets, P. (Eds.), Going Forward by Looking Back: Archaeological Perspectives on Socio-Ecological Crisis, Response, and Collapse, Catastrophes in Context. *Berghahn Books*, New York, NY. 17–31.

Riede, F., Walsh, M.J., Nowell, A., Langley, M.C., & Johannsen, N.N. 2021. Children and innovation: play, play objects and object play in cultural evolution. *Evolutionary Human Sciences* 3:e11.

Sabatini, F. M., et al. 2021. sPlotOpen - An environmentally balanced, open-access, global dataset of vegetation plots. *Global Ecology and Biogeography* 30:1740-1764. (**J.-C. Svenning**).

Scherer, L., **Svenning, J.-C.**, et al. 2020. Global priorities of environmental issues to combat food insecurity and biodiversity loss. *Science of The Total Environment* 730:139096.

Schowanek, S. D., et al. 2021. Reintroducing extirpated herbivores could partially reverse the late Quaternary decline of large and grazing species. *Global Ecology and Biogeography* 30:896-908. (**E. Lundgren, J.C. Svenning, R. Pedersen**).

Seliger, B. J., McGill, B. J., **Svenning, J.-C.**, & Gill, J. L. 2020. Widespread underfilling of the potential ranges of North American trees. *Journal of Biogeography* 48:359-371.

Sigsgaard, E. E., et al. 2020. Environmental DNA metabarcoding of cow dung reveals taxonomic and functional diversity of invertebrate assemblages. *Molecular Ecology* 30:3374-3389. (**J.C. Svenning, O. L. P. Hansen**).

Song, H., et al. 2021. Regional disparity in extinction risk: comparison of disjunct plant genera between eastern Asia and eastern North America. *Global Change Biology* 27:1904-1914. (**A. Ordonez, J.-C. Svenning**).

Svenning, J.-C. 2020. Rewilding should be central to global restoration efforts. *One Earth* 3:657-660.

Swanson, H. A., et al. 2021. History as grounds for interdisciplinarity: promoting sustainable woodlands via an integrative ecological and socio-cultural perspective. *One Earth* 4:226-237. (**J.-C. Svenning**).

Troiano, C., et al. 2021. Traditional Free-Ranging Livestock Farming as a Management Strategy for Biological and Cultural Landscape Diversity: A Case from the Southern Apennines. *Land* 10:957. (**J.-C. Svenning**).

Tylén, K., et al. 2020. Investigating the cultural evolution of the Blombos and Diepkloof engravings, in: Ravignani, A., Barbierei, C., Flaherty, M., Jadoul, Y., Lattenkamp, E., Little, H., Martins, M., Mudd, K., Verhoef, T. (Eds.), The Evolution of Language. Proceedings of the 13th International Conference on the Evolution of Language (EvoLang13). T*he Evolution of Language Conferences, Nejmegen*, 457–459. (**F. Riede**).

Van Meerbeek, K., Jucker, T., & **Svenning, J.-C.** 2021. Unifying the concepts of stability and resilience in ecology. *Journal of Ecology* 109:3114-3132.

Velazco, S. J. E., **Svenning, J.-C.**, Ribeiro, B. R., & Laureto, L. M. O. 2020. On opportunities and threats to conserve the phylogenetic diversity of Neotropical palms. *Diversity and Distributions* 27:512-523.

Vogel, S. M., Pasgaard, M., & **Svenning, J.-C.** 2021. Joining forces toward proactive elephant and rhinoceros conservation. *Conservation Biology* 36:e13726.

von Oppen, J., et al. 2021. Annual air temperature variability and biotic interactions explain tundra shrub species abundance. *Journal of Vegetation Science* 32:e13009. (**A. Blach-Overgaard, J. J. Assmann, S. Normand**).

Wagner, V., et al. 2021. Alien plant invasion hotspots and invasion debt in European woodlands. *Journal of Vegetation Science* 32:e13014. (**J.-C. Svenning**).

Wang, H., et al. 2021. From unusual suspect to serial killer: Cyanotoxins boosted by climate change may jeopardize African megafauna. *The Innovation* 100092. (**J.-C. Svenning**).

Wang, W.-T., **Guo, W.-Y.**, **Jarvie, S.**, & **Svenning, J.-C.** 2020. The fate of Meconopsis species in the Tibeto-Himalayan region under future climate change. *Ecology and Evolution* 11:887-899.

Wang, N., et al. 2021. Humus microhabitat affects distributions of soil fungi and bacteria in a temperate mountain forest. *Ecology and Evolution* 11:9148-9158 (**W. Li**).

Wang, X., et al. 2021. Regional effects of plant diversity and biotic homogenization in urban greenspace – The case of university campuses across China. *Urban Forestry & Urban Greening* 62:127170. (**J.-C. Svenning**).

White, H. J., et al. 2020. Methods and approaches to advance soil macroecology. *Global Ecology and Biogeography* 29:1674-1690. (**A. Ordonez**).

Williams, J. W., **Ordonez, A.**, & **Svenning, J.-C.** 2021. A unifying framework for studying and managing climate-driven rates of ecological change. *Nature Ecology & Evolution* 5:17-26.

Xi, J., et al. 2021. Distribution of Woody Plant Species Among Different Disturbance Regimes of Forests in a Temperate Deciduous Broad-Leaved Forest. *Frontiers in Plant Science* 12:618524. (**W. Li**).

Yin, X., et al. 2021. Niche overlap and divergence times support niche conservatism in eastern Asia–eastern North America disjunct plants. *Global Ecology and Biogeography* 30:1990-2003. (**J.-C. Svenning**).

Yin, X., et al. 2021. Effects of climate and topography on the diversity anomaly of plants disjunctly distributed in eastern Asia and eastern North America. *Global Ecology and Biogeography* 30:2029-2042. (**J.-C. Svenning**).

Yue, K., et al. 2020. Changes in plant diversity and its relationship with productivity in response to nitrogen addition, warming and increased rainfall. *Oikos* 129:939-952. (**J.-C. Svenning**).

Xu, C., T. A. Kohler, T. M. Lenton, **J.-C. Svenning**, and M. Scheffer. 2020. Future of the human climate niche. *Proceedings of the National Academy of Sciences USA* 117:11350-11355.

Zohner, C. M., et al. 2020. Late-spring frost risk between 1959 and 2017 decreased in North America but increased in Europe and Asia. *Proceedings of the National Academy of Sciences USA* 117:12192-12200. (**A. Ordonez, J.C. Svenning**).

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