AARHUS UNIVERSITY

BIOCHANGE
CENTER FOR BIODIVERSITY DYNAMICS
IN A CHANGING WORLD

ANNUAL REPORT 2019 / 2020

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IN A CHANGING WORLD

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Annual Report 2019/2020

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BIOCHANGE
Center for Biodiversity Dynamics in a Changing World
Annual Report 2019/2020

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FRONT-PAGE
A family of African elephants crossing the road in Northern Botswana.
Photo: Sophie Monsarrat, BIOCHANGE

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WORDS FROM **THE DIRECTOR**

Dear readers,
It is my pleasure to present the third 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. Overall, 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 on developing novel solutions to promote a biodiverse, liveable future to the benefit of humans and all our co-beings on this planet.

To maximize progress on 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 MSO 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); 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. 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 over the last year. 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 2019, Signe Normand was promoted to full professor, Felix Riede began his ERC Consolidator project CLIOARCH (CLIOdynamic ARCHaeology: Computational approaches to Final Palaeolithic/earliest Mesolithic archaeology and climate change), Robert Buitenwerf was BIOCHANGE's first appointed tenure-track assistant professor (in Remote Sensing of Ecosystem Dynamics), and the center has had many successful activities including an active outreach program, a number of BIOCHANGE-hosted international meetings and courses, the start 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

Photo: Else Magård

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.

THEME 1

FUNDAMENTAL BIODIVERSITY DYNAMICS

We aim to deepen our understanding of three phenomena that are likely to characterize future ecosystems, 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.

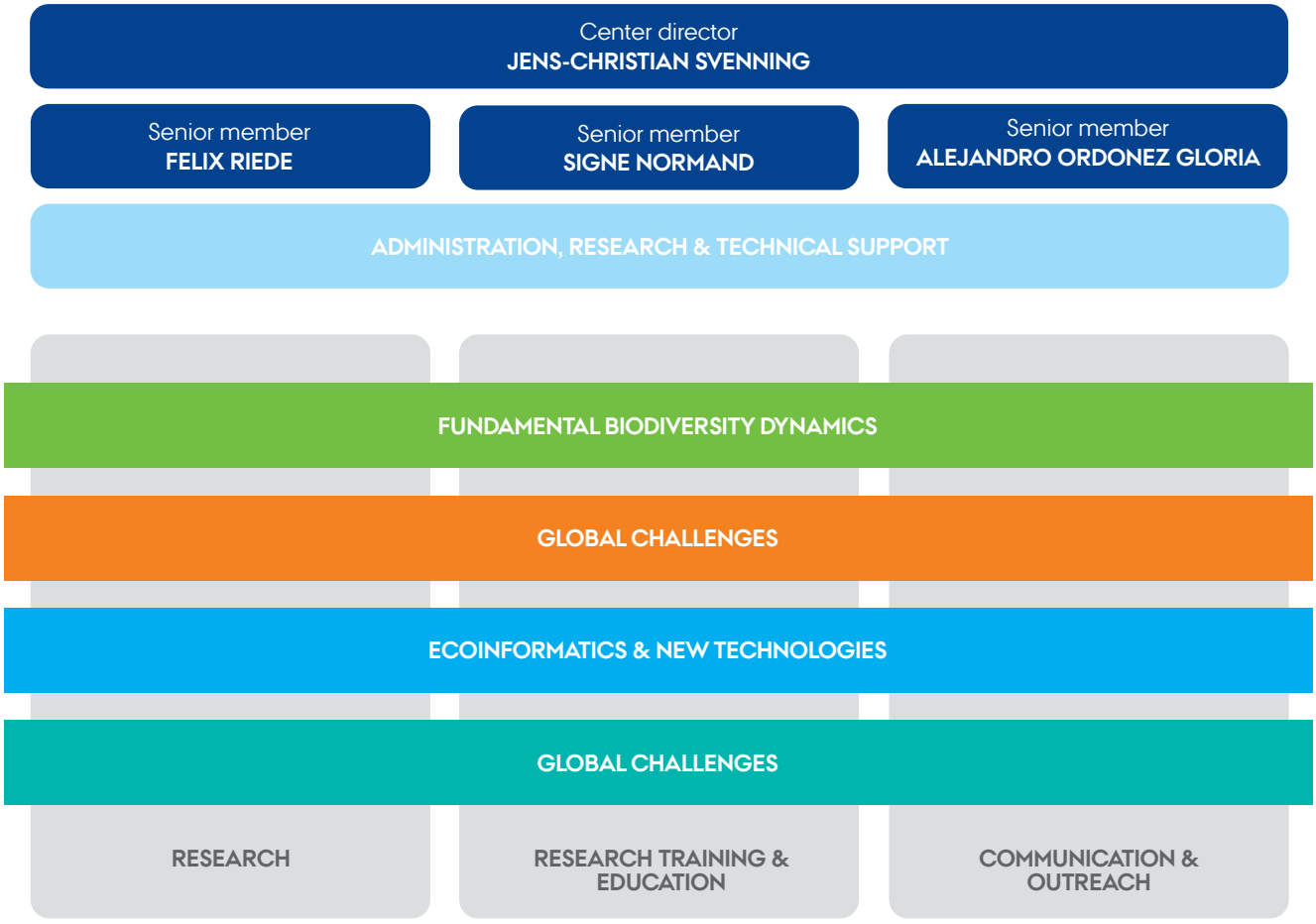
ORGANIZATION AND STAFF

ORGANIZATION AND STAFF

BIOCHANGE members at our Center retreat at Skanderborg in April 2019.

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 MSO **Felix Riede**,
Professor **Signe Normand**,
Tenure-track Assistant Professor **Alejandro Ordonez Gloria**.

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

ORGANIZATION AND STAFF

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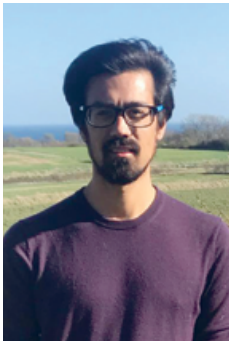

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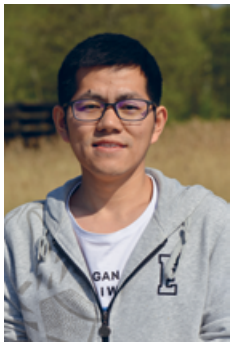

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In addition, the center includes 15 Bachelor students and 17 Master students.
(Further reading in section: Research Training and Education)

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Peder Klith Bøcher, Market Launcher,
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Photo: Sophie Monsarrat, BIOCHANGE.

PORTRAITS OF CORE GROUP LEADERS

JENS-CHRISTIAN SVENNING

WHO ARE YOU?
My name is Jens-Christian Svenning. I am a broadly based ecologist, with strong interest in biodiversity, global change biology, human-nature interrelations, and possibilities for ecological restoration and sustainable development. My work has led to a number of major recognitions, notably a Consolidator-phase European Research Council (ERC) Starting grant in 2013, the Ministry for Higher Education and Science's Eliteforsk award in 2014, Queen Margrethe II's Science Award in 2016, a Carlsberg Foundation Semper Ardens grant in 2016, a VILLUM Investigator grant in 2017, and identification as a Clarivate Highly Cited Researcher in 2018 and 2019.

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

MAIN RESEARCH AREAS
I have developed a research agenda on biodiversity dynamics in a changing world focused around 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 QUESTIONS
In my prior research, a major achievement has been my contribution to mainstreaming historical contingency and disequilibrium dynamics into ecology and global change biology. Some of the important discoveries and results that I have spearheaded include:

(i) an important role of climate stability in shaping Earth's biodiversity patterns and associated functional capacity,

(ii) dispersal limitation as an important factor for biodiversity dynamics under climate change as well as biodiversity patterns broadly,

(iii) the massive prehistoric megafauna losses are linked to human expansion and have had strong ecosystem effects,

(iv) development of a clear concept and research agenda for rewilding,

(v) application of remote sensing to ecosystem management under global change, and

(vi) a Big Data, interdisciplinary research agenda for assessing impacts of nature on human mental health.

FUTURE PLANS
My future research plans concentrate on developing the four research themes in BIOCHANGE. More specifically, I will have key focus on:

(1) Transient biodiversity dynamics, trophic changes (notably megafauna losses and comebacks and their ecosystem impacts), and novel ecosystems (i.e., human-caused self-sustaining ecosystems with species assemblages and/or environmental conditions without historical precedent).

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

(3) The rapidly rising potential 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 exposure to nature and biodiversity for human well-being and the macroecology of the human species.

(5) Ecosystem and landscape management to safeguard biodiversity and maximize co-benefits (nature-based solutions, ecosystem services) for society, with emphasis on rewilding as a key approach to ecosystem restoration and its potential to promote sustainable development in the Anthropocene.

Photo: Else Magård

KEY PAPERS

Engemann, K., C.B. Pedersen, L. Arge, C. Tsirogiannis, P.B. Mortensen, and **J.-C. Svenning.** 2019. Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences USA* 116:201807504.

Morueta-Holme, N., K. Engemann, P. Sandoval-Acuña, J.D. Jonas, R.M. Segnitz, and **J.-C. Svenning**. 2015. Strong upslope shifts in Chimborazo's vegetation over two centuries since Humboldt. *Proceedings of the National Academy of Sciences USA* 112:12741-12745.

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

Sandel, B., L. Arge, B. Dalsgaard, R.G. Davies, K.J. Gaston, W.J. Sutherland, and **J.-C. Svenning**. 2011. The influence of Late Quaternary climate-change velocity on species endemism. *Science* 334:660-664.

Sandom, C.J., R. Ejrnæs, M.D.D. Hansen, and **J.-C. Svenning**. 2014. High herbivore density associated with vegetation diversity in interglacial ecosystems. *Proceedings of the National Academy of Sciences USA* 111:4162-4167.

Svenning, J.-C., P.B.M. Pedersen, C.J. Donlan, R. Ejrnæs, S. Faurby, M. Galetti, D.M. Hansen, B. Sandel, C.J. Sandom, J.W. Terborgh, and F.W.M. Vera. 2016. Science for a wilder Anthropocene: Synthesis and future directions for trophic rewilding research. *Proceedings of the National Academy of Sciences USA* 113:898-906.

Teng, S.N., C. Xu, L. Teng, and **J.-C. Svenning**. 2020. Long-term effects of cultural filtering on megafauna species distributions across China. *Proceedings of the National Academy of Sciences USA* 117:486-493.

Watmough, G.R., C.L.J. Marcinko, C. Sullivan, K. Tschirhart, P.K. Mutuo, C.A. Palm, and **J.-C. Svenning**. 2019. Socioecologically informed use of remote sensing data to predict rural household poverty. *Proceedings of the National Academy of Sciences USA* 116:1213-1218.

FELIX RIEDE

Photo: Rógvi N. Johansen, Moesgård Museum

WHO ARE YOU?
My name is Felix Riede; I was born and raised in Germany but have for the last ten years lived in Denmark with my Danish-American wife and our two boys, Alexander (7) and Oskar (3).

POSITION AND BACKGROUND
I received my entire university education in the UK with first a BA from Durham, then an 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 became British Academy Postdoctoral Fellowship at the Centre for the Evolution of Cultural Diversity (UCL). In 2009, I joined Aarhus University, initially as Assistant Professor, then Associate Professor, with intermittent visiting appointments at Harvard (Anthropology) and Cambridge (Geography). After having been Head of Department for a few years, I became Professor MSO in Environmental Humanities and Climate Change Archaeology. In addition to my position at AU, I am also affiliated (since late 2019) with the Oslo School of Environmental Humanities as Visiting Professor II.

MAIN RESEARCH AREAS
When at Campus Moesgård, I lead the ERC Consolidator Grant project CLIOARCH and head the Laboratory for Past Disaster Science, the latter 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 and how this

KEY PAPERS

Jørgensen, E.K. and **F. Riede**. 2019. Convergent catastrophes and the termination of the Arctic Norwegian Stone Age: A multi-proxy assessment of the demographic and adaptive responses of mid-Holocene collectors to biophysical forcing. *The Holocene*. 29:1782–1800

Maring, R. and **F. Riede**. 2019. Possible wild boar management during the Ertebølle Period. A carbon and nitrogen isotope analysis of Mesolithic wild boar from Fannerup F, Denmark. *Environmental Archaeology* 24:15-27.

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

Pedersen, J.B., A. Maier, and **F. Riede**. 2019. A punctuated model for the colonisation of the Late Glacial margins of northern Europe by Hamburgian hunter-gatherers. *Quartär* 65:85–104.

Reinig, F., P. Cherubini, S. Engels, J. Esper, G. Guidobaldi, O. Jöris, C. Lane, D. Nievergelt, C. Oppenheimer, C. Park, H. Pfanz, **F. Riede**, H.-U. Schmincke, M. Street, L. Wacker, and U. Büntgen. 2020. Towards a dendrochronologically refined date of the Laacher See eruption around 13,000 years ago. *Quaternary Science Reviews* 229: 106128.

Riede, F. 2018. Deep pasts – deep futures: A palaeoenvironmental humanities perspective from the Stone Age to the Human Age. *Current Swedish Archaeology* 26:11–28.

Riede, F. 2019. Niche construction theory and human biocultural evolution. Pages 337-358 in A.M. Prentiss, ed. *Handbook of evolutionary research in archaeology*. Springer International Publishing, Cham.

Riede, F. 2019. Fra stenalderen til plastikalderen – palæomiljø-humanistiske perspektiver på arkæologiens forhold til klimaændringer. *Arkæologisk Forum* 41:3–138.

evidence can be brought forward into current debates about climate change, resilience, and vulnerability.

MAIN RESEARCH QUESTIONS

My work is focused on human-environment relations, on biocultural adaptations, and 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 also have an interest in the Anthropocene and how we can approach this, in many ways controversial, epoch, archaeologically. I am keen on bringing sophisticated quantitative and natural science methods to the humanities in general and archaeology in particular. In addition, I am keen on bringing our research out into the world.

FUTURE PLANS

My ERC Consolidator Grant project CLIOARCH has recently kicked off. We are recruiting vigorously and the first results are coming in. 2020 will also see the wrapping-up of my Sapere Aude II project, with a final exhibition at Moesgård Museum, which will open on September 18, 2020. In BIOCHANGE, I am involved in a variety of projects that are looking at past human-environment relations and at the potential impact of volcanism on endangered species, both of which will be high on my agenda in the coming time.

SIGNE NORMAND

WHO ARE YOU?
I am Signe Normand. I was born in Aarhus and lived the first six years of my life next to the botanical garden and greenhouses in Aarhus. Later, I lived in other parts of Denmark (Grenaa & Ribe), Norway, the US, and Switzerland. I have lived in Aarhus for the last 6 years, and live down town with my Swiss husband and our three children; Liv (11), Sia (9), and Noe (4).

POSITION AND BACKGROUND
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, and 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 afterwards a Master's and PhD degree by studying the distribution and diversity patterns of the European flora. After receiving my PhD degree, I went onto 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, and am now Professor in Botanical Macroecology and have established a research group focused on vegetation dynamics as well as the UAS4Ecology Lab, a research facility using the emerging Unmanned Aerial System (UAS) technology to answer questions in ecology. 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, as well as strongly involved in the establishment of a center focused on utilizing the potential of space science and earth observations across Aarhus University.

MAIN RESEARCH AREAS AND QUESTIONS
I am a macro- and vegetation ecologist dedicated to understand patterns of species' occurrence and biodiversity and to provide 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 effort and fieldwork have been centered in recent years. I mainly utilize remote sensing, range dynamic models, dendro- and trait-based ecology. The goal of my research is to find answers to fundamental questions in ecology, but also to inform nature conservation about the impact of global change on biodiversity. My current research has three main components:

(i) Empirical studies to gain insight on 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 dynamic 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
Continue to gain indebt 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 focus on climate change impacts on Arctic shrub dynamics.

Photo: Urs A. Treier, 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, and **S. Normand.** 2020. Detecting shrub encroachment in semi-natural grasslands using UAS LiDAR. *Ecology and Evolution.* (e-pub ahead of print).

Normand, S., U.A. Treier, C. Randin, P. Vittoz, A. Guisan, and 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.

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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, and 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 hu¬man 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, and **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.

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). A biologist by training who 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 Post-Doctoral appointment (2013-2017) at AU as part of the ERC-funded HISTFUNC project lead by Jens-Christian Svenning. In 2017, I became a lecturer in Global Change Biology at Queens 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 species.

MAIN RESEARCH AREAS

As a global change ecologist and macroecologist, my research focuses on quantifying and explaining how environmental changes shape diversity patterns in space and time, and how the current transformation of the biosphere can result in the emergence of novel ecosystems. In doing so, my work has evaluated how past, present, and future environmental changes can affect different biodiversity dimensions, and consequently, nature's contributions to people. My work has used a biogeographical and macroecological perspective to determine the implications changes in the environment (natural and anthropogenic) for biodiversity and nature's contributions to people. My aim has been to provide knowledge-based advice on how to manage nature under Earth's changing ecological and climatic conditions and 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 paleoclimate on species distributions, community composition, as well as biodiversity patterns (past and present). 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 establishing when, where, and how environmental and biological tipping points are crossed within and between trophic levels and the consequences of these changes for nature's contributions to people.

KEY PAPERS

Burke, K.D., J.W. Williams, S. Brewer, W. Finsinger, T. Giesecke, D.J. Lorenz, and **A. Ordonez.** 2019. Differing climatic mechanisms control transient and accumulated vegetation novelty in Europe and eastern North America. *Philosophical transactions of the Royal Society of London Series B, Biological Sciences* 374:20190218.

Ordonez, A. and J. Williams. 2013. Comparing 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. and J.-C. Svenning. 2015. Geographic patterns in functional diversity deficits are linked to glacial-interglacial climate stability and accessibility. *Global Ecology and Biogeography* 24:826-837.

Ordonez, A. and J.-C. Svenning. 2018. Greater tree species richness in eastern North America compared to Europe is coupled to denser, more clustered functional trait space filling, not to trait space expansion. *Global Ecology and Biogeography* 27:1288-1299.

Ordonez, A. and J.-C. Svenning. 2020. The potential role of species and functional composition ingenerating historical constraints on ecosystem processes. *Global Ecology and Biogeography* 29:207–219.

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

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

Photo: Dennis Pedersen, BIOCHANGE.

RESEARCH HIGHLIGHTS

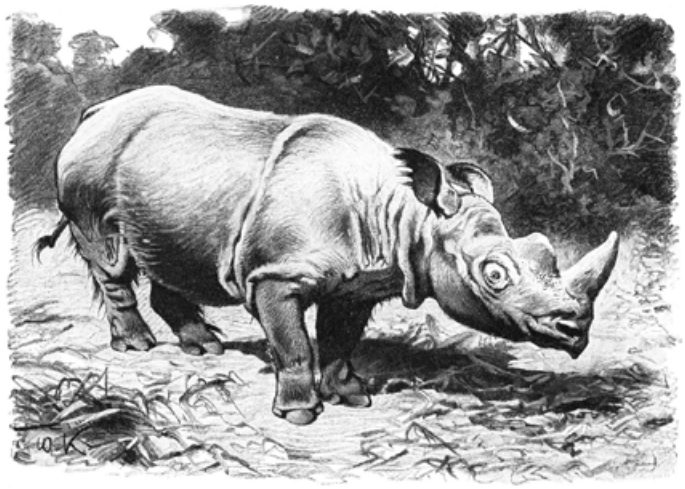
RESEARCH HIGHLIGHTS 2019/2020

THEME 1

Theme 1 focusses 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 change, (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. During the past year, we have achieved important research progress in all focal areas within theme 1. In the following, a few of these studies are highlighted.

Several new studies have contributed to BIOCHANGE's leadership on long-term disequilibria driven by past climate change thousands to millions of years back in time. One study, led by former team members and involving Signe Normand (SN), Alejandro Ordonez Gloria (AOG) and Jens-Christian Svenning (JCS), shows how species and phylogenetic endemism in Northern Hemisphere trees are concentrated in areas with muted glacial-interglacial climate instability (Feng *et al.* 2019, *Glob. Ecol. Biogeogr.*). Another study, led by Timo Conradi and involving BIOCHANGE alumnus Koenraad van Meerbeek, AOG, and JCS, shows that past glacial-interglacial climate instability not only still negatively affects stand-level tree functional diversity across Northern Hemisphere forest regions, but also penetrate to reduce their productivity (Conradi *et al.* 2020, *Ecol. Lett.*).

BIOCHANGE members have also provided important new advances on novel ecosystems: BIOCHANGE alumni Simon Schowanek and Matt Davis (MD), and JCS were involved in a global study on large herbivorous mammals with a focus on non-native species, mostly historically introduced for hunting or as domestic animals (now feral) and a key novel component of many ecosystems (Lundgren *et al.* 2020, *PNAS*). These aliens are often negatively perceived as 'invasive' species. However, our study shows that they provide net partial recovery of the functional composition of herbivore assemblages from human-linked past megafauna extinctions, pointing to a need for re-assessing their role in modern ecosystems. AOG was a co-author of a study showing climatic novelty as the main driver of novel vegetation assemblages during the last 21,000 years (Burke *et al.* 2019, *Phil. Trans. R. Soc. B.*). Finally, Wubing Xu led a study involving AOG and JCS, showing how land use in China today promotes already widespread species and pushes back naturally rare species, likely contributing to the formation of novel plant assemblages (Xu *et al.* 2019, *PNAS*).

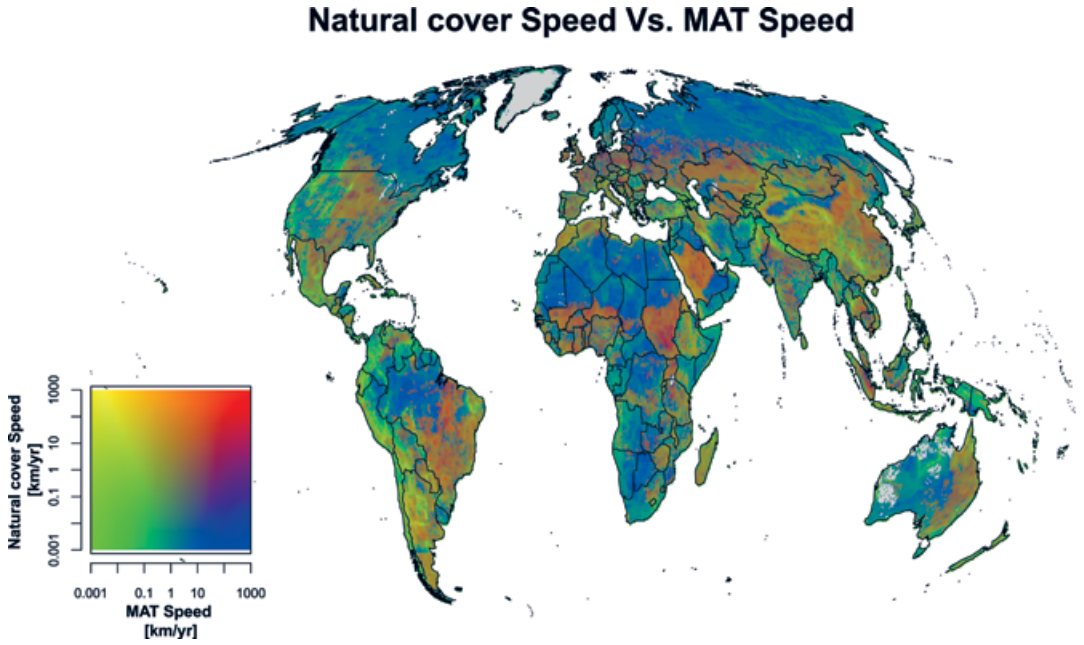


A BIOCHANGE study by Teng *et al.* (2020) shows how megafauna distributions in China across the last 2000 years have declined in response to rising human pressures, including the total loss of rhinos from the country. Here a Sumatran rhinoceros (*Dicerorhinus sumatrensis*). Image: Friedrich Wilhelm Kuhnert, Brehms Tierleben, Small Edition 1927 (Wikimedia Commons).

Multiple studies have pushed forward the research frontier on megafauna dynamics and effects in relation to rewilding (see also Theme 4): The Lundgren *et al.* study mentioned above intersects the novel ecosystems and megafauna research agendas. Another study led by Shuqing Teng (as a result of his BIOCHANGE-based PhD) with JCS shows how megafauna distributions in China across the last 2000 years have declined in response to rising human population densities and changing land-use practices (Teng *et al.* 2020, *PNAS*). Looking to the marine realm, MD and JCS have also participated in an international research collaboration showing that marked reductions in the functional diversity of marine megafauna (whales, sharks, etc.) are likely if existing pressures continue during the next century, with likely negative consequences for oceanic and coastal ecosystems (Pimiento *et al.* 2020, *Sci. Adv.*).

Full references for the publications mentioned on these pages can be found in section Communication and Outreach under Publications.

THEME 2



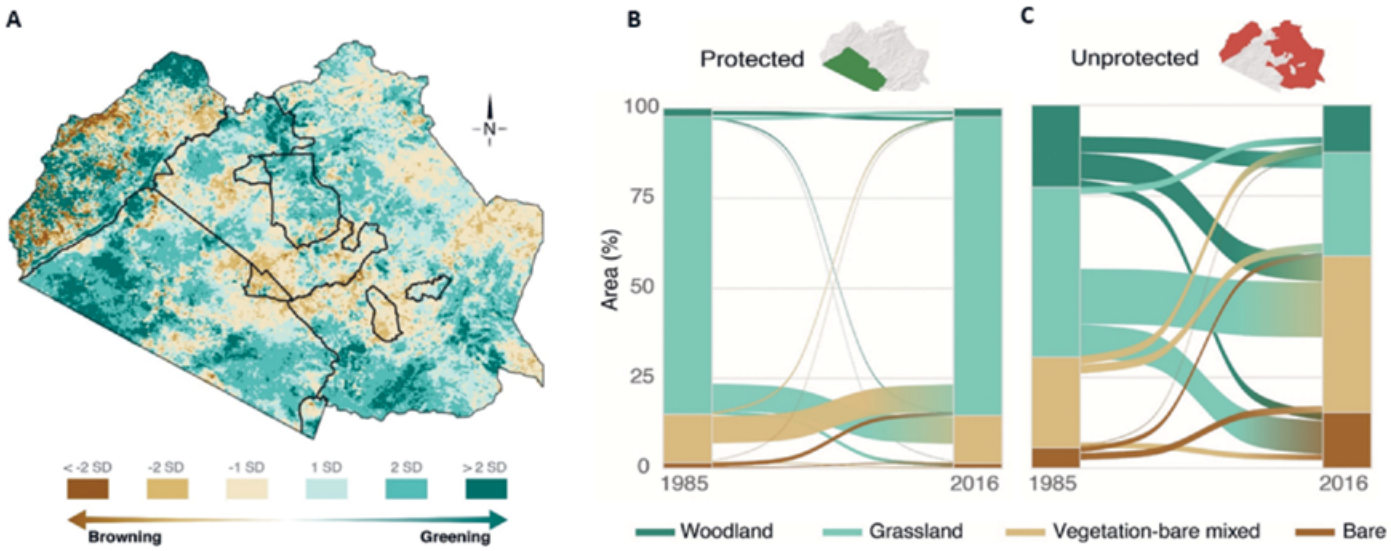
The degree to which species or communities would need to respond to keep up with the spatiotemporal changes in climate (Mean Annual Temperature (MAT)) and natural vegetation cover for the 1961-2013 period. Rates of environmental changes are measured as speeds of change (a balance between changes in time and changes in space). This metric indicates how fast climatic and vegetation cover conditions are moving across geographical space, and hence how fast ecological entities would need to move to keep up with these changes. Red areas are those where climate and vegetation are changing the most. Blue regions are those where the climate is the main driver of change. Last, yellow regions are those where shifts in vegetation cover drive environmental rearrangements. Map: Alejandro Ordonez Gloria, BIOCHANGE.

In theme 2, we have a focus on one of humanity's greatest challenges, namely human-induced climate change, aiming to strengthen our predictive capacity of climate change impacts on ecosystems and biodiversity and to develop methods for society to optimize its responses to these dynamics. During the last year, we have made significant advances in our understanding of how climate change has affected biodiversity and ecosystems, our ability to forecast these changes, and determining possible strategies to manage, mitigate or adapt to these changes. Here, we highlight a few selected studies.

Alejandro Ordonez Gloria (AOG) and Jens-Christian Svenning (JCS) have contributed to show the importance of considering the legacies of past climatic events in determining how ecosystems will respond in an Anthropogenic dominated future (Conradi *et al.* 2020, *Ecol. Lett.*; also highlighted in Theme 1; and Ordonez & Svenning 2020, *Glob. Ecol. Biogeogr*). This conceptual framework has implications for understanding the (ir)reversibility of ecological changes. It also shows the need to consider biogeographical contingencies in global vegetation models to make better predictions. In related work, AOG and JCS have contributed to two studies that show the utility of paleoecological data to determine how biodiversity and ecosystems could respond to current environmental changes (Knight *et al.* 2020, *Am Nat.*; Burke *et al.* 2019, *Phil. Trans. R. Soc. B.*; the latter also highlighted in Theme 1).

BIOCHANGE has made significant contributions to the way we assess vulnerability and determining conservation needs under the current rates of climate change and land degradation Specifically, Anne Blach Overgaard and JCS were involved in a study, where a novel approach to accelerate the assessment of the conservation status of species at large were developed and used to show how over 1/3 of tropical African vascular plant species are likely in danger of extinction and vulnerable to climate change (Stévart *et al.* 2019, *Sci. Adv.*). In addition, JCS has contributed to a study showing that almost 40% of land plant species have been observed and recorded less than five times, meaning that very rare plants constitute a major part of global plant diversity (Enquist *et al.* 2019, *Sci. Adv.*). The study also shows that these rare species are clustered in hotspots that have been climatically stable across many thousands of years but are experiencing disproportionately high levels of pressure from human land use. JCS also contributed to a study, which shows that limiting climate change to 2°C and conserving 30% of the terrestrial area could more than halve extinction risk for tropical plants and vertebrates compared with uncontrolled climate change and no increase in nature conservation areas (Hannah *et al.* 2020, *Ecography*).

THEME 3

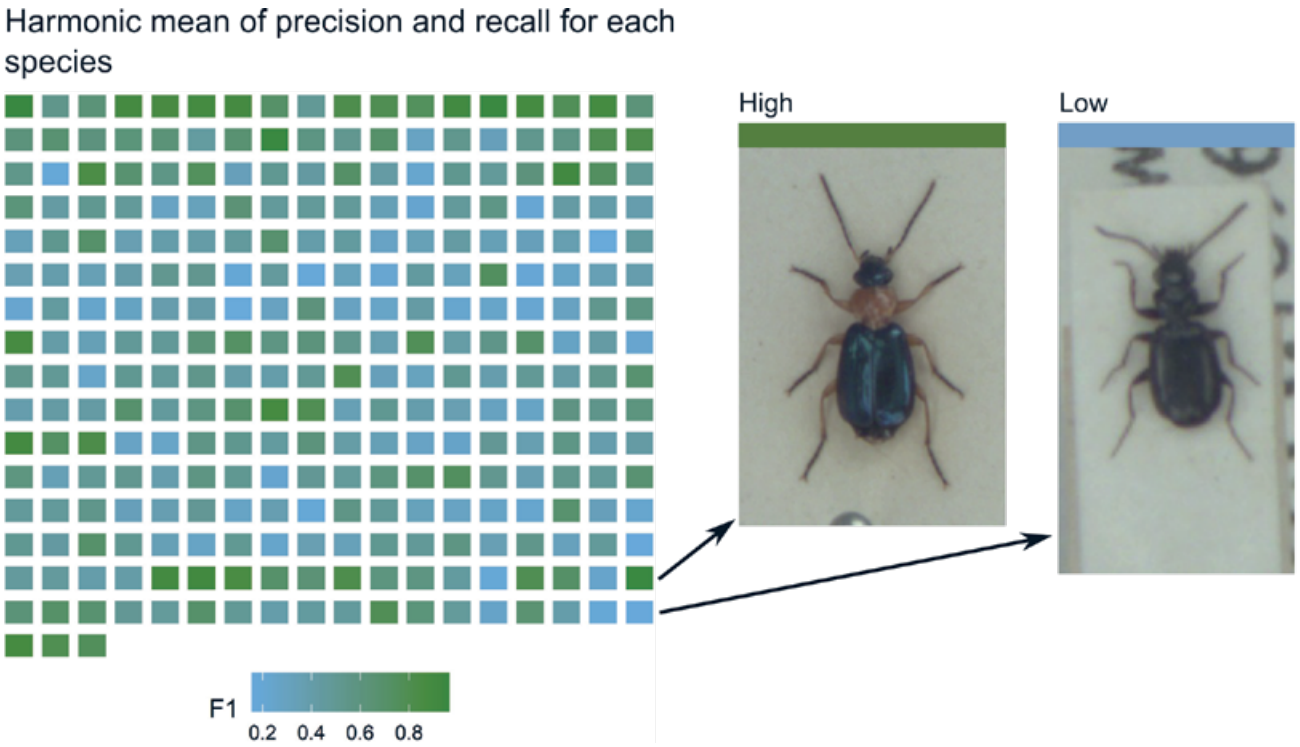


Accelerating savanna degradation threatens the Maasai Mara socioecological system. (A) Vegetation dynamics – greening/browning trend observed from MODIS satellite between 2000 and 2016; (B,C) Land cover transitions observed from Landsat satellites between 1985 and 2016 within protected and unprotected areas. Figure: Wang Li, BIOCHANGE.

Big data and machine-learning analyses of remote sensing data from satellites, airplanes, 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 is done, e.g., in a study with contribution from Urs A. Treier (UT) and Signe Normand (SN) in the Arctic (Westergaard-Nielsen *et al.* 2020, *Environ. Res. Lett.*), and several other studies mentioned below, as well as in relation to human health, illustrated in a study led by Kristine Engemann with Jens-Christian Svenning (JCS) (Engemann *et al.* 2020, *Schizophr. Res.*).

Global change is accelerating across the globe. In Africa, degradation of the savanna ecosystem is accelerating, as shown by Wang Li, Robert Buitenwerf, Michael Munk, and JCS based on 32 years of satellite imagery from the Maasai Mara ecosystem (Li *et al.* 2020, *Glob. Environ. Chang*). Rapid warming is associated with terrestrial greening in the global north. However, detecting greening of the Arctic from satellites is complicated by many ecological and methodological factors, as discussed in a study co-led by BIOCHANGE associate Jeff Kerby with Jakob J. Assmann and SN (Myers-Smith and Kerby *et al.* 2020, *Nat. Clim. Chang.*). One factor affecting the greening signal is insect outbreaks. Linking time-series of NDVI from satellites with insect outbreaks, BIOCHANGE associate Angela Prendin, SN, and UT disentangle the effect of warming and outbreaks, and map their spatio-temporal dynamics (Prendin *et al.* 2020, *J. Biogeogr.*). SN and JCS have also contributed to highlighting the importance of remotely sensed data for macroecology and its linkage with dynamics at local to landscape scales in several papers (Teng *et al.* 2020, *Curr. Landsc. Ecol. Reports*; Wüest *et al.* 2020, *J. Biogeogr.*).

Several studies led by BIOCHANGE members have illustrated the strength of different machine learning algorithms for detecting individual species. As an important step towards the use of camera traps for monitoring the diversity of arthropods, Oskar L.P. Hansen and JCS show that convolutional neural networks can be used to successfully identify species of carabid beetles from habitus images (Hansen *et al.* 2020, *Ecol. Evol.*). Using



The harmonic mean of precision and recall (F1) with tiles representing the 291 carabid beetle species included in the classification model in the Hansen *et al.* study. Tiles are ordered by the species number in the checklist of beetles of the British Isles (i.e. species within a genus or subfamily are placed closer to each other). Two example species of high and low F1 values in right panel, *Lebia chlorocephala* (high) and *Syntomus truncatellus* (low).
Figure Oskar L.P. Hansen, BIOCHANGE.

drone-based LiDAR, Bjarke Madsen (BM), UT, and SN show that shrub individuals and their biomass change can be detected within 3D point clouds, and illustrate the potential for assessing vegetation dynamics in relation to rewilding (Madsen *et al.* 2020, *Ecol. Evol.*). Besides insects and plants, these approaches have also been used for vegetation cover in a study led by Samira Kolyaie with UT, BM, and SN (Kolyaie *et al.* 2019, *Polar Biol.*).

As part of BIOCHANGE's focus on improving predictive models (see Theme 2), we have an emphasis on how new data and technologies can improve these. An excellent example is a paper by Felix Riede, Shumon T. Hussain, and JCS, showing how computational approaches can be used in archaeological and climate change research (Riede *et al.* 2020, *Antiquity*), also linking to our interdisciplinary work on human-environment relations in theme 4.

THEME 4

In Theme 4, we 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, with a major focus on human-environment relations. In the past year, we have made research progress on several fronts within theme 4: human-wildlife interactions, ecosystem services, green spaces and mental health, and long-term human-environment interactions/dependencies. Some of the more noteworthy are highlighted here.

A major study, led by Wubing Xu, together with Jens-Christian Svenning (JCS), Alejandro Ordonez Gloria (AOG) shows how human activities have differential effects on rare and common plant species in China, causing rare species to further contract and common species to become more widespread, an effect leading to a significant homogenization of ecosystems over time (Xu *et al.* 2019, *PNAS*). Staying in China, another study, led by Shuqing Teng together with JCS, focuses on megafauna and finds that pressures arising from expanding Iron Age agriculturalists in Chinese history and later societal developments, rather than climate change, have driven declines of megafauna species across China (Teng *et al.* 2020, *PNAS*; also see Theme 1). The idea of long-term human-environment interactions is also key to the first results arising from Felix Riede's (FR) ERC-funded CLIOARCH project, which FR, JCS present together with Shuman T. Hussain and external collaborators (Riede *et al.* 2020, *Antiquity*).

To overcome the ongoing decline of biodiversity and environmental degradation, there is a strong need to broadly implement ecosystem restoration in manners that are effective, scalable, and socio-ecologically sustainable. This is a major focus of BIOCHANGE's work in theme 4, notably via a leading role in developing rewilding as a restoration approach, leading to a number of empirical and practice-oriented papers this year (including a review paper in Science with JCS' contribution). Related to this, drawing on findings of how anthropogenic pressures, climate change and species properties interact, Sophie Monsarrat, Scott Jarvie and JCS propose the idea of 'Anthropocene refugia' as an evidence-based conservation tool that integrates historical datasets, large species databases and sophisticated modeling tools. More specifically, this work highlights the importance of historically-informed baselines to define the best strategies to protect biodiversity in the Anthropocene, notably providing a fuller representation of restoration options (Monsarrat *et al.* 2019, *Phil. Trans. R. Soc. B)*. The environment also plays a key role in one of BIOCHANGE's most highly publicized finding of the last year, namely the positive influence of residential green space access during childhood for adult mental health, a novel study led by Kristine Engemann with JCS and made possible through the Danish register data and powerful Big Data analytics (Engemann *et al.* 2019, *PNAS*).

Children who grow up within greener surroundings have up to 55% less risk of developing various mental disorders later in life. This is shown by Engemann *et al.* 2019, emphasizing the need for designing green and healthy cities for the future. Photo: MonkeyBusiness/Depositphotos.com.

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 what 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 strong 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). With the VILLUM Investigator project the ambition is to improve our understanding and predictive capacity of the complex biodiversity dynamics under anthropogenic global change and their consequences for people and society, and based hereon, on developing 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 capabilities 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.

Since the project started in 2017, we have achieved strong 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

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

VILLUM FONDEN

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 under way. As a key development, the first of three tenure-track positions linked to the BIOCHANGE project has been filled, namely Robert Buitenwerf as assistant professor in Remote Sensing of Ecosystem Dynamics.

KEY PAPERS

Buitenwerf, R., B. Sandel, **S. Normand**, A. Mimet, and **J.-C. Svenning**. 2018. Land surface greening suggests vigorous woody regrowth throughout European semi-natural vegetation. *Global Change Biology* 24:5789-5801.

Engemann, K., C.B. Pedersen, L. Arge, C. Tsirogiannis, P.B. Mortensen, and **J.-C. Svenning**. 2019. Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences USA* 116:201807504.

Li, W., R. Buitenwerf, M. Munk, I. Amoke, **P.K. Bøcher**, and **J.-C. Svenning**. 2020. Accelerating savanna degradation threatens the Maasai Mara socio-ecological system. *Global Environmental Change* 60:102030.

Svenning, J.-C. 2018. Proactive conservation and restoration of botanical diversity in the Anthropocene's "rambunctious garden". *American Journal of Botany* 105:963-966.

Watmough, G.R., C.L.J. Marcinko, C. Sullivan, K. Tschirhart, P.K. Mutuo, C.A. Palm, and **J.-C. Svenning**. 2019. Socioecologically informed use of remote sensing data to predict rural household poverty. *Proceedings of the National Academy of Sciences USA* 116:1213-1218.

MEGAPAST2FUTURE:

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

14

Principal investigator: Jens-Christian Svenning

Prior to 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 to the present day, 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 the 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 intensifying human impacts on Earth's environment – with pronounced increases in the human population and strong climate changes likely 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 and its functional importance?

Wisents in a pre-release pen in Lille Vildmose, Denmark.
Photo: Jens-Christian Svenning, BIOCHANGE

The project focuses on developing a solid, synthetic understanding of megafauna ecosystem ecology and its potential role in developing a sustainable, biodiverse future. To this end, MegaPast2Future aims to develop new theory on the role of megafauna in ecosystems (work package 1), provide a novel understanding of the evolutionary and biogeographic development of the world's megafaunas and their ecosystem importance (work package 2), do field-based testing of key theory and hypotheses (work package 3), and assess and improve the scope for human-megafauna coexistence in the Anthropocene (work package 4). Given the complexity of the problem, the methodology is 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.

The project will run until end of 2020 and many results will come out this year, with more in the coming years. Core field sites have been established in Denmark, Argentina, Kenya, and South Africa with much fieldwork already well in progress. We have held a second successful international megafauna symposium (this time on the potential for upscaling megafauna restoration to achieve real impact on global sustainable development), a 2019 repetition of our successful megafauna PhD course, with a new instance to be held in August 2020, with many attendees already signed up. Finally, we have been very active in public outreach in relation to this project nationally and internationally. Important new studies from this project have been published in the last year. This includes a paper in PNAS in the beginning of 2020 on megafauna dynamics across China through the last millennia, and a paper in Bioscience in the fall of 2019 on how to integrate rewilding with conventional conservation management

The project is funded by the Carlsberg Foundation 'Semper Ardens' research project, with 13,777,082 DKK and runs 2016-2020. It currently employs four postdocs and three PhD students.

CARLSBERG FOUNDATION

Giraffe feeding on woody vegetation in Kruger National Park, South Africa. Photo: Jens-Christian Svenning, BIOCHANGE

KEY PAPERS

Davis, M., S. Faurby, and **J.-C. Svenning**. 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.

Jarvie, S. and **J.-C. Svenning**. 2018. Using species distribution modelling to determine opportunities for trophic rewilding under future scenarios of climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences* 373:20170446.

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

Schweiger, A.H., I. Boulangeat, T. Conradi, **M. Davis**, and **J.-C. Svenning**. 2019. The importance of ecological memory for trophic rewilding as an ecosystem restoration approach. *Biological Reviews* 94:1-15.

Svenning, J.-C., **M. Munk**, and **A.H. Schweiger**. 2019. Trophic rewilding: ecological restoration of top-down trophic interactions to promote self-regulating biodiverse ecosystems. Pages 73-98 in J.T. du Toit, N. Pettorelli, and S.M. Durant, eds. *Rewilding.* Cambridge University Press, Cambridge.

Teng, S.N., C. Xu, L. Teng, and **J.-C. Svenning.** 2020. Long-term effects of cultural filtering on megafauna species distributions across China. *Proceedings of the National Academy of Sciences USA* 117:486-493.

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

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 plays a central role in forest ecosystems and for 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.

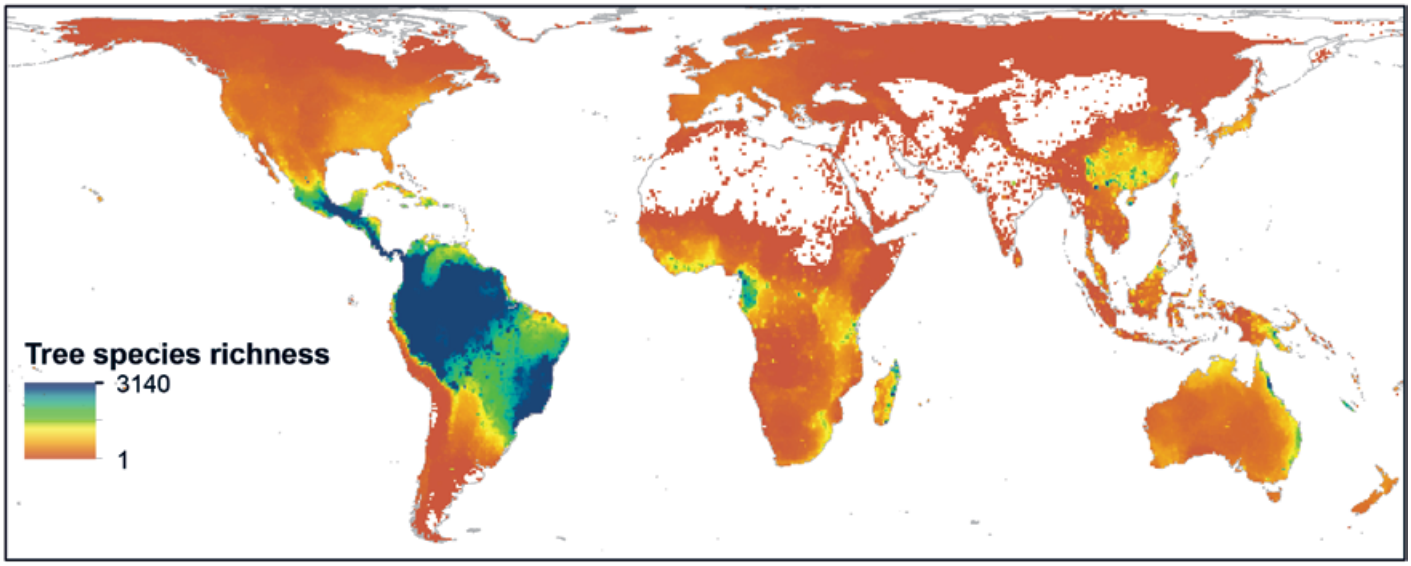
To improve our understanding of global tree distributions, we have carried out a large effort to collect, integrate, and quality check data on distributions, traits, and phylogeny for ca. 65,000 identified tree species globally, and are now applying advanced modelling approaches to generate estimates of distributions and climate niches and for estimating 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 ca. 500,000 tree species and including ca. 37 million species occurrence records as well as 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. Further major papers both led by TREECHANGE and with us as collaborators are in the works. During 2019, we held two successful international workshops, one on Big Data for plant diversity research (TREECHANGE-Botanical Information & Ecology Network collaboration) and one on how to implement reforestation to maximally benefit biodiversity globally, with many, important papers as the expected outcome in the coming years.

Bialowieza forest is Europe's largest remaining semi-natural lowland woodland and contains very large individuals of a variety of European tree species (here, European hornbeam, Carpinus betulus), especially in its most protected parts. Photo: Jens-Christian Svenning, BIOCHANGE.

The project is funded by Danish Council for Independent Research | Natural Sciences, with 2,587,678 DKK and runs 2016-2019. It has 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



Global pattern of tree species richness based on 46,767 estimated species distribution maps using data from the TREECHANGE occurrence database with a total of 7,066,785 occurrence records. Map use the Behrmann projection at 50 km × 50 km spatial resolution.
Map: Wenyong Guo, BIOCHANGE

KEY PAPERS

Feng, G., Z. Ma, B. Sandel, L. Mao, **S. Normand, A. Ordonez**, and **J.-C. Svenning**. 2019. Species and phylogenetic endemism in angiosperm trees across the Northern Hemisphere is jointly shaped by modern climate and glacial-interglacial climate change. *Global Ecology and Biogeography* 28:1393-1402.

Jensen, D.A., K.P. Ma, and **J-C. Svenning**. 2019. Steep topography buffers threatened gymnosperm species against anthropogenic pressures in China. *Ecology and Evolution* 10:1838-1855.

Serra-Diaz, J.M., B.J. Enquist, B. Maitner, C. Merow, and **J.-C. Svenning**. 2018. Big data of tree species distributions: how big and how good? *Forest Ecosystems* 4:30.

Steidinger, B.S., T.W. Crowther, J. Liang, M.E. Van Nuland, G.D.A. Werner, *et al.*, **J.-C. Svenning**, *et al.*, and G. consortium. 2019. Climatic controls of decomposition drive the global biogeography of forest-tree symbioses. *Nature* 569:404-408.

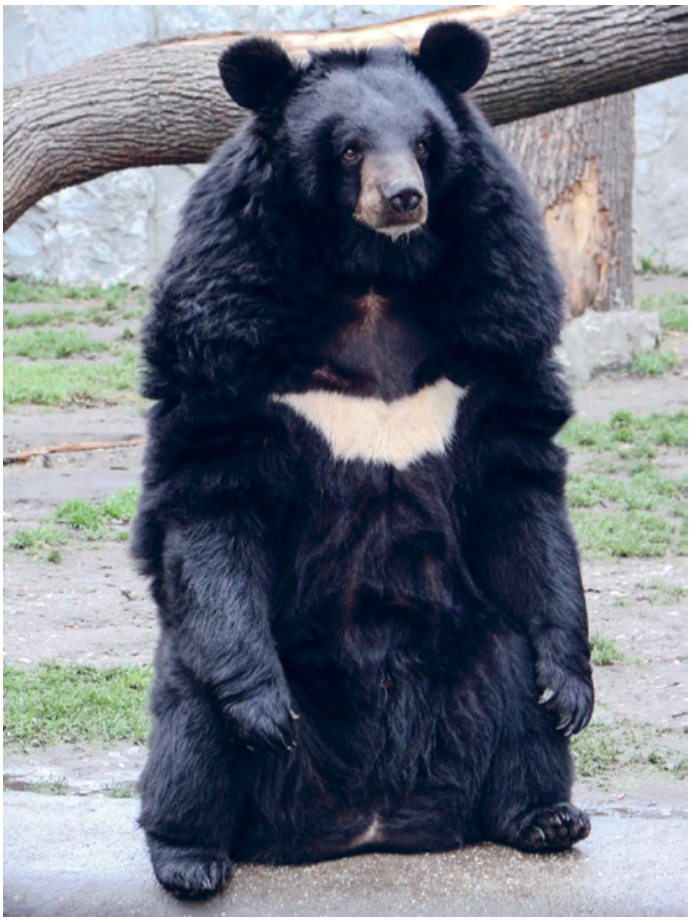
TERRANOVA:

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 at improving our long-term understanding of ecosystem and landscape histories, and land-use strategies and impacts in Europe in the Holocene and Anthropocene, and 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, and together with the academic beneficiaries form an unprecedented inter-sectoral consortium for training the next generation of scientists, policy makers, and entrepreneurs.

Two of the 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 been successfully recruited and started with good progress in late 2019 or January 2020. This project contributes to theme [1] Fundamental Biodiversity Dynamics and theme [4] Interdisciplinary Innovation of BIOCHANGE.

FURTHER READING

http://terranovaproject.eu

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).

As part of TerraNova, the two AU PhD students are estimating vegetation structure and megafauna distributions during the Last Interglacial (ca. 125,000 years ago), to inform on the European ecosystem structure prior to the arrival of modern humans, *Homo sapiens.*
The fauna included species such as:
Left the Asian black bear (now only in Asia)
Above the Straight-tusked elephant (extinct).
Photos: Guérin Nicolas, Wikimedia Commons and Apotea, Wikimedia Commons

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 and that 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 culturehistorical narrative relating to this period. In so doing, the project will pioneer a fully transparent and replicable – and eminently transferable – methodology for the study of 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 (Fig. 1). 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.

Further reading

http://cas.au.dk/en/ERC-clioarch/

KEY PAPERS

Reynolds, N. and **F. Riede.** 2019. House of cards: cultural taxonomy and the study of the European Upper Palaeolithic. *Antiquity* 93:1350–1358.

Riede, F., **C. Hoggard**, and S. Shennan. 2019. Reconciling material cultures in archaeology with genetic data requires robust cultural evolutionary taxonomies. *Palgrave Communications* 5:55.

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 2019-2022.

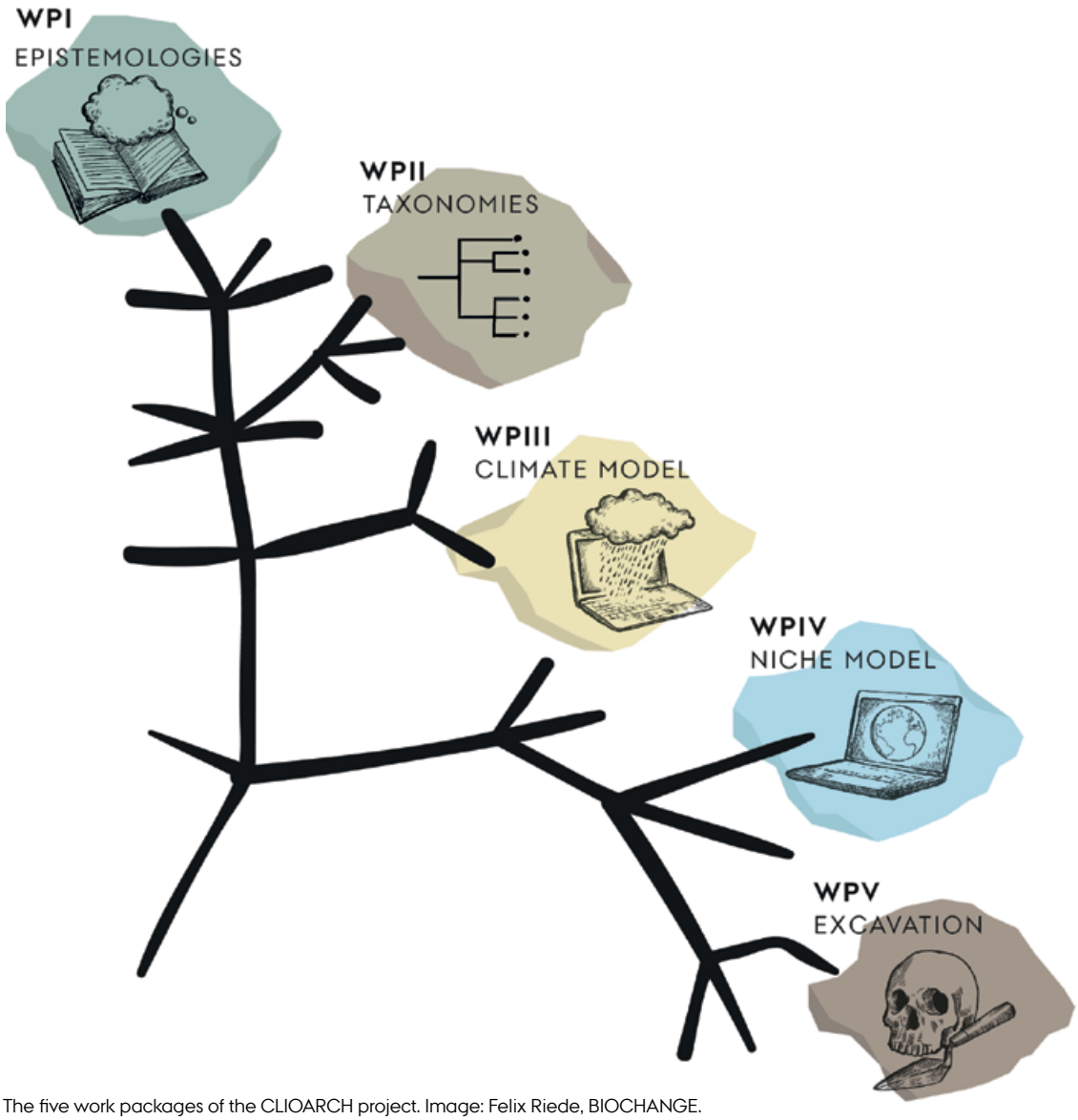


Figure 1. The five work packages of the CLIOARCH project. Image: Felix Riede, BIOCHANGE.

LAPADIS (PHASE 2):

4

APOCALYPSE THEN? THE LAACHER SEE VOLCANIC ERUPTION (13,000 YEARS BEFORE PRESENT), DEEP ENVIRONMENTAL HISTORY AND EUROPE'S GEO-CULTURAL HERITAGE

Principal investigator: Felix Riede

This project is funded by the Independent Research Council Denmark's Sapere Aude Starting Grant instrument and represents phase two of LAPADIS – the Laboratory for Past Disaster Science. In the project, we conduct ground-breaking research centered on a cataclysmic environmental event that punctuated an early period on Nordic prehistory – the Laacher See volcanic eruption that occurred ca. 13,000 years ago in present-day Germany (Fig. 1), and its impact on communities in Europe and especially in southern Scandinavia. On this basis, we wish to develop novel outreach engagements that make Europe's geo-cultural heritage work for environmental literacy.

By exploring in parallel and unprecedented detail the cultural and geological dynamics of the Laacher See eruption and its suggested consequences, this project will lead to: (1) a significantly improved understanding of this last major continental European eruption, and (2) allow us to test the dual hypothesis of its regionally varying human impact in Central Europe and southern Scandinavia respectively. This project will furthermore (3) provide a robust historically informed evidence-base for engagement of deep-time Environmental Humanities with the profound ethical predicaments of present and future climate change and climate catastrophe.

This project is now in its final phase; several papers are being written up, an edited volume and a journal special issue are in press. The project's final deliverable is a special exhibition scheduled to take place at Moesgård Museum, Denmark, in the last quarter of 2020. The idea with this exhibition is to use past disasters and what we know about these geologically and in terms of societal impacts as forecast scenarios for future impacts. This builds on the idea of so-called Realistic Disaster Scenarios but extends these with knowledge gained from case studies provided by archaeology and history. The rationale is that the archaeological record serves as a database of completed natural experiments of history that can inform surge capacity tests and scenarios of future societal trajectories. For the planned exhibition, we use this idea to mirror potential future impacts of re-activated volcanism at the Laacher See volcano in the many results produced by the project. For instance, we will bring together map data on volcanic ashfall as recorded in our geological and archaeological archives with similar data on contemporary population densities and critical infrastructures in Europe to create powerful hazard maps. This project contributes to theme [4] Interdisciplinary Innovation of BIOCHANGE.

Further reading
http://projects.au.dk/lapadis/

KEY PAPERS

Sauer, F., D. Stott, and **F. Riede**. 2018. Search for new final Palaeolithic rock shelter sites in the Federal State of Hesse. *Journal of Archaeological Science: Reports* 22:168–178.

Sauer, F. and **F. Riede**. 2019. A critical reassessment of cultural taxonomies in the Central European Late Palaeolithic. *Journal of Archaeological Method and Theory* 26:155–184.

The project is funded by Danish Council for Independent Research | Natural Sciences with 6,926,238 DKK.

Figure 1. The crater remains of the Laacher See volcano as seen from a drone. What 13.000 years ago was an inferno is today an idyllic lake. $C0_2$ bubbling up from the lake bottom reveals the still-active magma reservoir below, however, and reminds us of the lingering danger posed by low-frequency/high-magnitude geological hazards such as volcanic eruptions.
Photo: Florian R. Sauer, BIOCHANGE associate.

CEH:
CENTRE FOR ENVIRONMENTAL HUMANITIES

Principal investigator: Felix Riede

The Aarhus University Centre for Environmental Humanities (CEH) is concerned with re-engaging the environment in disciplines such as history, religion, literature and media, ethics, archaeology, anthropology, education, and artistic practice – all with a specific interest in reflecting on present concerns in a deep historical perspective. In the face of the profound environmental crises that loom large in politics and the popular imagination, exploring the cultural interfaces of different societies and their sur-roundings, synchronically and diachronically, has attained a new urgency. The AU CEH aims to bring together hitherto isolated Environmental Humanities scholars at Aarhus University, and to provide a major longer-term catalyst for the diverse research conducted under its aegis. The CEH has been seed-funded directly from the School of Culture and Society and currently hosts an International Network Programme (INP) grant from the Danish Agency for Science and Higher Education for developing the Aarhus-Cape Town Environmental Humanities Partnership.

Founded by myself, the leadership of the CEH has now passed on to the environmental anthropologist Heather Swanson. The CEH has hosted a series of workshops with our South African colleagues to design and implement a PhD course focused on water infrastructures and water cultures. While originally planned to be held in Cape Town, the ongoing water crisis there led us to relocate the event to Aarhus. This project contributes to theme [2] Global Challenges and theme [4] Interdisciplinary Innovations of BIOCHANGE.

Further information on this and other CEH activities can be found here: http://ceh.au.dk

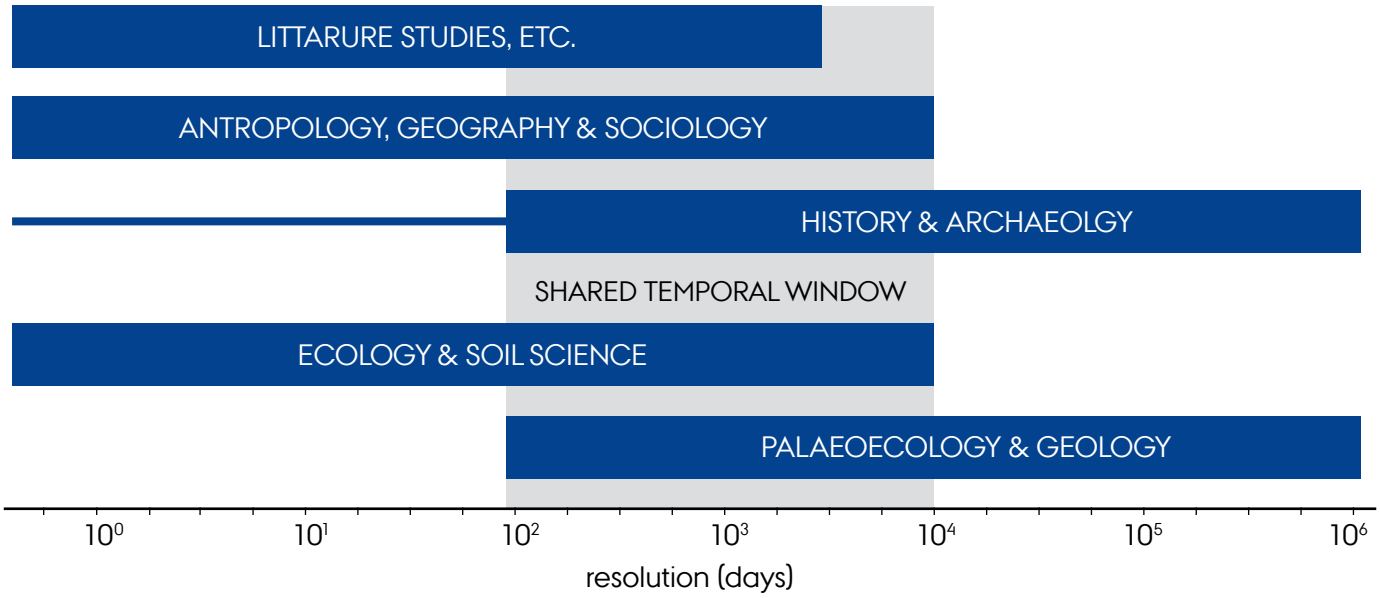
KEY PAPERS

Riede, F. 2018. Deep pasts – deep futures: A palaeoenvironmental humanities perspective from the Stone Age to the Human Age. *Current Swedish Archaeology* 26:11–28.

Riede, F. 2019. Fra stenalderen til plastikalderen - palæomiljøhumanistiske perspektiver på arkæologiens forhold til klimaændringer. *Arkæologisk Forum* 41:3–13.

The project is funded by Danish Agency for Science and Higher Education with 272,197 DKK and Committee for Research and External Cooperation at Aarhus University with 274,135 DKK. Finally, the School for Culture and Society supports the CEH with internal funds.

CEH
CENTRE FOR ENVIRONMENTAL HUMANITIES



The overlapping temporal windows of disciplinary perspectives within the established (neo-) and the deep time (palaeo-) environmental humanities.
Figure: Felix Riede, BIOCHANGE

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

24

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 en-vironmental and cultural historical datasets together in order to provide evidence-based snapshots of past environmental conditions and human responses. With a focus on hydrolog-ical changes in inland (river, lake) and coastal contexts, C24 connects directly with other C2C CC projects and makes use of ex-isting 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 (e.g., National konference om klimatilpasning, 23.-24.10.2019 in Horsens: http://www.c2ccc.eu/aktiviteter/tidligere-aktiviteter/national-konference-om-klimatilpasning/). Finally, the project will add value to C2C CC overall by translat-ing climate history into components useable also in sustainable growth via tourism. The popular outreach portal danmarkshisto-rien.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: http://danmarkshistorien.dk/leksikon-og-kilder/vis/materiale/miljoehistorie-hvad-er-det/. We have also curated a small exhibition on environmental his-tory 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 PAPER

Riede, F. and U. Krogh (Eds.). 2019. Combatting climate change culturally: how cultural and natural heritage can strengthen climate change adaptation. Aarhus University, Aarhus. Download it here: https://pure.au.dk/portal/files/170207625/PI_Climate_Heritage_Booklet_digital.pdf.

The project is supported by the EU LIFE-program with approximately 52 million DKK and has a total budget of ca. 90 million DKK. It currently employs one research assistant.

Our report and mini-exhibition at the national conference on climate change adaptation in Horsens.
Photo: C2C CC secretariat.

HUMAN COLONIZATION:

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

14

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, 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 their subsistence economy, however, the two phases of the Hamburgian culture diverge only in their diagnostic projectile point forms. A chronological as well as 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 palaeolecological remains – including the remarkably well-preserved bones of Denmark's oldest gull (Fig. 1). 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 demograpic 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 re-think 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] Fundamental 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.

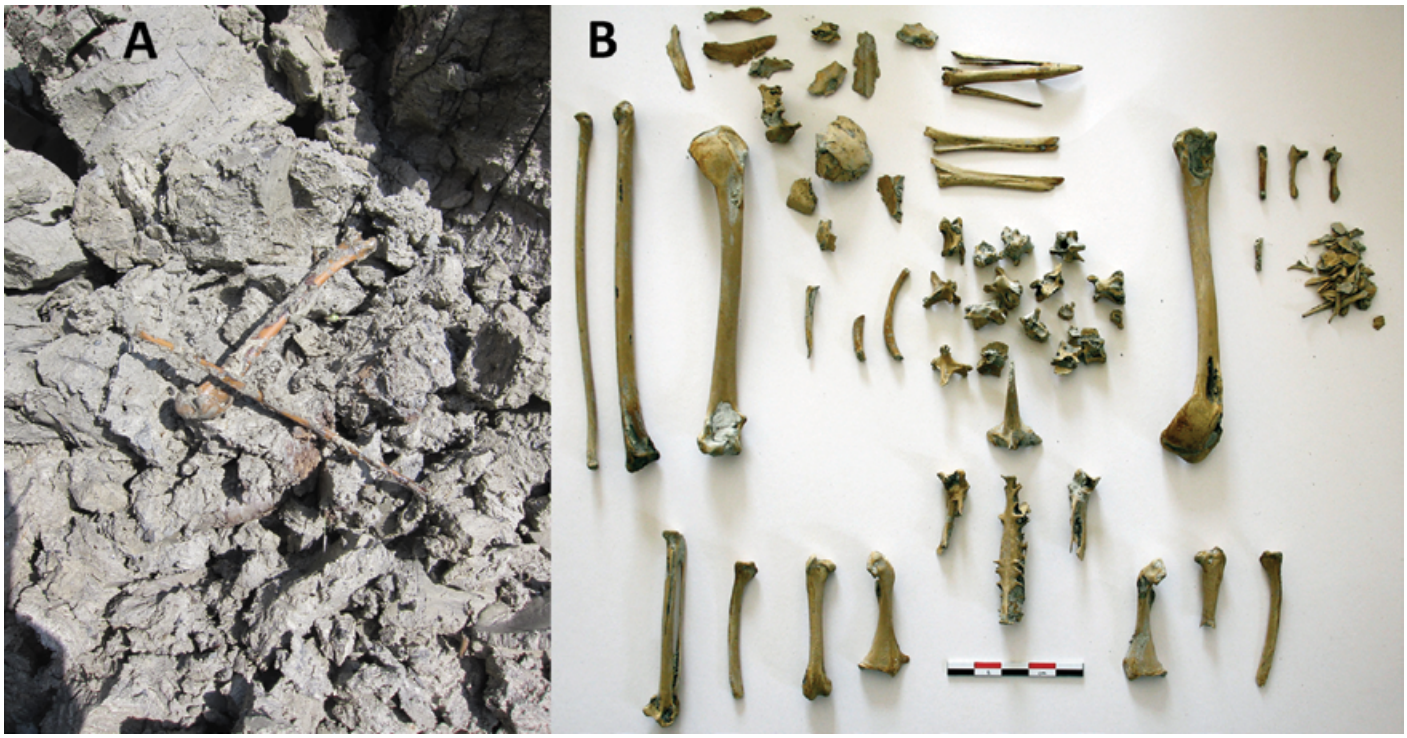


Figure 1. The gull (Larus sp.) bones from the Krogsbølle palaeolake: (A) in the Late Pleistocene lake mud and (B) in rouch anatomical order. Note how well preserved even the fragile beak structures are! Figure: Felix Riede, BIOCHANGE.

KEY PAPERS

Pedersen, J.B., A. Maier, and **F. Riede**. 2019. A punctuated model for the colonisation of the Late Glacial margins of northern Europe by Hamburgian hunter-gatherers. *Quartär* 65:85–104.

Riede, F., M.-J. Weber, B. Westen, K.M. Gregersen, K.K. Lundqvist Eriksen, A.S. Murray, P.S. Henriksen, and M.F. Mortensen. 2019. Krogsbølle, a new Hamburgian site in eastern Denmark, in: Eriksen, B.V., S.K. Harris, E. Rensink. (Eds.). *The Final Palaeolithic of Northern Eurasia. Proceedings of the Amersfoort, Schleswig and Burgos UISPP Commission Meetings*, Schriften des Museums für Archäologie Schloss Gottorf – Ergänzungsreihe. Ludwig, Kiel, pp. 11–30.

BIOSENS:

SENSING BIODIVERSITY CHANGE AND ITS DRIVERS

1 3

Principal investigator: Signe Normand

The newest sensor technology mounted on drones (Unmanned Aerial System, UAS) provides novel opportunities for assessing how biodiversity and its drivers change at ultra-high spectral (wavelengths in nanometres), structural (dense 3D point clouds), spatial (millimeter to meters), and temporal (days to years) resolution. In particular, combining measurements of highly differentiated spectrometric signals and detecting the range of emitted laser light pulses, show great potential for simultaneously assessing the functional, structural, and taxonomic components of biodiversity, as well as its environmental drivers (e.g. hydrology, topography, nutrient status). BIOSENS is one of the first projects worldwide that combines the newest hyperspectral and LiDAR sensor technology for UAS with a detailed assessment of temporal and spatial changes in local diversity and ecological parameters. Since 2017, repeated drone-flights have been conducted across a controlled grassland experiment (in Bern, Switzerland, Fig. 1), with controlled levels of plant diversity, as well as across a natural grassland with substantial variation in plant diversity, vegetation structure, function, and ecological factors (Rewilding area, Mols, Denmark, Fig. 2). Simultaneously, highly detailed and spatially explicit information on plant diversity and structure have been measured with traditional ecological methods and hand-held hyper-spectral sensors.

Using the LiDAR data collected across the Rewilding area, Mols, Denmark, we have been able to recognize and map specific shrub species in 3D. We especially targeted the classification of *Cytisus scoparius*, because of the particular concern in landscape management (Fig. 2), and we successfully estimated biomass changes between autumn 2017 and spring 2018 (Madsen *et al.* accepted). The next steps are to understand the drivers of these changes.

With the grassland experiment in Switzerland, we have recently explored the relationship between LiDAR derived measures vegetation structure, plant diversity and plant biomass. The first results indicate that a reasonable amount of variation can be explained, but also that this depends on the nutrient status and overall plant diversity of the vegetation. We are currently further evaluating the accuracy of plot-scale biomass estimates from non-destructive LiDAR measurements.

Within BIOSENS, we have produced a comprehensive Denmark-wide mapping of vegetation and terrain structures based on the national LiDAR point-cloud. The derived LiDAR-based measures were used in Moeslund *et al.* (2019) to explain the diversity of different groups of organisms, and have recently been used to model and map forest quality in Denmark.

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

KEY PAPERS

Madsen B., U.A. Treier, A. Luciier, A. Zlinszky, and **S. Normand**. 2020. Detecting shrub encroachment in semi-natural grasslands using UAS LiDAR. *Ecology and Evolution*. (e-pub ahead of print).

Moeslund, J.E., A. Zlinszky, R. Ejrnæs, A.K. Brunbjerg, **P.K. Bøcher, J.-C. Svenning**, and **S. Normand**. 2019. LIDAR explains diversity of plants, fungi, lichens and bryophytes across multiple habitats and large geographic extent. *Ecological Applications* 29:e01907.

The project is funded by the Carlsberg Foundation Distinguished Associate Professor Fellowships from 2017-2020. It currently employs one PhD student.

CARLSBERG FOUNDATION

Figure 1. Experimental plots factorially manipulated by leaf fungal pathogens, nitrogen and plant diversity (PaNDiv experimental site in Münchenbuchsee, Switzerland). The experiment is led by Eric Allan, University of Bern. Photo: Bjarke Madsen, BIOCHANGE.

Figure 2. UAS surveying the rewilding area in Mols dominated by yellow flowering *Cytisus scoparius.*
Photo: Bjarke Madsen, BIOCHANGE.

DRONE ECOLOGY:

THE MISSING LINK FOR CROSS-SCALE INTEGRATION IN ECOLOGY

1 3

Principal investigator: Signe Normand

How and why the fate of individuals, populations, and species vary across space and time is a fundamental question in ecology. Currently, a prominent gap exists in our knowledge on the local dynamics of individuals, their drivers, and how they scale to the dynamics of species distributions across space. Closing the scale gap is essential for understanding vegetation dynamics under global change and their related biodiversity, ecosystem, and societal consequences. The main aim of this project is to: (1) investigate the degree to which drone-based remote sensing contributes to closing the scale-gap and add distinctive insight on vegetation dynamics, and (2) establish and consolidating the infrastructure and competences needed for mastering unique and innovative applications of drone-based remote sensing to answer questions in ecology. The project substantially contributed to establishment of the UAS4Ecology Lab, a research facility using Unmanned Aerial System (UAS) technology in combination with novel sensor technology (see BIOSENS) to address ecological questions. The project is mainly focused on using cross-scale integration to understand vegetation dynamics in Arctic and temperate ecosystems.

With climate warming, shrub cover is expected to expand across the Arctic. Vegetation dynamics vary across space and detecting greening trends from space is complex. In a paper in Nature Climate Change, BIOCHANGE members discuss the many ecological and methodological factors that complicate the study of 'the Greening of the Arctic' (Myers-Smith & Kerby *et al* . 2020).

With warming, shrubs are expected to expand upward in elevation. Detecting vegetation change with imagery requires that models are transferrable across time and space. To quantify the likelihood with which we can detect vegetation change in the future, we assessed the transferability of vegetation classification across 108 plots randomly stratified across altitudes (Kolyaie *et al.* 2019). We find good transferability of Arctic shrub cover classification, which is promising for vegetation monitoring using image classification of ultra-high spatial resolution imagery acquired with hand-held cameras or from drones.

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

KEY PAPERS

Kolyaie, S., U.A. Treier, G.R. Watmough, **B. Madsen, P.K. Bøcher,** A. Psomas, R. Bösch, and **S. Normand**. 2019. Transferability and the effect of colour calibration during multi-image classification of Arctic vegetation change. *Polar Biology* 42:1227–1239.

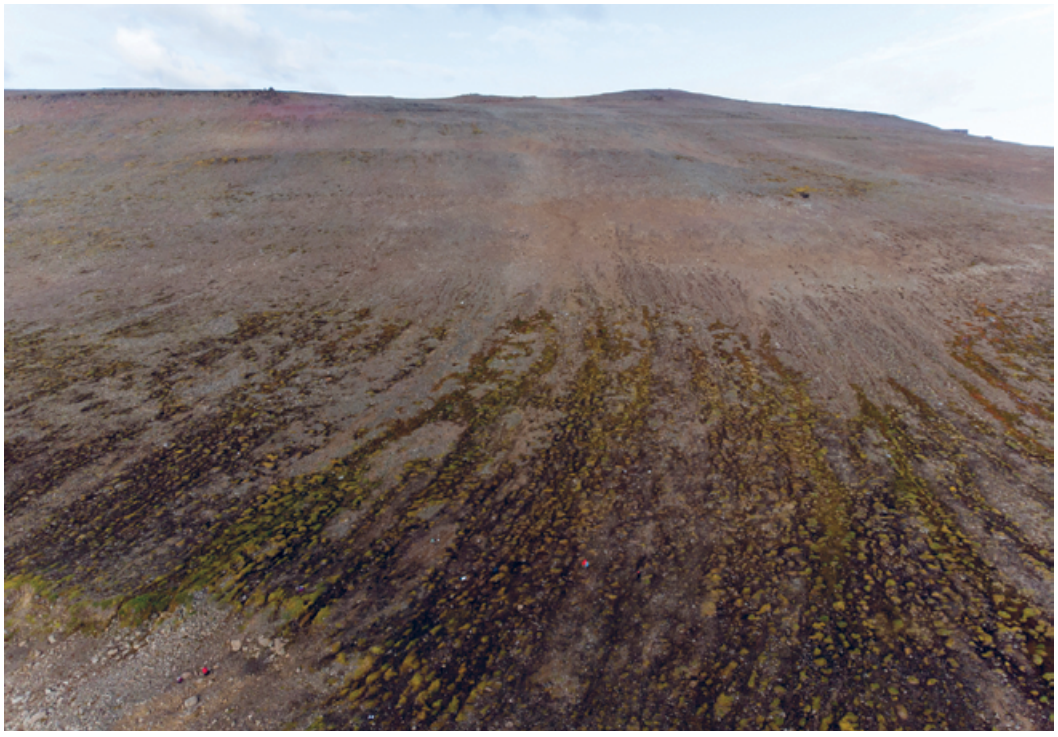
Myers-Smith, I.H., **J.T. Kerby**, G.K. Phoenix, J.W. Bjerke, H.E. Epstein, *et al.*, **S. Normand**, *et al.* 2020. Complexity revealed in the greening of the Arctic. *Nature Climate Change* 10: 106–117.

Westergaard-Nielsen, A., T. Balstrøm, **U.A. Treier**, **S. Normand**, and B. Elberling. 2020. Estimating meltwater retention and associated nitrate redistribution during snowmelt in an Arctic tundra landscape. *Environmental Research Letters* 15:1-13.

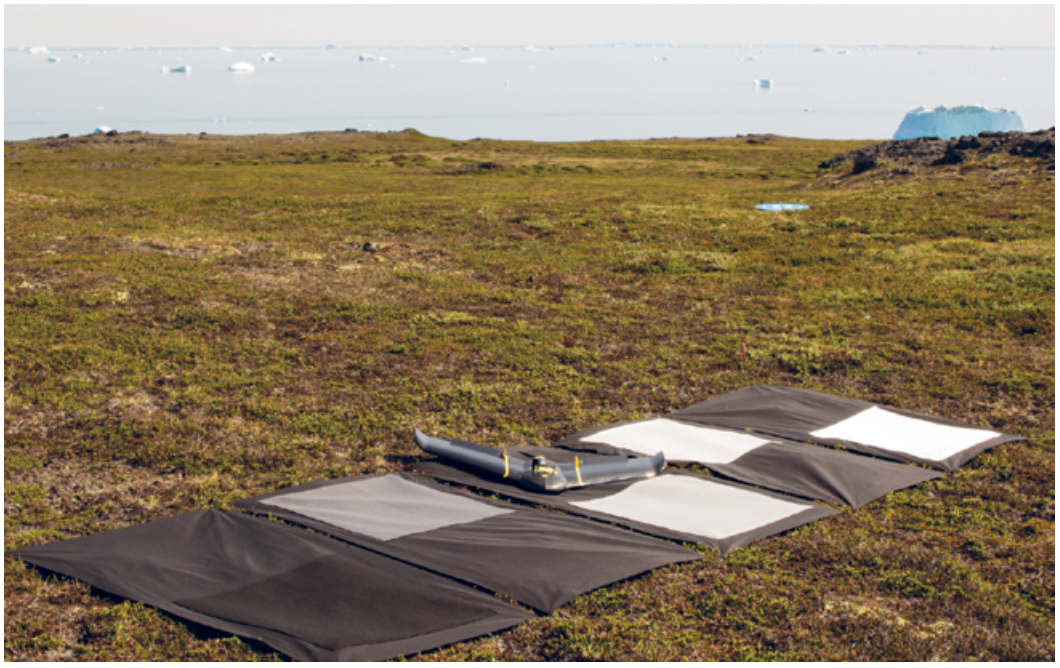
Wüest, R.O., N.E. Zimmermann, D. Zurell, J. Alexander, S.A. Fritz, *et al.*, **S. Normand**, *et al.* 2019. Macroecology in the age of big data – where to go from here? *Journal of Biogeography* 47:1-12.

The project is funded by the Aarhus University Research Foundation Starting Grant from 2016-2020. It currently employs one PhD student and one research assistant.

AARHUS UNIVERSITETS FORSKNINGSFOND
AARHUS UNIVERSITY RESEARCH FOUNDATION



Drone footage of a field site at ca. 700 m.a.s.l., Skarvefjelten, Disko Island, Greenland



Drone ready to take off, Disko Island, Greenland.
Photos: Urs A. Treier, BIOCHANGE.

sDYN:
CROSS-SCALE INTEGRATION OF ARCTIC SHRUB DYNAMICS

1 2 3

Principal investigator: Signe Normand

Figure 1. View from "Lyngmarksfjeldet" across "Blæsedalen" to "Skarvevefjeldet" showing the variation in topography and vegetation of the research area. Photo: Urs A. Treier, BIOCHANGE.

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 an innovative integration of satellite- and drone-based remote sensing, functional traits, dendroecology, and dynamic modelling.

The empirical basis for this project stems from data collected at multiple sites across the whole of Greenland during past, present and future field campaigns. A centerpiece of the project is the eight-week field campaign on Disko Island completed in summer 2019, during which a team of fourteen researchers studied the variation in vegetation, microclimate and landscape features at 90 plots spread across fifteen square kilometers of tundra (Fig. 1, further reading under Field Campaigns). Key to this campaign were a unique stratified random sampling design, in-depth ecological field observations and the deployment of top-of-the range drone and microclimate logger technologies (Fig. 2). Fused with high- and moderate- resolution images from satellites, the data from this field site allows for cross- and landscape scale mapping of vegetation dynamics, and their geophysical drivers.

The preliminary findings of the sDYN project have already highlighted the importance of studying microclimate in Arctic tundra environments and have allowed for the confirmation of fundamental ecological hypotheses rarely tested at such large landscape scales. For example, the amount of microclimatic variation observed amongst the plots on Disko Island during July 2019 was larger than the amount of macroclimatic variation reported for Arctic field sites at continental scales during the same time (Fig. 3). Furthermore, elevation and vegetation cover were identified as the dominant drivers of microclimate at the site (Fig. 4). These findings underline the potential for species survival in local microrefugia amidst the average warming of the tundra and illustrate the role that vegetation plays in shaping microclimatic conditions and ecosystem functioning in the biome. sDYN is providing 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.

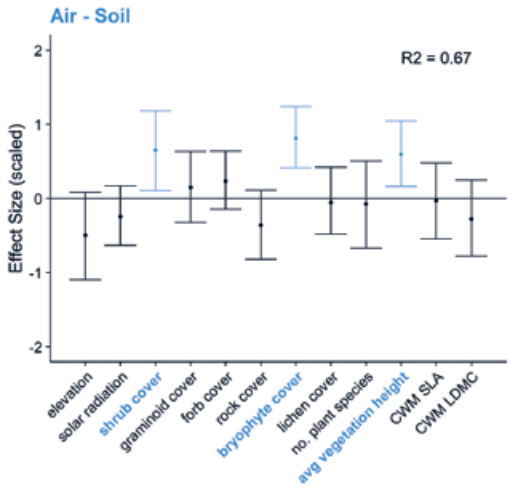


Figure 4. Effect sizes from Bayesian linear mixed effect models demonstrating the buffering effects of vegetation cover and elevation on differences between air vs. soil temperatures across the tundra on Disko Island, Greenland. Figure: Jonathan von Oppen, BIOCHANGE

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 BIOCHANGE associate, postdoc Angela Luisa Prendin.

DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK

KEY PAPER

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**. 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.

Figure 2. Does microclimate relate to plant community composition and trait variation? Sampling at a TMS microclimate logger on a slope, Disko Island, Greenland. Urs A. Treier, BIOCHANGE.

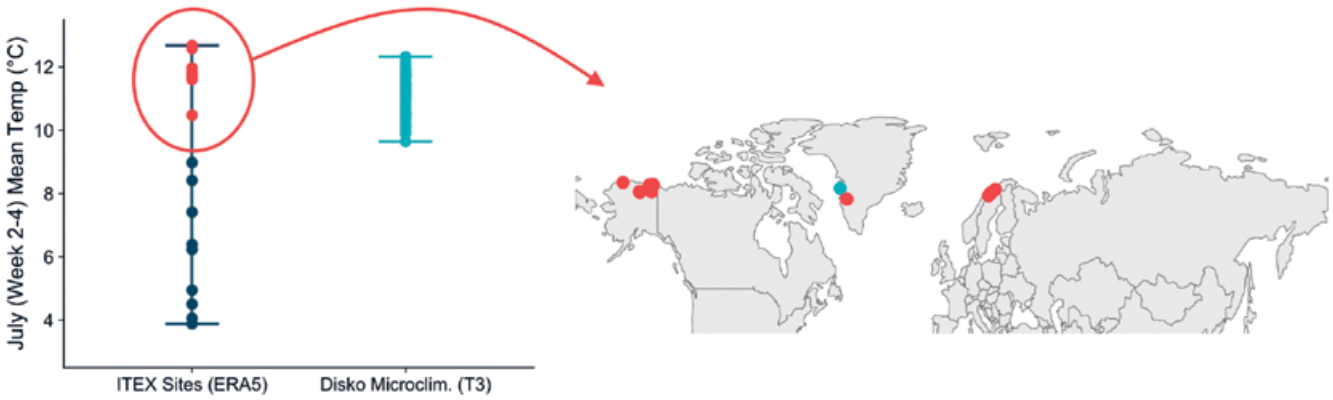


Figure 3. Comparison between macroclimatic temperature variation observed across Arctic research sites from the international tundra experiment (ITEX, ERA5 air temperatures) and microclimatic temperature variation observed at Disko Island, Greenland (TMS microclimate loggers, temperature 15 cm above ground) during July 2019.
Figure: Jakob J. Assmann, 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. As a consequence, conservation efforts have focused on species at risk (endangered) instead of considering variations in species assemblage composition. In addition, the interactions across multiple trophic levels are not considered, even as these are an essential modulator of the functions and services nature provides. BIORATES aims to define how much changes we can expect in biodiversity composition and interaction structure accords trophic levels due to the current ongoing transformation of the biosphere. Using trees as a study system, BIORATES is evaluating how much β-diversity (variation in composition) changes in space in three different ecological dimensions (species, functional traits, and phylogenetic relations), and the role of present and past climate as a driver of these changes (Fig. 1A). BIORATES is also assessing the biological structure (i.e., species, functional traits, and genetic composition) of producers (i.e., vascular plants) and consumer (i.e., birds and mammals) and how global change phenomena will affect the interaction between these (Fig. 1B). This project will contribute to theme [1] Fundamental Biodiversity Dynamics and theme [2] Global Challenges of BIOCHANGE.

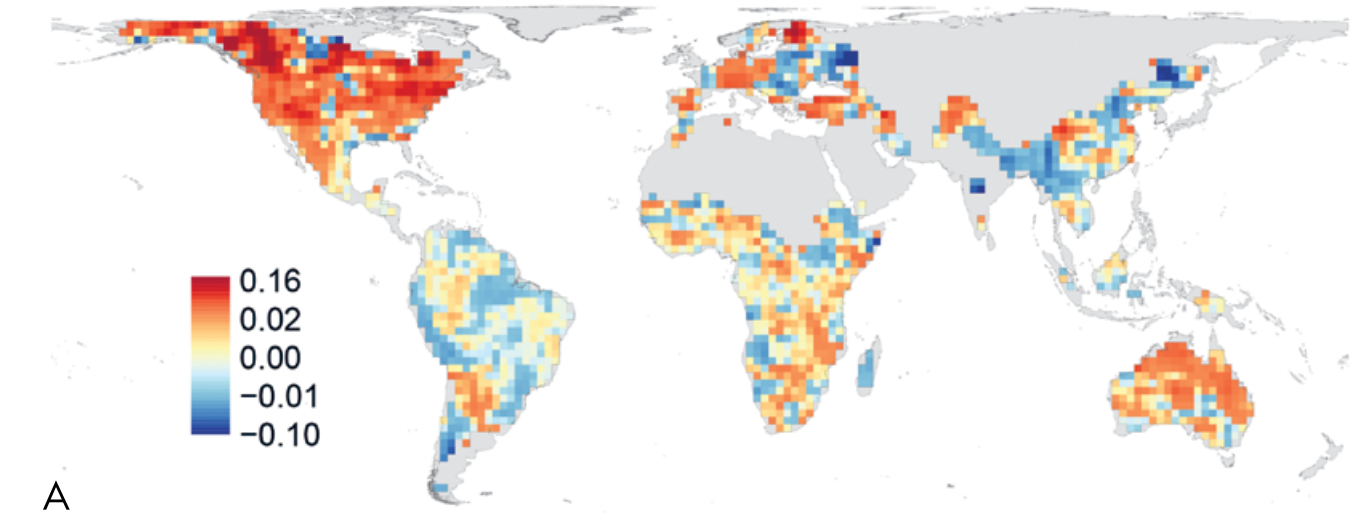
KEY PAPERS

Conradi, T., **K. Van Meerbeek, A. Ordonez**, and **J.-C. Svenning**. 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*. (e-pub ahead of print).

The project is funded by the Aarhus University Research Foundation with 1,900,000 DKK and runs from 2018-2020. It currently employs one postdoc and one PhD student.

AARHUS UNIVERSITETS FORSKNINGSFOND
AARHUS UNIVERSITY RESEARCH FOUNDATION



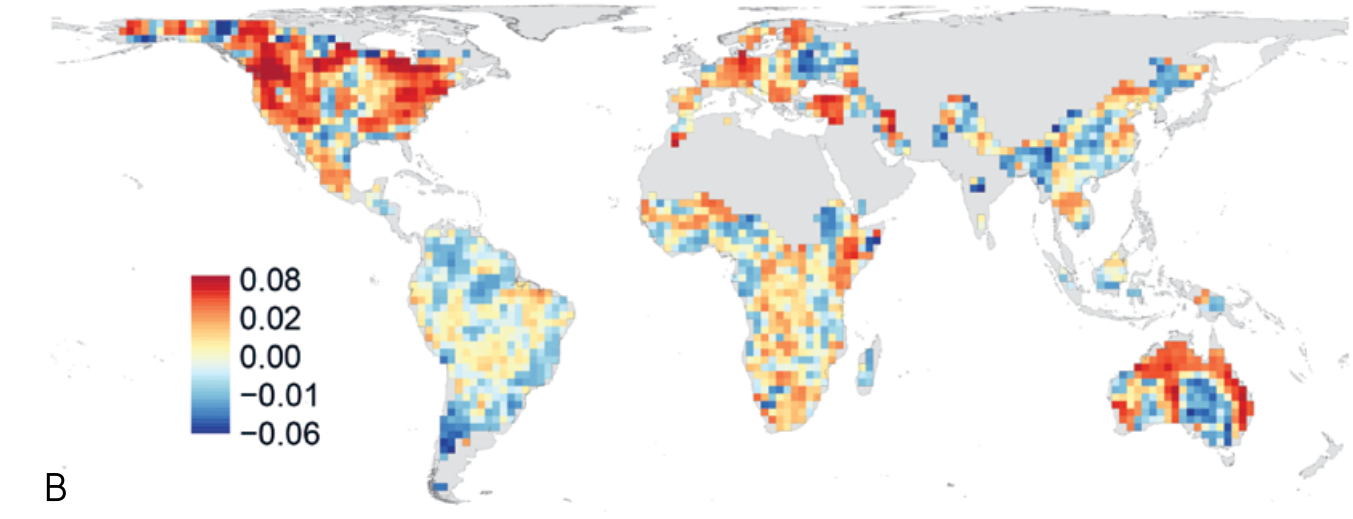


Figure 1. (A) Estimates of phylogenetic and (B) functional nestedness for forested areas globally. The colors show the standardized nestedness after controlling for species richness. Positive (negative) values show larger (smaller) than expected richness given the local tree species richness.
Figures: Wubing Xu, BIOCHANGE.

MMSDI:
MAASAI MARA SCIENCE AND DEVELOPMENT INITIATIVE

Chair: Jens-Christian Svenning

1 2 4

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 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 through interdisciplinary research and development activities. Therefore, the MMSDI operates as a multi-stakeholder platform with representatives from academics, business, 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 inputs to the research about core challenges and research questions and provide data to 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 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
https://mgmt.au.dk/maasaimarascience/

Maasai Mara Science and Development Initiative symposium 2019. This event marked the fifth anniversary of the initiative. MMSDI researchers and invited guests and speakers (incl. Dr Joseph Ogutu, Universität Hohenheim, Germany, and Bente Jessen Graa, Norvegian University of Science and Technology, Norway) met at Aarhus University August 2019 to discuss how the MMSDI research could contribute to the sustainable development of the Mara-Serengeti ecosystem in the coming decade.
Photo: Jens-Christian Svenning, BIOCHANGE.

Board meeting at Aarhus University August 2019.
The board and secretariat of MMSDI met at Aarhus University to welcome new board member Dr Irene Amoke, CEO of Kenya Wildlife Trust and to discuss the needs for future research in the area.

From left: Saningo Dominic Kuluo (secretariat), Karen Blixen Camp
Jesper Stagegaard (board member), Karen Blixen Camp Trust
David Noosaron (board member), Mararienta Community
Jens-Christian Svenning (Chair), BIOCHANGE
Alice Odingo (secretariat), University of Nairobi
Irene Amoke (board member), Kenya Wildlife Trust
Anne Blach Overgaard, BIOCHANGE
Pernille Kallehave (secretariat), Aarhus University
Benedict Walubengo, Karen Blixen Camp Trust Educational Initiative
Photo: Dennis Pedersen, BIOCHANGE.

Maasai Mara
Science and Development Initiative

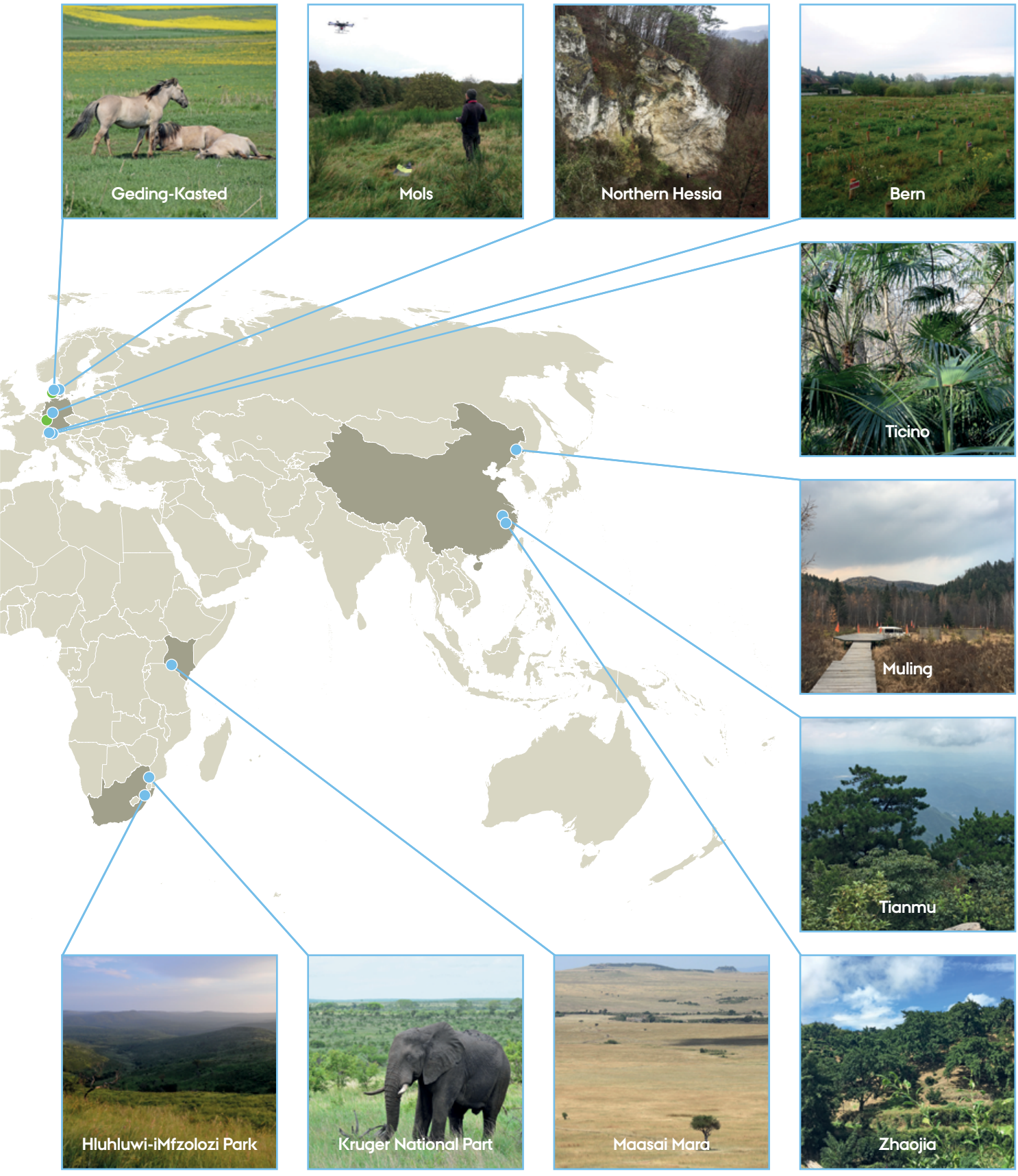
FIELD CAMPAIGNS

BIOCHANGE FIELD SITES

ON THE FOLLOWING PAGES, WE DESCRIBE A SELECT OF CURRENT FIELD CAMPAIGNS CONDUCTED IN 2019-2020.

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:
Vincent Fehr,
Ditte Arp Jensen,
Normand-Treier,
Bjarke Madsen,
Simon Schowanek,
Florian Rudolf Sauer,
Anne Blach Overgaard,
Jens-Christian Svenning,
BIOCHANGE.


Geding-Kasted
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Bern
Ticino
Muling
Tianmu
Hluhluwi-iMfzolozi Park
Kruger National Part
Maasai Mara
Zhaojia

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

MAASAI MARA, KENYA

Figure 1. Identification of tree species in Trans-Mara, to identify the vegetation to improve vegetation classification maps of the area. Photo: David Noosaron, MMSDI/Mararienta Community.

Figure 2. BIOCHANGE student counting a herd of cattle in the Mara North Conservancy, Maasai Mara, Kenya, as part of her work on the interaction between wild herbivores and grazing livestock. Photo: Lea Bach Sloth, BIOCHANGE.

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 ecosystem dynamics, including 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, with the aim of providing a scientific basis for sustainable management of this key natural heritage site.

Several large field campaigns have been conducted in Maasai Mara since the start of BIOCHANGE. The main aim of the first expeditions was to build a baseline for time-series studies and calibrate satellite remote sensing data for classification studies with collected ground validation data. These data have so far been used in two studies. The first has been published and reveals widespread and accelerating land degradation within the Maasai Mara since 1985. Initial results from the second study show very promising land cover maps, with substantially more detail than has been possible previously. During May 2019, another team of BIOCHANGE researchers conducted a trip to Maasai Mara to acquire ground-truthing data. The objectives of this field trip were to establish a comprehensive sampling database of GPS-tagged photos to be used for satellite-based land-cover and land-use classifications (e.g., mapping of fences), with further vegetation data collected in January-March 2020 (Fig. 1).

This year we had two master students in the Maasai Mara from September to December 2019. Their projects are focused on quantifying the interaction between wild herbivores and grazing livestock (cattle, sheep and goats); one of the main human impacts in the conservancy areas of the Maasai Mara (Fig. 2-3). From January-March 2020, a MegaPast2Future postdoc conducted data collection on the social acceptance of large herbivores (elephants and rhinos) across the Mara conservancies in order to determine the suitability of the area for these species. Both anthropogenic and ecological factors determine the suitability of an area for elephants and rhinos, with social

Figure 3. BIOCHANGE students are using a drop disc to estimate the grass biomass in the Mara North Conservancy, Maasai Mara, Kenya. Photo: Louise V. Sørensen, BIOCHANGE.

acceptance of the animals by local stakeholders a key factor. Therefore, we aim to measure the spatial distribution of the social acceptance of elephants and rhinos across the Mara conservancies, and relate this to conservancy type, demographics, and experience with the animals, to understand the underlying drivers of the level of acceptance. We further conducted focus group discussion games in primary schools to gain insights into the attitude of future generations of landowners towards living with elephants and rhinos (Fig. 4).

A second aim of the field trips has been to develop contacts and collaborations with local stakeholders and scientists, promoting the needed interdisciplinary research and contributing to local capacity building. In May 2019, BIOCHANGE hosted a 1-week GIS course in Mara North Conservancy for 22 participants from local stakeholders.

Figure 4. Children scoring how big the impact is of the different ways they consider elephants to influence their family's life, both in positive and in negative ways. Photo: Susanne M. Vogel, BIOCHANGE.

TROPHIC REWILDING IN THE GLOBAL SOUTH

CORRIENTES, ARGENTINA

Figure 3. Axis deer (*Axis axis*) caught in a camera trap image, the cameras were set up to identify herbivores that could be impacting the vegetation. Photo: Julia C. Mata, BIOCHANGE.

Trophic rewilding is a new idea for ecological restoration and is centered around restoring the top-down trophic processes via re-establishment of missing species (typically megafauna) to promote self-regulating biodiverse ecosystems. In this project, we focus on a key understudied biome, namely the South America 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 megafauna remain understudied, hampering planning, restoration, and management toward a biodiverse future. At our field-sites in Argentina's Corrientes province, we work toward filling these knowledge gaps.

A particularly important unanswered question is to what extent the loss of megafauna has changed vegetation structure, as vegetation forms the backbone of terrestrial ecosystems. The ratio and spatial distribution of e.g., forest, savanna, and grassland have large consequences for overall biodiversity and for ecosystem functioning, e.g., carbon sequestration and fire frequency.

Our field site, Rincon del Socorro (Fig. 1), is a reserve that was recently donated to National Parks (http://www.proyectoibera.org/en/). It has an active rewilding program where locally extinct species such as lowland tapir, pampas deer, and collared peccary are reintroduced. To assess impacts of megafauna, we characterize vegetation structure and biodiversity using remote sensing and traditional vegetation plots and we study herbivore diet by genetically sequencing barcodes of plant DNA from dung collected in the field.

Figure 1. View of the field site in Rincon del Socorro.
Photo: Julia C. Mata, BIOCHANGE.

Figure 2. Fenced plot in a short grass area one year after herbivores were excluded. Photo: Julia C. Mata, BIOCHANGE.

Figure 4. Surveying the plant community in a plot from the herbivore exclosure experiment. Photo: Dennis Pedersen, BIOCHANGE.

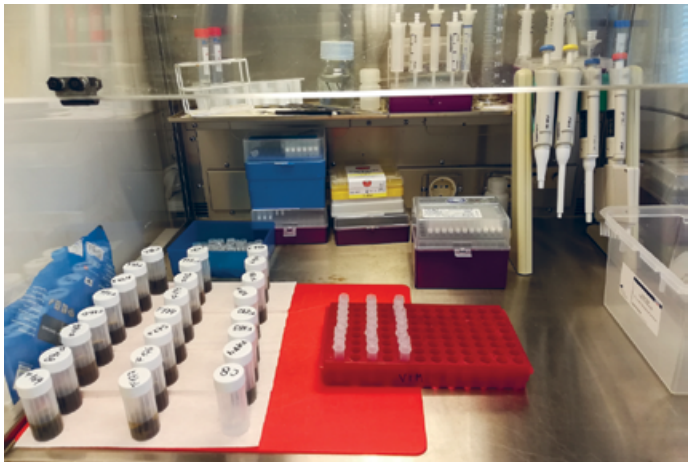


Figure 5. Laboratory set up for DNA extraction of fecal samples, performed at SLU (Swedish University of Agricultural Sciences) in Umeå, Sweden.
Photo: Julia C. Mata, BIOCHANGE.

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 and final re-measurement of the herbivore exclosures (Fig. 4). The data show a clear effect of capybara grazing, as vegetation inside the exclosure plots was significantly taller than outside the plots, where capybaras graze the vegetation short. The next analysis will focus on revealing whether the species composition inside exclosure plots has changed relative to the control plots. 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 those samples are still being analyzed in the lab (Fig. 5).

Finally, in a recent MSc project, we mapped vegetation structure using novel data fusion of terrestrial LiDAR and high-resolution satellite imagery. Upscaling detailed LiDAR-based measurements of vegetation structure to a large area using satellite data has not been attempted before in savanna ecosystems. The results look very promising, suggesting that we are now able to track ecologically meaningful metrics (from terrestrial LiDAR) of vegetation change and rewilding development from space.

MEGA-HERBIVORE REWILDING IN SOUTH AFRICAN SAVANNA

ASSOCIATION OF PRIVATE GAME RESERVES AND KRUGER NATIONAL PARK, SOUTH AFRICA

There is an increasing focus on restoring historically depleted mega-herbivore assemblages as a means to facilitate self-managing biodiverse ecosystems. At the same time, our knowledge of the ecological and biodiversity effects of such mega-herbivore restoration is relatively limited. Our project addresses this knowledge gap through field-based studies in South African savanna, making use of the numerous nature reserves in the region with varying levels of restored mega-herbivores. Specifically, our research investigates how the savanna elephant indirectly influences fauna by altering habitat complexity through herbivory and habitat modification (Fig. 1). Because elephant impacts may take time to become apparent, we focus on time since elephant reintroduction as a process influencing elephant -habitat-fauna interactions.

In 2019, we conducted a landscape-scale field survey across four nature reserves with different elephant reintroduction times (1927, 1972, 1995, 2003), and a control reserve where elephants are excluded but other native herbivores present, to determine how elephant herbivory impacts fauna habitat: i.e., woody vegetation, tree hollow/cavities and ground wood. We returned to our field sites in March 2020 to quantify how functionally different fauna species utilize these habitat attributes.

First, elephants can advantage meso-herbivores by reducing shrub density and increasing predator detection, or disadvantage meso-herbivores by felling trees, which reduces predator escape. We tested these predictions by conducting shrub and ground wood surveys at 40 of our field sites stratified across three reserves where trail cameras were deployed in 2019. The habitat data and photographs will be used to determine how meso-herbivore site occupancy and behavior vary with shrub density and ground wood attributes.

Second, elephants can advantage smaller fauna (e.g., rodents) by felling trees, which creates refuges from predation. We tested this prediction by placing a trail camera within a felled tree (Fig. 2) and in an adjoining open area (Fig. 3) at eight sites within one nature reserve. 30-sec video clips will be used to compare rodent site-occupancy and vigilance behaviors between the two microhabitats.

Third, elephants can influence birds that use tree hollows/cavities by felling trees, which reduces hollow density, or breaking branches, which facilitates hollow formation (Fig. 4). Audio sound recorders were deployed at twelve sites in 2019 to determine how bird site-occupancy varied between areas with high and low tree hollow densities. We added to this dataset in 2020 by deploying sound recorders and conducting hollow surveys at an additional ten sites across one reserve.

Forth, elephants can influence reptile communities by altering floristic diversity and reducing shrub density, which changes the thermal profile of landscapes, or by felling trees, which creates habitat refugia. We tested these predictions by conducting active reptile searches at 30 sites across three reserves where intensive vegetation/habitat surveys were conducted in 2019. The data will be used to compare reptile community composition and habitat-use across reserves.

Figure 1 (right). A herd of elephants browsing on Sickle Bush (*Dichrostachys cinerea*) at the Greater Makalali Private Game Reserve. Elephants were introduced to the reserve upon establishment in 1995.

Figure 2 (top left). A trail camera monitoring rodent behavior within a tree felled by an elephant. We predict higher rodent activity within felled trees than in adjoining open areas due to increased habitat complexity and decreased predation pressure.

Figure 3 (opposite page). A trail camera monitoring rodent behavior within an open habitat. We predict lower rodent activity in opened areas than within adjoining felled trees due to decreased habitat complexity and increased predation pressure.

Figure 4 (top right). Small mammal remains within a large Leadwood tree (*Combretum imberbe*) containing many large-sized tree hollows. An audio-sound recorder was placed on the tree to monitor hollow and non-hollow using birds over a 2-month period.

Photos:
Christopher E. Gordon, BIOCHANGE.

PALMS AS GENERATORS OF NOVEL ECOSYSTEMS

BRAZIL, MEXICO, SWITZERLAND

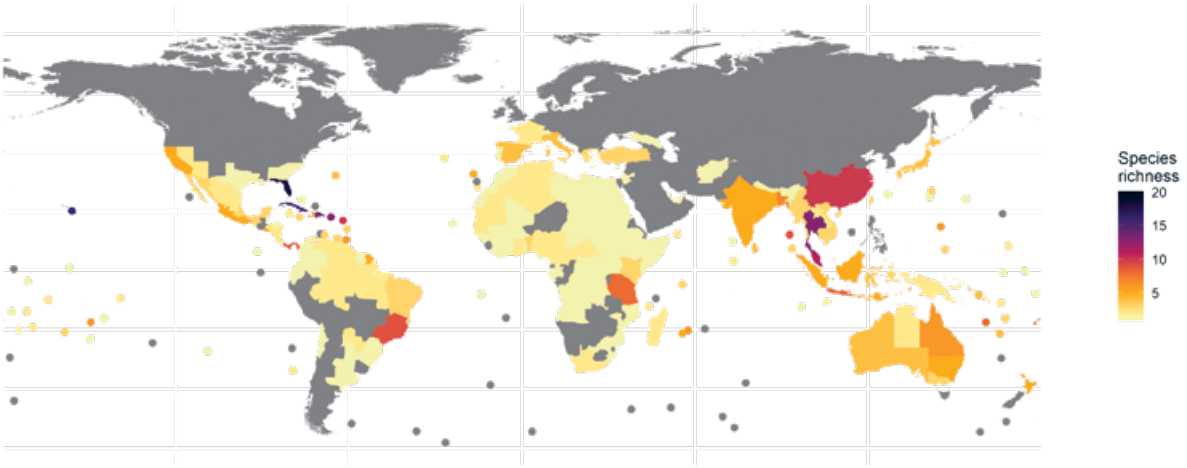


Figure 1. Global distribution of the 86 naturalized palm species based on the collected records from our literature review. Map: Vincent Fehr, BIOCHANGE.

Humans facilitate the emergence of novel ecosystems by moving species around the world. However, it is unclear whether species differ in their propensity to generate novel ecosystems. To quantify this, we use the palm family, which has a pantropical distribution, high ecological importance in native ecosystems, is sensitive to global warming, and has been introduced extensively by humans for horticulture.

Using an extensive literature review, we found that of the 2557 recognized palm species, 3.4% (86 species, Fig. 1) were recorded as naturalized and 1.1% as invasive, which is more than the average for woody plants.

To generalize and quantify the effects of palm invasions on biodiversity and ecosystem functioning, we conducted extensive fieldwork between March 2018 and February 2019 focusing on four non-native invasive palm species in four different biomes in three countries: the Chinese windmill palm (*Trachycarpus fortunei*) in Switzerland (Fig. 2), the African oil palm (*Elaeis guineensis*) and the Alexander palm (*Archontophoenix alexandrae*, Fig. 3) at two different sites in Brazil, and the Date palm (*Phoenix dactylifera*) in Mexico (Fig. 4).

Due to the key roles of palms, we examined a broad range of ecosystem components and variables (e.g., richness of plants, arthropods and soil inhabiting cryptic groups, vegetation structure, light regime, litter accumulation and air temperature), which we hypothesize may respond to the presence of non-native palms in invaded plots and uninvaded control plots. We applied novel sampling techniques such as a handheld 3D laser scanner to quantify vegetation structure (Fig. 5A, B). We also collected soil samples to analyze the presence of soil-inhabiting cryptic groups (e.g., fungi and other microorganisms) by extracting environmental DNA of the samples. We started processing the soil samples (DNA extraction, PCR, bioinformatics) in February 2020. Preliminary results indicate that at all four sites, the presence of naturalized palms resulted in a reduced abundance and diversity of recruiting woody species, increased canopy cover, and marginally decreased litter accumulation. The magnitude of the effects varied between the four different naturalized palm species. Naturalized palms strongly affected the understory density, but with variables effects among palm species.

In southern Switzerland, we are running a case study where we focus on the effects of the non-native, invasive Chinese windmill palm (*Trachycarpus fortunei*) on the diversity, abundance and biomass of various guilds of arthropods and on the process of litter decomposition. Studying how non-native plants affect the arthropod community is crucial to understand the effects

Figure. 2. The Chinese windmill palm (*Trachycarpus fortunei*) from East Asia has transformed the understory of deciduous forests in Southern Switzerland into evergreen, palm-dominated thickets, radically changing the physical structure and eventually triggering a biome shift.
Photo: Vincent Fehr, BIOCHANGE.

of plant invasions on higher trophic levels as a huge number of organisms depend on arthropods as prey. Additionally, key ecosystem processes like leaf litter decomposition and pollination are also directly influenced by arthropods. The arthropods were collected between May and August 2019 using various sampling methods (e.g., pitfall and window traps). We monitored the process of litter decomposition under site-specific conditions by accounting for the weight loss of leaf-litter material in litterbags. The litterbags have been installed in February 2019 and were collected in autumn 2019.

Figure. 3. The Alexander palm (*Archontophoenix alexandrae*) from Australia is building monodominant stands in a subtropical rainforest in Southern Brazil. Photo: Vincent Fehr, BIOCHANGE.

Figure. 4. The Middle Eastern date palm (*Phoenix dactylifera*) was introduced as a crop plant to the desert oasis in Baja California, Mexico by Jesuit settlers' centuries ago. The date palm quickly escaped from cultivation and is now dominating in many parts of the desert oasis.
Photo: Vincent Fehr, BIOCHANGE.

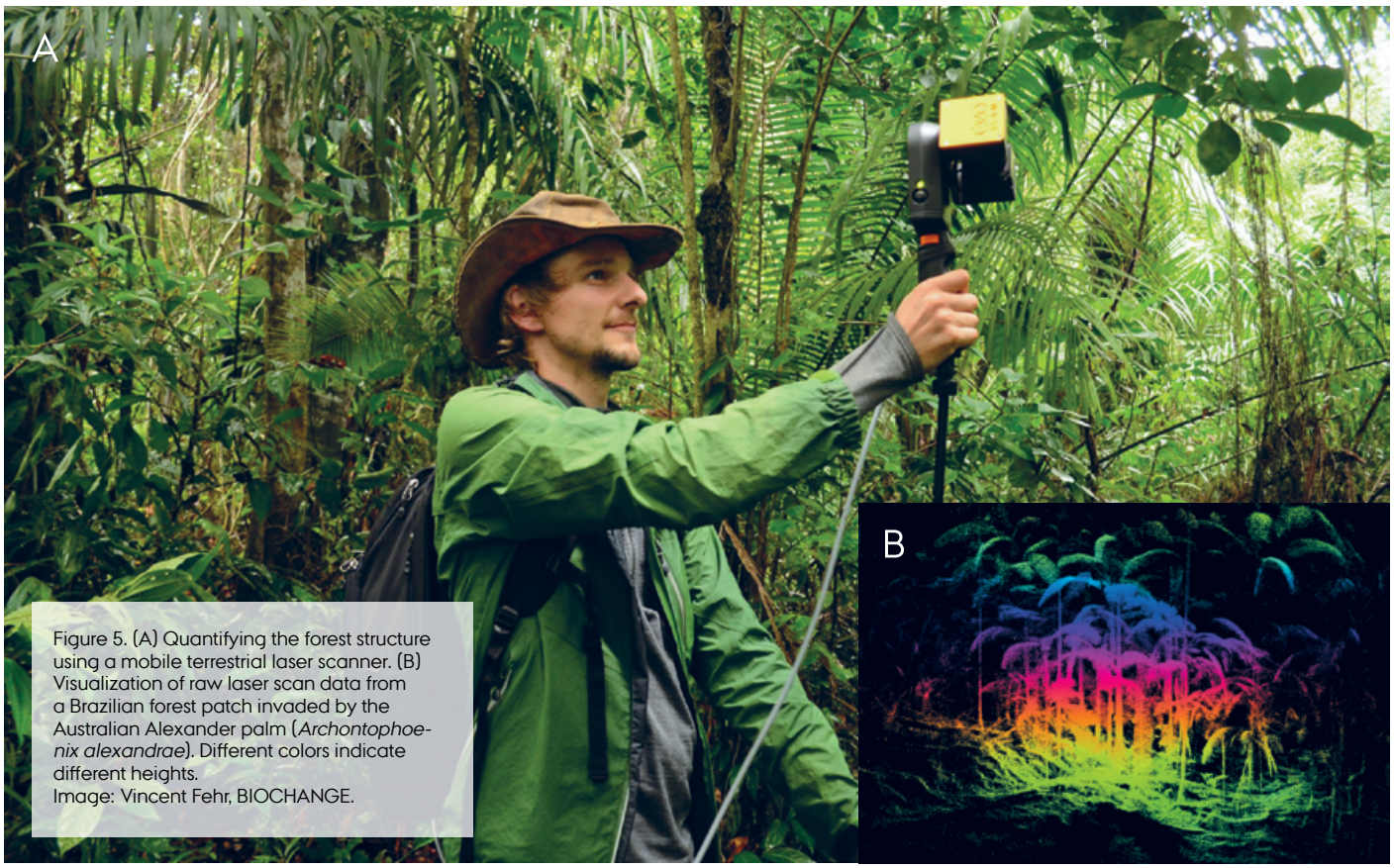


Figure 5. (A) Quantifying the forest structure using a mobile terrestrial laser scanner. (B) Visualization of raw laser scan data from a Brazilian forest patch invaded by the Australian Alexander palm (*Archontophoenix alexandrae*). Different colors indicate different heights.
Image: Vincent Fehr, BIOCHANGE.

TROPHIC REWILDING IN DENMARK

MOLS BJERGE NATIONAL PARK AND GEDING-KASTED MOSE, DENMARK

Trophic rewilding in Europe is often done with feral or semi-feral horses and cattle, which serve as a functional replacement of extinct megafauna. The main principals of maximizing ecological integrity and minimizing human input and output have been implemented in a small but heterogeneous and diverse spot in a Danish national park. In 2016, the Natural History Museum, Aarhus, started the project Rewilding Mols in Mols Bjerge National Park by introducing horses and cattle as wild-living populations. Since then, the Natural History Museum Aarhus and BIOCHANGE have studied the impact of rewilding at Mols, including running an exclosure experiment, which was designed to study the impact of the large grazers by fencing them out of small areas.

Ecosystems with a natural density regulation of large herbivores assert a range of effects. 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.

Figure 1. Exmoor horses utilize the many different habitats at the Rewilding Mols site. (A) The grassland patches, and (B) the forested areas. Photos: Bjarke Madsen, BIOCHANGE.

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 actively used for development and testing of new field methods, including camera traps for arthropods, and drone-surveys for vegetation data. The drones have been equipped with basic RGB cameras, advanced multispectral and LiDAR sensors, which potentially will provide new perspectives in the way we monitor vegetation.
In 2019, the monitoring of large herbivore activity and their condition was carried out throughout the year while the exclosure experiment continued in its third year. A plant species survey was carried out as well as sampling of arthropods with pitfall traps and pan traps. For a subset of the plots, camera traps were deployed to monitor flowering resources and arthropod activity.
In 2019, BSc and MSc students studied how the horses and cattle utilize the landscape, by carefully tracking their locations and behavior (Fig. 1A, B). The herbivore pressure in different parts of the area will be linked to vegetation dynamics that are quantified from Sentinel satellite imagery. With the use of drone-based LiDAR measurements from 2017 and 2018, we have successfully detected and mapped 12 different shrub species in a smaller area (6.7 ha) of the enclosure. As the shrubs are classified directly in a 3D point cloud, it is possible to estimate biomass change of single species as e.g., *Cytisus scoparius*. In the future, these results can be used to assess the impact on shrub species by the animals.

Geding-Kasted Mose is a peri-urban rewilding area on the outskirts of Aarhus. The area is a mixture of bog, former cattle grazing fields, and former agricultural fields. To prevent the vegetation from developing into forest, three large herbivore species were introduced in 2016: Galloway cattle, Konik horses (Fig. 2), and water buffalo. Since 2017, we have tracked the landscape use and behavior of these animals, to identify areas of high and low usage. One question of particular interest is whether the water buffalo actually graze in the wetter areas, as was expected. Simultaneously, we have repeated a baseline biodiversity survey for plants (conducted in 2016), in the spring of 2018 and 2019. These studies show a considerable temporal change in the vegetation structure (generally taller vegetation) and composition (a shift to taller-growing species). Most importantly, we observe 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.

Fgure 2. Konik horse at Geding-Kasted Mose, Aarhus.
Photo: Jens-Christian Svenning, BIOCHANGE.

SHRUB DYNAMICS AND MICROCLIMATIC VARIATION ACROSS AN ARCTIC LANDSCAPE

DISKO ISLAND, GREENLAND

Over eight weeks between June and August 2019, a large team of BIOCHANGE members, affiliates, and students, led by Signe Normand, investigated variation in shrub-dominated vegetation and microclimate in Disko's arctic tundra landscape (Fig. 1). We distributed 90 plots à 100 m^2 across two mountain slopes and a total area of 15 km^2. Placement of plots followed a stratified random approach to reflect the large heterogeneity in vegetation structure and water availability across the landscape. We divided both slopes into five elevation bands of six plots each and placed the remaining 30 plots in five clusters of high local variation (core areas) along the eastern slope (Fig. 2).

In each plot, we installed a microclimate logger measuring temperature in different strata above- and belowground as well as soil moisture (Fig. 3) before conducting extensive species inventories of vascular plants, bryophytes, and lichens. We also measured functional traits in vascular plants and conducted spectral analyses of leaf and soil samples (Fig. 4). The plots consisted of several concentric circles of different diameters, matching the spatial resolution of various standardized protocols and remote sensing products. In an additional 250 plots, we recorded the growth and recruitment of two dominant shrub species. On top of that, we conducted a landscape-scale mapping of microclimate, vegetation productivity, cover, structural heterogeneity, and terrain features with RGB, multispectral, and thermal sensors, as well as site-specific areas mapped with UAS-LiDAR. The collected dataset is used to address fundamental questions of biodiversity ('dark diversity') and its relationship to geodiversity, as well as connections between vegetation and microclimate, on different spatial scales. Analyses are under way and the first results look very promising (see the sDYN project description).

For summer 2020, we will conduct a follow-up field campaign, aiming to collect additional loggers that by then will have constantly recorded soil temperatures from early summer 2019 to late summer 2020. In addition, we will collect previously installed litterbags to investigate decomposition dynamics in response to microclimates as an important ecosystem process.

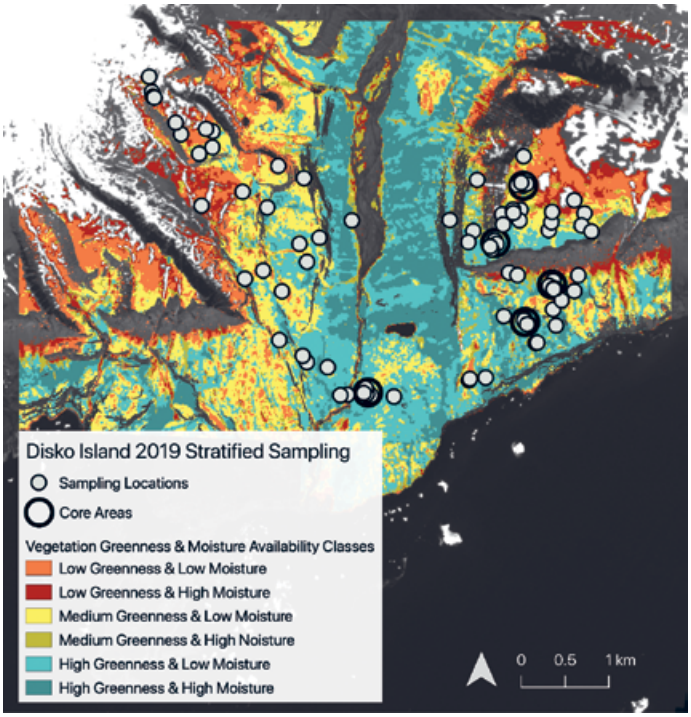


Figure 2. Sampling design. Map: Jakob J. Assmann, BIOCHANGE.

Figure 3. TMS logger installed in each plot measuring temperature in different strata above- and belowground as well as soil moisture.
Photo: Urs A. Treier, BIOCHANGE.

Figure 1. Base camp at Skarvefjeld, Disko Island, Greenland. A perfect spot for incredible views, whale watching, and saving about two hours walk each day. Photo: Urs A. Treier, BIOCHANGE.

Figure 4. How does spectral bio- and geodiversity relate? Field spectrometer used to measure spectral analyses of leaf and soil samples at Disko Island, Greenland. Photo: Oliver Baines.

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 the Graduate School of Science and Technology (GSST), BIOCHANGE 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. BIOCHANGE and ECOINF have organized and hosted two PhD courses in the past year, namely on Bayesian statistics, and Megafauna ecology. In addition, BIOCHANGE members have taken part in PhD course on remote sensing in China in 2019.

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 in accordance with the rules and regulations of GSST. 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.

Photo: Jonathan von Oppen, BIOCHANGE.

PHD COURSES

PHD COURSE ON BAYESIAN STATISTICS

As Bayesian approaches are getting more and more popular in ecology, this international PhD course intended to provide a practical introduction to the topic for PhD students. It was taught November 11-15, 2019 by Anne Bjorkman (BIOCHANGE associate) from Gothenburg University, and organized by Jonathan von Oppen and Signe Normand. Participants were given an overview of Bayesian theory and provided with numerous real-data examples for practical modeling using JAGS syntax in R. Topics covered included basic linear regression, hierarchical models, how to deal with uncertainty in your data, and mixture models using several distributions. The week was wrapped up with a seminar day, where all participants presented their PhD research and discovered many connections between their projects. The course was funded by the Danish Society OIKOS, as a networking opportunity for young researchers.

Photo: Anders Lundt Hansen, Weekendavisen..

Photo: ECNU, China.

PHD COURSE ON MEGAFAUNA ECOLOGY – SHAPING PAST, PRESENT AND FUTURE ECOSYSTEMS

From August 19-23, 2019, BIOCHANGE hosted a PhD course on megafauna ecology organized by Robert Buitenwerf, Scott Jarvie and Jens-Christian Svenning. The course provided a general overview of megafauna ecosystem ecology including the evolutionary history and biogeography of megafauna, current theoretical concepts of megafauna-ecosystem interactions, practical analysis of megafauna trait and occurrence datasets, overview of megafauna conservation and restoration ecology, and a rigorous assessment of ongoing and future megafauna-based rewilding projects. The course was instructed by several BIOCHANGE members from the MegaPast2Future project and by guest lecturers Joris Cromsight (Swedish University of Agricultural Sciences) and Camilla Fløjgaard, Department of Bioscience, Aarhus University. The course consisted of a mixture of lectures, discussion groups, hand on analytical labs, and field excursions, including a great overnight trip to the Mols Rewilding project and Lille Vildmose where we learned about the background, management and experiences with these projects, and saw wild boar and wisent. This course was part of the ongoing MegaPast2Future project supported by a Carlsberg Foundation Semper Ardens Grant to Jens-Christian Svenning.

PHD COURSE ON SATELLITE AND DRONE-BASED REMOTE SENSING IN ECOLOGY

BIOCHANGE members Signe Normand, Urs A. Treier, and Bjarke Madsen contributed to a PhD course on satellite and drone-based remote sensing in ecology organized by Professor Jian Zhang at the School of Ecological and Environmental Sciences East China Normal University (ECNU) in Shanghai, China. The objective of the course was to give the participants the tools and insight needed, to get started using high-resolution remote sensing data to answer questions of relevance for environmental sciences. The course alternated between lectures, where the students were introduced to different methods, and exercises, where the students applied the methods to various image data sets.

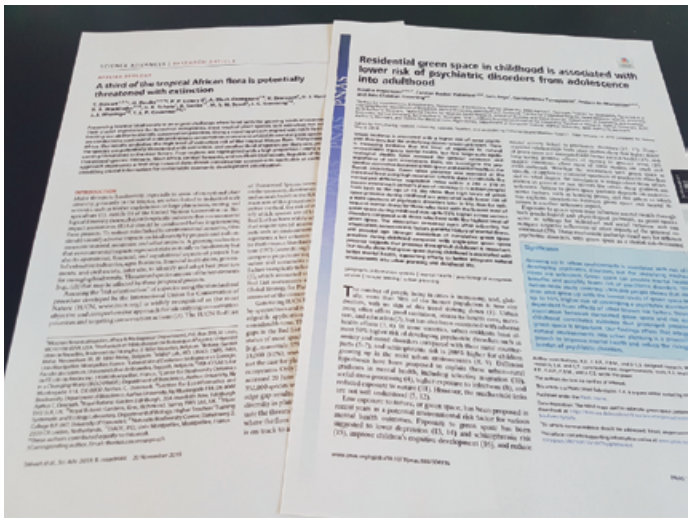


Photo: Anne Blach Overgaard, BIOCHANGE.

Photo: Anne Blach Overgaard, BIOCHANGE.

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 (this year: BIOCHANGE postdocs Scott Jarvie, Susanne Vogel, and Christopher E. Gordon). 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.

METHOD WORKSHOPS

At BIOCHANGE (jointly with ECOINF), we have a tradition of organizing method workshops open for all interested in our group and taught by BIOCHANGE PhD students and postdocs to promote knowledge and skills sharing. The past year, several workshops have been arranged by postdoc Scott Jarvie, and led by several of our group members:

- On the use of species distribution modeling in ecology and evolution
- On how to clean repository data for use in biogeography and macroecology
- On species distribution modeling in R
- On statistical packages for data analysis and visualization in R
- On online resources for biodiversity data

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:

- Remote sensing
- Socio-ecological systems
- Megafauna

EDUCATIONAL ACTIVITIES

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.
Photo: Anne Blach Overgaard, BIOCHANGE.

BSC AND MSC COURSES

- **Biogeography & Macroecology**
  (Aarhus University, 10 ECTS)
- **Cultural-Historical Overview**
  (Aarhus University, 10 ECTS)
- **Danish Flora and Vegetation**
  (Aarhus University, 10 ECTS)
- **Geospatial Ecology**
  (Sino-Danish Center for Education and Research (SDC), jointly with Graduate University of Chinese Academy of Sciences (GUCAS), 3.75 ECTS)
- **Geographic Information System (GIS)**
  (Aarhus University, 5 ECTS)
- **Statistical and Geospatial Modelling**
  (Aarhus University, 10 ECTS)

BSC AND MSC STUDENTS

BSc

- **Ask Herrik** (BSc)
  Supervisor: Jens-Christian Svenning
- **Astrid Andersen** (BSc)
  Supervisor: Signe Normand
- **Camilla Sandager Lange** (BSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Emil Kobberup** (BSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Emma Estrup Løw** (BSc)
  Supervisor: Signe Normand
- **Jonathan L. Hansen** (BSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Laura Bille** (BSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Morten Kræpping** (BSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Niels Tang** (BSc)
  Supervisors: Jens-Christian Svenning and Peder Klith Bøcher
- **Rasmus Attrup** (BSc)
  Supervisor: Signe Normand
- **Signe Tonnesen** (BSc)
  Supervisor: Signe Normand

MSc

- **Alexander V. Rudbeck** (MSc)
  Supervisors: Wolf Eiserhardt (ECOINF) and Jens-Christian Svenning
- **Clelie Reynaud** (MSc)
  Supervisors: Jens-Christian Svenning and Wolf Eiserhardt (ECOINF)
- **Jonas Ravn Jensen** (MSc)
  Supervisor: Signe Normand
- **Julie K. M. Drud** (MSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Lea B. Sloth** (MSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Line Skipper** (MSc)
  Supervisors: Jens-Christian Svenning, Robert Buitenwerf and Ashley Buitenwerf
- **Louise V. Sørensen** (MSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Maria J. Nørmark** (MSc)
  Supervisors: Jens-Christian Svenning and Camilla Fløjgaard (Dept. of Bioscience, Aarhus University)
- **Mathilde Skjoldager** (MSc)
  Supervisors: Signe Normand and Jesper E. Moeslund (Dept. of Bioscience, Aarhus University)
- **Mette Grøn** (MSc, Sino-Danish Center for Education and Research & Copenhagen University)
  Supervisors: Jens-Christian Svenning, Xiangchen MI (IB-CAS) and Peder Klith Bøcher
- **Rie Nielsen** (MSc)
  Supervisor: Jens-Christian Svenning
- **Sofie L. Vesterdal** (MSc)
  Supervisors: Jens-Christian Svenning and Robert Buitenwerf
- **Sofie Møller Rasmussen** (MSc)
  Supervisor: Signe Normand
- **Stine Juul Eriksen** (MSc)
  Supervisor: Signe Normand
- **Sune L. Jepsen** (MSc)
  Supervisor: Robert Buitenwerf and Jens-Christian Svenning

Photo: Bjarke Madsen, BIOCHANGE.

COMMUNICATION AND OUTREACH

COMMUNICATION AND OUTREACH

INVITED AND CONTRIBUTED TALKS

JUNE 2019
Jens-Christian Svenning: Naturlig storhed. Forskningens Skønhed symposium, Royal Danish Academy of Sciences and Letters, Copenhagen, Denmark

Jens-Christian Svenning: Totalnatur. Carlsbergfamilien, Folkemødet, Allinge, Denmark

Jens-Christian Svenning Trophic rewilding – background, opportunities and challenges for megafauna-based restoration in the Anthropocene, Biodiversity-Seminar, WSL Birmensdorf, Switzerland

Jens-Christian Svenning: Rewilding – det manglende led i naturgenopretningen? IPBES symposium: Naturgenopretning i et globalt-lokalt perspektiv, Aarhus University, Aarhus, Denmark

JULY 2019
Felix Riede: Apocalypse then? The past human impacts of volcanic eruptions on European societies. LMU VPG-Seminar, Munich, Germany

Alejandro Ordonez Gloria: Do species move, adapt or die? Exploring biodiversity dynamics in the fossil record. INQUA 2019, Dublin, Ireland

AUGUST 2019
Jens-Christian Svenning: Future perspectives (research needs relative to threats and opportunities) including links to SDGs and to the UN Decade of Ecosystem Restoration. Maasai Mara Science and Development Initiative Symposium 2019, Aarhus University, Aarhus, Denmark

SEPTEMBER 2019
Jens-Christian Svenning: Rewilding – the missing link in nature restoration? EU LIFE Nordic Platform meeting 2019, Tønder, Denmark

Signe Normand: Hvordan nye teknologier bidrager til forståelse på tværs af skala. Dansk teknologihistorisk selskab, Aarhus, Denmark

Signe Normand: Biodiversitet Mentor workshops i Videnskabsklubben, Aarhus, Denmark

OCTOBER 2019
Signe Normand: Cross-scale integration for improved understanding of biodiversity dynamics. Laboratoire d'Ecologie Alpine, CNRS, University Grenoble Alpes, Saint-Martin-d'Héres, France

Jens-Christian Svenning: Rewilding in the Anthropocene – learning from the past to promote a sustainable future. Back to the – Future landscapes; Public TERRANOVA seminar; Honig Fabriek, Nijmegen, The Netherlands

Felix Riede: Kultur, historie og læring med klimatilpasning i sigte. National conference for climate change adaptation, Horsens, Denmark

NOVEMBER 2019
Jens-Christian Svenning: Rewilding - concepts, scientific background, and current state of the science. Wallenberg Seminar: Rewilding as a New Paradigm for Nature Conservation? Royal Swedish Academy of Agriculture and Forestry, Stockholm, Sweden

Felix Riede: Volcanoes, climate and past human impacts in Scandinavia – two case studies from before the 6th century. Centre for Earth Evolution and Dynamics, UiO, Oslo, Norway

Jens-Christian Svenning: Hvad sker der med Jordens biodiversitet i Menneskets Epoke? Wilhjemkonferencen 2019, University of Copenhagen, Copenhagen, Denmark

DECEMBER 2019
Jens-Christian Svenning: Biodiversity Dynamics in a Changing World. WWF, Aarhus, Denmark

JANUARY 2020
Felix Riede: Volcanoes, climate and societal change in the prehistory of northern Europe – does the past hold lessons for the future? KlimaCampus Colloquium, Hamburg Uni/MPI-Meteorology, Hamburg, Germany

FEBRUARY 2020
Jens-Christian Svenning: Towards a biodiverse future: Lessons from a macro-scale perspective on ecology. World Biodiversity Forum, Davos, Switzerland

Jens-Christian Svenning: The long-term baseline for nature in Denmark. Dansk Flora & Vegetation, Department of Biology, Aarhus University, Aarhus, Denmark

MARCH 2020
Jens-Christian Svenning: Fremtidens natur. Marselisborg Gymnasium, Aarhus, Denmark

Jens-Christian Svenning: Fremtidens natur. Offentlige foredrag i Naturvidenskab, Aarhus Universitet, Aarhus, Denmark (repeated twice).

MEDIA / DEBATES / NEWS

Below is a selection of media appearances, participation in debates and feature articles by BIOCHANGE core members.

JUNI 2019
Felix Riede: Menneskets evolution i biokulturelt perspektiv. De Blindes Oplysningsforbund, Aarhus, Denmark. June 18, 2019

AUGUST 2019
Jens-Christian Svenning: Baboons show climate change drove human origins (feature article). Filthy Monkey Men. August 1, 2019

SEPTEMBER 2019
Jens-Christian Svenning: Lad naturen passe sig selv (podcast). Science stories. September 6, 2019

Jens-Christian Svenning: Grønne papegøjer og palmer kan blive fremtiden i Østjylland (feature article). TV2 Østjylland. September 10, 2019

Jens-Christian Svenning: Danmark Planter træer (tv-contribution). TV2 Østjylland. September 10, 2019

Signe Normand: Hvad sker der i Østjylland, hvis klimaudviklingen fortsætter? (tv-contribution). TV2 Østjylland. September 10, 2019

OCTOBER 2019
Jens-Christian Svenning: Genskabt vildskab (article). Weekendavisen – Ideer, pp. 8-9. October 11, 2019

DECEMBER 2019
Jens-Christian Svenning: Invasive arter (interview). Radio4. December 17, 2019

JANUARY 2020
Felix Riede: 'être vivant' – evolution: from theory to emergency (debate). Night of Ideas, DOKK1 Aarhus. Jan 29, 2020

FEBRUARY 2020
Jens-Christian Svenning: En stærk australsk natur behøver hjælp (article). Frederiksborg Amts Avis – Danmark, p. 6. February 8, 2020

Jens-Christian Svenning: Hvad sker der, efter skovbrandene i Australien er slukket? (feature article). Videnskab.dk. February 9, 2020

Jens-Christian Svenning: Professor i biodiversitet: Mårhunden er ikke det store problem (feature article). TV Midtvest. February 22, 2020

Jens-Christian Svenning: Dan Jørgensen vil se på certificering af biomasse (feature article). ING/GRIDTECH. February 28, 2020

MARCH 2020
Jens-Christian Svenning: Forvildede dromedarer og andre fremmede dyr genskaber fortidens natur (press release). nat.au.dk. March 23, 2020

Jens-Christian Svenning: Forvildede dromedarer og andre fremmede dyr genskaber fortidens natur (press release). Ritzau. March 24, 2020

Jens-Christian Svenning: Invasiv nytte (article). Weekendavisen – Idéer, p. 2. March 27, 2020

MAY 2020
Jens-Christian Svenning: 'Near-unlivable' heat for one-third of humans within 50 years if greenhouse gas emissions are not cut (press release). Faculty of Natural Sciences. May 4, 2020

Jens-Christian Svenning: Forskere advarer: 3,5 milliarder mennesker risikerer at bo i ulidelig varme indenfor 50 år (feature article). Videnskab.dk. May 4, 2020

Jens-Christian Svenning: Frygter at milliarder må leve i ulidelig varme inden for de næste 50 år, viser studie (feature article). nyheder.tv2.dk. May 6, 2020

OTHER OUTREACH ACTIVITIES

Felix Riede: Det gode liv i oldtiden - Oldtiden set med datidens briller i nutidens øjne (digital exhibition): https://skolehistorie.au.dk/digitale-udstillinger/det-gode-liv-i-oldtiden/

Jens-Christian Svenning giving his keynote *'Towards a biodiverse future: Lessons from a macro-scale perspective on ecology'* at the World Biodiversity Forum in Davos, Switzerland in February 2020. Photo: Sophie Monsarrat, BIOCHANGE.

EVENTS

TREECHANGE WORKSHOPS

In August and December 2019, BIOCHANGE hosted two workshops organized by Jens-Christian Svenning, Wenyong Guo and Josep M. Serra-Diaz (associate and alumnus of BIOCHANGE) in relation to the project TREECHANGE funded by the Danish Council for Independent Research (see chapter on Research). Here we provide a brief description of both workshops.

TREECHANGE-BIEN WORKSHOP

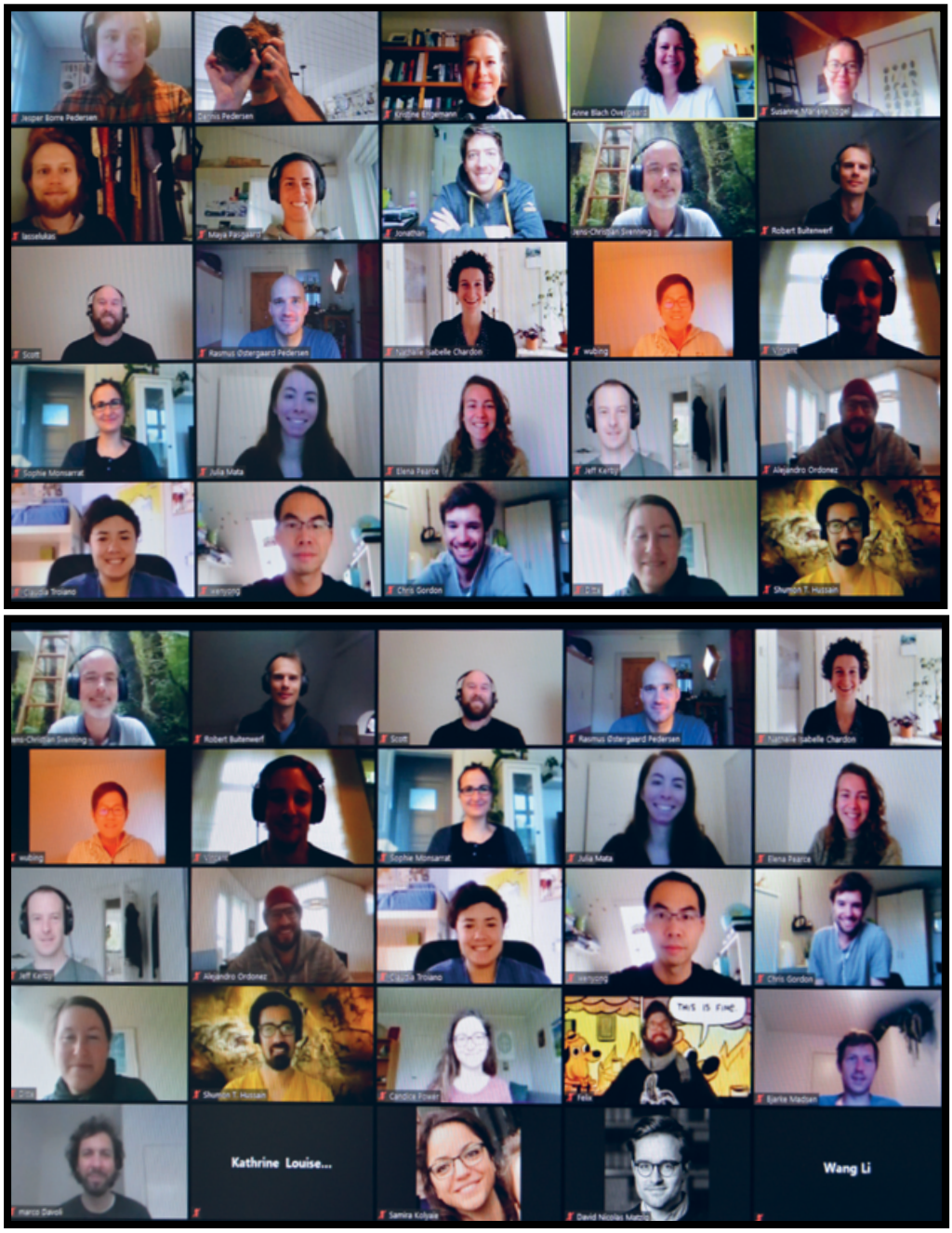
From 12-16 August 2019, Jens-Christian Svenning and Brian Enquist, from University of Arizona, hosted a joint BIEN & TREECHANGE workshop at BIOCHANGE, Aarhus University with about 20 precipitants from USA, Australia, China, Switzerland, Czech Republic, France, and Denmark. During the workshop, many of the attendees presented their projects and potential ideas related to BIEN/TREECHANGE. We discussed the future work of collecting species traits and distribution data and of building a global data network, with separate data hubs located in each main region. Jens-Christian Svenning and other European participants further discussed the possibility and logistics of the European hub. Apart from the technical part, all attendees spent about two days discussing how to use the current data to answer important ecological, evolutionary and conservation questions we are facing now and subsequently identified over fifteen potential projects after intensive debates.

Photo: Dennis Pedersen, BIOCHANGE.

RESTORING GLOBAL FORESTS AND BIODIVERSITY WORKSHOP

Current global analysis attempts have been focusing on restoring forest cover to increase the Earth's carbon sink capacity, but little is known to what extent such efforts could be accompanied by efforts to halt the mass extinction of species too. To address the issue, an international group of 15 researchers with different expertise and perspectives on land-, social-, and ecological sciences were gathered during 2-6 December 2019 at BIOCHANGE hosted by Jens-Christian Svenning. The workshop intended to analyze, project and write-up how global restoration efforts may have the potential to restore biodiversity in the 21st century. The workshop attendees from France, Spain, Sweden, the USA, China, Netherlands, and South Africa, including six BIOCHANGE researchers discussed the framework of the proposed project, put together available data and prepared the initial analyses.

Photo: Dennis Pedersen, BIOCHANGE.



Photos: Dennis Pedersen BIOCHANGE.

BIOCHANGE SEMINAR

This year, we had to cancel our annual center retreat due to the COVID-19 situation. However, we did manage to get the BIOCHANGE community together via Zoom for a couple of hours of interesting interdisciplinary talks on human-environment relations, delivered by our new assistant professors Kristine Engemann on green space and mental health, and Shumon T. Hussain on deep-time human-animal relations. In addition, Felix Riede introduced the newly ERC-funded CLIOARCH project (see the RESEARCH chapter) and visualized how it matches the overall BIOCHANGE themes [3] Ecoinformatics and New Technologies and [4] Interdisciplinary Innovation.

MEGAFAUNA RESTORATION SYMPOSIUM

UP-SCALING MEGAFAUNA RESTORATION FOR GLOBAL BIODIVERSITY AND CLIMATE GAINS

Between May 4-7, 2020, the MegaPast2Future project hosted a four-day symposium overviewing current advances in the field of megafauna restoration, with a key focus on developing ideas to achieve regional-global biodiversity and climate gains. The symposium was attended by a diverse group of nine experts in the fields of megafauna ecology, restoration ecology, macroecology, climate science and social ecology, the BIOCHANGE organizing committee and an audience of 50 invited guests. Owing to the COVID-19 pandemic, the symposium was a fully online event.

The invited guests and BIOCHANGE members presented their current research within a 'mini-conference' on the first 2-days of the symposium. Day 1 of the symposium focused on megafauna as biodiversity and climate engineers. Robert Buitenwerf (BIOCHANGE), Brian Enquist (University of Arizona), Steven Higgins (University of Bayreuth), Scott Jarvie (BIOCHANGE) and Jens-Christian Svenning provided unique insights on megafauna effects on biodiversity at macroecological scales. Chris Gordon (BIOCHANGE) discussed how these effects manifest at smaller scales. Ana Rodrigues (CNRS, France) described how historical losses of megafauna (i.e., whales) impact extant ecological processes. Jeppe Aa. Kristensen (GEUS, Aarhus University) and Yadvinder Malhi (University of Oxford) discussed megafauna's relevance for climate change mitigation.

Day 2 of the symposium focused on social drivers of megafauna restoration, aiming to understand processes that both facilitate and constrain reintroductions. Wang Li and Sophie Monsarrat (both BIOCHANGE) described where megafauna restorations are best directed within the Anthropocene. Hanna Tuomisto (University of Helsinki) discussed ideas about megafauna restoration within agricultural systems. Silvia Ceauşu (University College London), Tobias Kuemmerle (Humboldt-Universität zu Berlin), Jamie Lorimer (University of Oxford) and Susanne Vogel (BIOCHANGE) overviewed social-ecological barriers to, and opportunities for, megafauna restoration within a human dominated world.

In addition to the academic content, an artist (Catherine Williams) also attended the symposium, which added a creative and unique element to the meeting. Catherine made "on-the-fly" sketches during each presentation. A final artwork created from the sketches succinctly communicated the core-ideas of the symposium via a beautiful (and accessible) platform: (See her artwork on the opposite page).

Photos: Ana Rodrigues.

The invited experts and the BIOCHANGE members attended a workshop on the final 2-days of the symposium. During the workshop, the participants developed ideas and started writing an academic manuscript relating to the core-ideas of the symposium; megafauna restoration for regional-global biodiversity and climate gains. The workshop involved both group discussions where general ideas about megafauna restoration were discussed and more focused break-out meetings where specific aspects of the manuscript were teased-out. The workshop was a huge success and we aim to publish our findings by the end of 2020.

Artwork by Catherine Williams @cjaw_art.

PHD DEFENSE

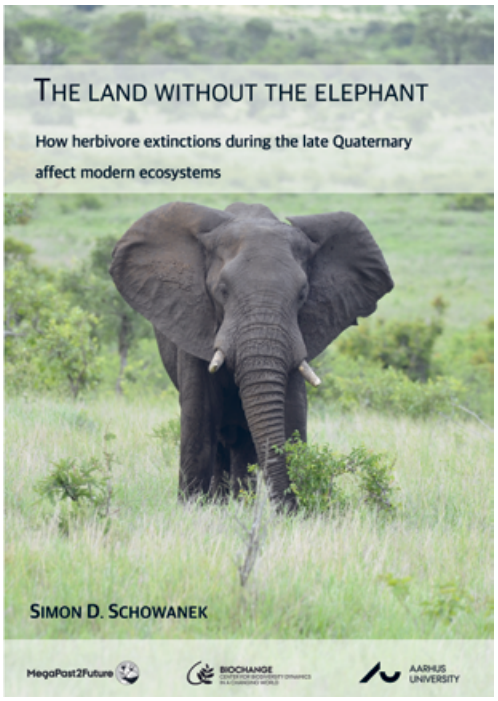
This year we have celebrated a successful PhD defense in the BIOCHANGE center.

On May 12, 2020, MegaPast2Future PhD student **Simon Schowanek** defended his thesis *'The land without the elephant. How herbivore extinctions during the Late Quaternary affect modern ecosystems'*, supervised by:

- Professor Jens-Christian Svenning
- Dr. Matt Davis
  (Natural History Museum of Los Angeles County, USA)

Members of the assessment committee consisted of:

- Associate Professor Carl-Gustaf Thulin
  (The Swedish University of Agricultural Sciences, Sweden),
  Dr. Andrew Tanentzap
  (University of Cambridge, United Kingdom)
- Chair Professor Signe Normand
  (Aarhus University).



PUBLICATIONS

Below BIOCHANGE-related publications published in 2019 and to April 2020 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).

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Anderson, R.M., *et al.* 2019. Introducing rewilding to restoration to expand the conservation effort: a response to Hayward *et al. Biodiversity and Conservation* 28:3691-3693. (**R. Buitenwerf, J.-C. Svenning**).

Araújo, M.N., **J.-C. Svenning**, and H. Toumisto. 2019. Ecography's flip to a pay-to-publish model. *Ecography* 42:1456-1457.

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**).

Bjørnevad, M., *et al.* 2019. The life and times of an Estonian Mesolithic slotted bone "dagger". Extended object biographies for legacy objects. *Estonian Journal of Archaeology* 23:103–125. (**F. Riede**).

Bruelheide, H., *et al.* 2019. sPlot – a new tool for global vegetation analyses. *Journal of Vegetation Science* 30:161-186. (**J.-C. Svenning**).

Bull, J.W., R. Ejrnæs, D.W. Macdonald, **J.-C. Svenning**, and C.J. Sandom. 2019. Fences can support restoration in human-dominated ecosystems when rewilding with large predators. Restoration Ecology 27:198-209.

Burke, K.D., *et al.* 2019. Differing climatic mechanisms control transient and accumulated vegetation novelty in Europe and eastern North America. *Philosophical Transactions of the Royal Society B* 374:20190218. (**A. Ordonez**).

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

Dagallier, L.P.M.J., *et al.* 2019. Cradles and museums of generic plant diversity across tropical Africa. *New Phytologist* 225:2196-2213. (**A. Blach-Overgaard, J.-C. Svenning**).

Doughty, C.E., *et al.* 2020 Megafauna decline have reduced pathogen dispersal which may have increased emergent infectious diseases. *Ecography.* (e-pub ahead of print). (**J.-C. Svenning**).

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Eggers-Kaas, **T.**, **J.B. Pedersen, C.S. Hoggard, F. Sauer,** and **F. Riede**. 2019. A technological and typological analysis of lithic material from Skovmosen I, Denmark. *Danish Journal of Archaeology* 8:1–18.

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Genes, L., **J.-C. Svenning**, A.S. Pires, and F.A.S. Fernandez. 2019. Why we should let rewilding be wild and biodiverse. *Biodiversity and Conservation* 28:1285-1289.

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Hannah, L., *et al.* 2020. 30% land conservation and climate action reduces tropical extinction risk by more than 50%. *Ecography.* (e-pub ahead of print). (**J.-C. Svenning**).

Hansen, O.L.P., *et al.* 2020. Species-level image classification with convolutional neural network enable insect identification from habitus images. *Ecology and Evolution* 10:737-747. (**J.-C. Svenning**).

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Kambach, S., *et al.* 2019. Of niches and distributions: range size increases with niche breadth both globally and regionally but regional estimates poorly relate to global estimates. *Ecography* 42:467-477. **(J.-C. Svenning).**

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African elephant in Addo Elephant National Park, Eastern Cape, South Africa.
Photo: Sophie Monsarrat, BIOCHANGE

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