

Project title:	AlterEco -Understanding the “Anthropocene”: human alteration of ecosystems in our deep history
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Executive Summary

Current debates about the role of humans in climate change and the validity of the concept of the “Anthropocene” have put an emphasis on the way humans have recently been modifying their habitats to increase the yield of their natural environments, up to the point of their depletion. These recent activities build upon a deep history of modifications within the human niche with impacts on ecosystems and influence on trophic cascades. Aspects of “landscape management” practices by (sub)-recent hunter-gatherers have become a subject of anthropological research, but the time depth of human influence on “natural” ecosystems is unknown and has thus far only very rarely been addressed. This is partially related to the implicit assumption that the ecological footprint of past hunter-gatherers was generally negligible. However, to understand the fundamentals of human impact on past and present habitats and food-webs and to obtain data possibly relevant for ecological restoration it is imperative to characterise the role of humans in modifying natural environments in the deep past.

The 28ha landscape of Neumark-Nord (GER) (Last Interglacial, 125.000 years ago) provides the unique potential to study the possible time depth of anthropogenic changes to “natural” landscapes, commonly thought to be a recent phenomenon, a characteristic of the “Anthropocene”, from the start of agriculture onward. Large-scale long-years excavations and subsequent analyses uncovered fine-grained data on Neanderthal subsistence strategies over a ca 7,500 years period as part of a virtually complete palaeo-community (4 apex predators; 13 large herbivore species, more than 500 individuals).

The Leibniz Collaborative Excellence “AlterEco - Understanding the “Anthropocene”: human alteration of ecosystems in our deep history” worked at the interface of ecological, zooarchaeological-, isotope- and genetic studies, originally with a focus on two potential anthropogenic effects: (1) human alterations of plant communities, (2) human interactions with animal communities.

The Corona pandemic put some challenges on the project at the very beginning, as we couldn’t collect basic data for zooarchaeological, isotopic and genetic analyses for over one year. This delay however had no impact on the work programme and flow of analyses, but as a compensation we made some changes to the composition of staff and to the laboratory costs. This turned out to be the right decision during data interpretation, as it allowed us to incorporate other lines of analysis to obtain additional relevant and valuable results.

Thes results obtained by AlterEco challenge fundamentally our current perception of Neanderthal ecology and interactions with their environment, which has major consequences for the frames of references with which we interpret the Pleistocene archaeological record. For instance, the project could demonstrate local vegetation opening by an anthropogenic fire regime over a period of minimally 2,500 years, to date the oldest evidence for anthropogenic landscape modification in the archaeological record. Our analyses indicate a purely anthropogenic origin of the animals excavated at Neumark, ranging from massive hunting of the local population of straight-tusked elephants, again the first evidence in the archaeological record, to exploitation of the small European pond turtle. In addition, we could present the first zooarchology- based evidence for bone grease rendering at the site NN2/2B in the Neumark

lake land. In sum, our results indicate that Neanderthal ecology at Neumark is quite similar to Early Holocene and ethnohistorically documented hunter-gatherers, involving at least temporary gatherings of larger groups (>100 individuals), division of labour, and a more place-based organisation of subsistence with surplus killing of animals in the landscape, caching of cadavers and delayed consumption chains. This interaction with the environment lasted for minimally 2,500 years on a sustainable basis as our population viability simulation could demonstrate.

The results of the project inspired new lines of research and new collaborations, which aim to trace human consumption practices during the last glaciation and early Holocene (ca. 100.000 – 6,500 years before present), to develop new analytical techniques and indices to overcome equifinality issues in taphonomy during early stages of bone diagenesis, and to connect information from fossil mammal populations with current issues in wildlife management.

1. Contribution to strategic goals of the funding programme

Leibniz collaborative excellence funds innovative networks, strengthens interdisciplinary cooperation under a high risk / high gain research umbrella to obtain scientific breakthrough to overcome complex challenges. AlterEco aimed for the first time to qualify an “ecological footprint” of pre-modern humans in the archaeological record. Our results provide new lines of research using data about our deep past to inform current debates about the present state and the future of our planetary health - thanks to a motivated working group.

Since archaeology is generally a slow science driven by a comparatively small research community, it will take some time until our results are fully digested, applied and new research implemented. However, we are confident that our findings will have an enormous impact on research in the coming years and thus serve as a good example of Leibniz Collaborative Excellence. The (in one case: exceptionally) large amount of attention three of our key papers in Science Advances have received, visible in the Metrics scores of these papers, make us very confident of this claim.

2. Achievement of objectives and milestones

AlterEco was subdivided into 6 work packages (1) Isotopes, (2) Palaeogenetics, (3) Zooarchaeology, (4) Fire regime, (5) Synthesis and (6) Transfer. For the workpackage 1-3 extensive sampling of material stored at LEIZA-Monrepos and in the holdings of the Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt (the legal owner of the Neumark-Nord material) was planned for the beginning of the project. Due to the Corona pandemic, which didn't allow travel and joined lab work for over a year, we were forced to reschedule, but thanks to a prolongation and cost-neutral reallocations we were able to stick stubbornly to our working plan and achieved all the objectives originally formulated. In sum, and thanks to the motivated working group, we collected even more data than planned in the original proposal. In addition to the elephant skeletons and material from excavation trenches we have performed a complete zooarchaeological analyses of the Neumark-Nord 1 material, a complete revision of the Neumark-Nord 2/2B material and as a comparative sample material from the Eemian sites of Taubach and Gröbern, as well of the Middle Pleistocene site of Bilzingsleben (in sum more than 130,000 bone specimens). Also, the genetic and isotope study sampled more specimens than originally proposed. In addition, more isotopic signatures and analytical measures were taken, including oxygen as a proxy for seasonality and laser ablation MC-ICPMS for strontium analysis to trace elephant migration. An additional prolongation and cost-neutral reallocations of the budget allowed the comprehensive sampling and analysis. The results achieved justify this decision.

3. Activities and obstacles

The obstacles AlterEco faced during the Corona pandemic are outlined above. We used the delay to finish the work package for the fire regime, because only here the relevant data were

accessible during the pandemic. In addition, we worked on a publication plan, that we strictly followed during the project. Joint activities of the project partners were the collaborative sampling in Monrepos and Halle in the first “proper year” of the project and annual in person workshops to organize the ongoing work, discuss the results, and tweak the publication plan. Apart from that we had weekly online meetings, in the beginning mostly on an informal basis to keep track of the work and the data management in the individual laboratories, zooarchaeology, isotopes and genetics, later to organize additional analyses with new partners and review our manuscripts. For this, in the second year a core group (Sabine Gaudzinski-Windheuser, Wil Roebroeks, Lutz Kindler) formed, that constantly wrote draft manuscripts from incoming results. A second group (Theo Tacail, Fulco Scherjon, Lutz Kindler) took the responsibility of data management. This allowed a rather fluid process from sampling via analysis and interpretation to publication. Obstacles in this publication process consisted of time-consuming handling of manuscript by publishing houses and long review processes. Although we have published a considerable amount of our results, we still have a few papers in revision and finished manuscripts ready for submission. Submission of a synthesis summarizing all results of AlterEco must be delayed until all individual papers are published.

4. Results and successes

Key results of AlterEco include a reconstruction of the full trophic ecology of the larger mammal community via isotopic signatures, scheduled for publication in 2026. Genetic evidence shows a higher diversity of fallow deer at Neumark alone than in all recent populations today combined, ready for publication in iScience after revision. In contrast, the elephant population is genetically quite homogenous, and most likely represents a local population during the Eemian, publication also scheduled for 2026. Publication date of isotopic and proteomic data on elephant mobility, diet and sex at Neumark is March 2026. The articles on landscape modification, elephant hunting and bone rendering by Neanderthals were very successful and obtained high attention from the scientific community and the public as indicated by high downloads and exceptionally high Altmetric scores. Three of our papers were ranked in the Top10 in the field of Human Evolution of their respective publication year by the Smithsonian Institution, for example. The relevance of the project's results is also reflected by conference invitations, e.g. the annual meeting of the ECONOVO Center for Ecological Dynamics in a Novel Biosphere at Aarhus, Denmark or the Symposium of the ROCEEH project of the Heidelberg Academy of Sciences at Senckenberg, Frankfurt.

Concerning transfer, A youtube-video of AlterEco created together with the video channel of “BreakingLab” has won the “Fast Forward Science Award” in the category Tandem Award 2022/23. Our contributions to elephant hunting and bone grease rendering in particular have received widespread media coverage globally, from news outlets in Manila, Bangkok and Mumbai to the New York Times, Washington Post and Wall Street Journal, as well as radio interviews, e.g. for “All Things Considered” (NPR) and “Quarks and Quirks” (CBC).

5. Equal opportunities, career development and internationalisation

While the core group of AlterEco consists of senior researchers, funded staff in the project as well established cooperations during the project allowed career development from the stage of BA and MA students up to PhD candidates and early career post-Docs. This includes a female BA from Mainz University, female MSc from Leiden University, the Netherlands, a male Mexican PhD and a female Italian PhD-student, a male French PostDoc and a female PostDoc from the US. This blend of different people is not the result of any specific measures or initiatives we have developed, but the result of their individuality, personality, profession and dedication that made them all fantastic colleagues throughout the project.

Samples from Neumark were part of two cumulative PhDs, one for paleogenetic studies and one for isotopes. Sampling, investigation, interpretation and writing were closely supported and guided by the AlterEco crew. With the publication of the papers, both PhD-students will complete their dissertation in 2026.

Against the background of the scientific significance of AlterEco three important steps towards internationalization were implemented. We formed an international group of zooarchaeologist cooperating with their respective expertise in the development of new methods and analytical tools. We started a cooperation with the WWF to assist with data from the deep past in today's protection of the African forest elephant, the closest relative of the Neumark elephants, in Cameroon and we started a cooperation with the Mammal Research Center of the Polish Academy of Science for neotaphonomic investigations in the Bialowieza National Park, Poland.

6. Structures and collaboration

The structure and governance of AlterEco maintained their original description in the proposal. The collaboration of the partners, workflow organization and communication was fruitful and non-problematic. Additional collaborations were established for isotope studies, e.g. to implement oxygen and novel techniques of strontium analyses. These studies were funded from the isotope budget and didn't require any additional agreements or an additional collaboration partnership.

7. Quality assurance

No animal testing has been conducted.

Research in AlterEco and dissemination of the results follows the FAIR guiding principles for scientific data. All relevant data of any publication is part of the main article or rolled out in the supplementary information with open access. In addition, a complete documentation of all analyses performed on the material of Neumark-Nord will be handed to the Landesamt für Denkmalpflege und Archäologie and stored with the material to facilitate reuse in future studies of the material.

8. Outlook

AlterEco provided novel and unexpected insights into Neanderthal ecology. It established one of the largest isotopically and genetically sampled faunal communities in the Pleistocene record world-wide. The results challenge fundamentally our current perceptions of Neanderthal social behaviour and their interactions with their environment, which has major consequences for the frames of references in which we interpret the Pleistocene archaeological record.

From an ecological perspective the results of AlterEco call for an in depth analyses of the isotopic trophic community structure as well as genetic changes of large mammals during the last 100,000 years to fill the knowledge and data gap between the Last Interglacial period at Neumark and the current one, the Holocene. The results should also stimulate the scientific field to study and detect additional proxies of anthropogenic landscape modification in the geological record of the last 100,000 years.

From an archaeological perspective the question of group sizes, division of labour, cadaver caching, food preparation and storage has become very prominent through our work, and is widely considered to be of the utmost anthropological significance. For this we have added a project to a new TRC initiative for the DFG to trace Palaeolithic and Mesolithic consumer and consumption practices. In addition, AlterEco inspired the formation of an international group of zooarchaeologists to develop new analytical tools and indices for answering new research questions and to overcome decade long discussion about equifinality in the fossil record. With an emphasis on biostratigraphic processes during early stages of bone deposition we have proposed a new Leibniz Cooperative Excellence "TNT – Towards a new taphonomy", which was recently granted.