The European Landscape Learning Initiative: Past and Future Environments and Energy Regimes shaping Policy Tools

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About TERRANOVA

TERRANOVA: The New Learning Initiative between Humanities and Science: Mapping Past Environments and Energy Regimes, Rethinking Human Environment Interaction and Designing Land Management Tools for Policy.

This project aims at improving our diachronic long-term understanding of landscape histories and land use strategies in Europe in the Eemian, Holocene and Anthropocene. Previously identified socio-cultural transitions and the effects of natural forcings will be critically assessed in a new intellectual interdisciplinary arena created by the TERRANOVA project. 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 will contribute to identifying major previous shifts in resource use and energy regimes and provide options for the future transition to a low carbon society.

Beneficiaries

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Beneficiary 4: UU	Uppsala University	
Beneficiary 5: RE	Rewilding Europe	
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1   EXECUTIVE SUMMARY

TERRANOVA is an ITN (2019-2023) training 15 ESRs in a new learning initiative between Humanities and Science: Mapping past environments and energy regimes, rethinking human environment interaction and designing land management tools for policy.

TERRANOVA will produce an unprecedented atlas with layers of reconstructed human-environment relations, land use dynamics, climate change, fauna history and species pools from the Eemian time-period up until the present day. This deliverable describes the preliminary results of 1 year of research into Atlas building of a large group (n=9) ESRs. Communication and data exchange, as well as the process of atlas generation work flow has been undertaken, including examples of datasets from ancient landscapes, energy regimes and climate scenarios.

The atlas database is currently formed by four main data types: Archaeological data, Climate data, Land cover data, and Megafauna distribution. The preliminary publication concludes with listing the next steps to take for final publication of the digital atlas for landscape evolution, including connections to policy.

2   INTRODUCTION

2.1   BACKGROUND

TERRANOVA investigates the deep history of human-environment interactions and how these interactions have shaped European landscapes as a foundation to design sustainable environmental policies in Europe. Between 2019 and 2023, fifteen PhD students will be trained to conduct interdisciplinary research around this topic in order to promote a long-term understanding of the structure and functioning of European landscapes to meet current challenges caused by reduced biodiversity and climate change. TERRANOVA seeks knowledge through landscape energy regimes and transitions, which will help in the transition to future low-carbon society.

Linking extended landscape histories with innovative strategies

for future landscape management

By combining climate and landscape modelling we will gain new insights into the importance of climate versus humans in the development of European landscapes over the pre-industrial Holocene and contribute to future scenario generation.

The effects of humans on global climate before the Industrial Era, with its increased use of hydrocarbons, is currently a subject of debate. We know that Holocene human-natural interactions influenced the development and present state of terrestrial ecosystems. Bottom-up modelling approaches, which did not represent large amounts of anthropogenic land cover change[1], contrast with models suggesting significant anthropogenic land cover change in the pre-industrial Holocene, with consequent implications for the development of European landscapes[2]. Independent methods for reconstructing past land cover tend to support early deforestation, showing considerable clearances in Europe millennia ago and over multiple interglacials[3]. TERRANOVA intends to address the discrepancies between the different scenarios of anthropogenic land cover change. Thematic resolution in current scenarios with cropland, pasture and urban areas differentiated limits our ability to quantify the importance of human activities for the current state of European landscapes*.*

TERRANOVA represents a strong interdisciplinary and intersectoral co-production of knowledge, collaboration, innovative teaching and supervision and working experience with multiple data types in the research programme. TERRANOVA presents an interdisciplinary set of projects hosted by academic and non-academic beneficiaries to link climatic and numerical modelling of land cover with archaeological data (x, y, z) and palaeoecological data (macrofauna and pollen) in order to develop new policies on European future landscape management.

Landscapes reflect the changing interactions between humans and the environment through time. Successful management strategies use a range of options for dealing with this dynamic relationship. Considerable relevant data on human-environment relations in Europe exists and will be used in TERRANOVA. We will deal with issues of complexity from both a multi-scalar and a multi-temporal perspective leading to a consideration of linear and nonlinear causality[4].

The transdisciplinary approach of TERRANOVA bridges the past and the future by 1) learning from the past to manage the future and 2) exploring strategies to preserve landscapes of the past as values for landscape users of the future. Designing land management for the future will benefit from reconstructing past landscape changes in relation to past energy regimes and associated environments; and enrich future policy guidelines. Reconstructions of past environments will produce high-resolution data of energy regimes and their transitions from the continental scale to the TERRANOVA field laboratory regions supporting analysis of human- environment

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[1] Klein Goldewijk et al 2010; Pongratz et al., 2009

[2] Kaplan et al, 2009; Kaplan et al, 2011

[3] e.g. Fyfe et al, 2013, Trondman et al, 2015

[4] Garnsey & McGlade, 2006.

interactions. Results will be documented in an open access digital atlas of ancient landscapes, energy regimes and climate scenarios (Fig. 1).
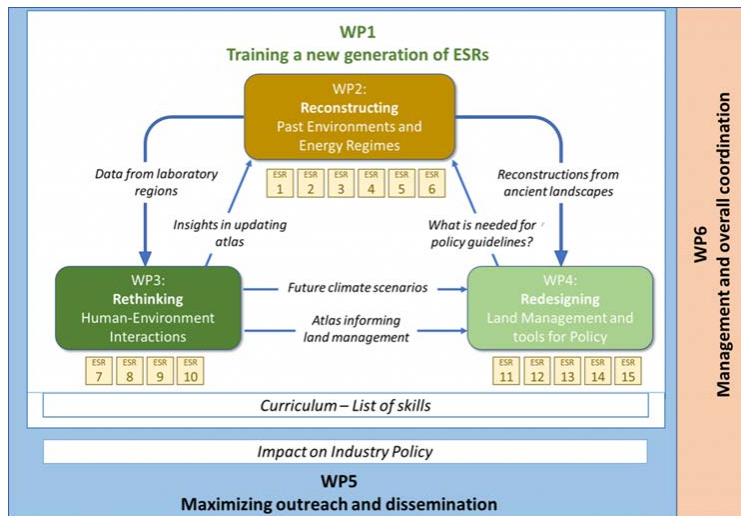

Fig. 1: Work package structure and work flow: training, dissemination, management.

TERRANOVA is divided into six WPs (Table 1). The 15 individual Early Stage Researcher (ESR) projects are grouped together to ensure continuous interdisciplinary and intersectoral exchange of research experience and results (Table 2).

All projects contribute to a) the interdisciplinary assembly of the digital atlas of integrated modelling of Eemian and Holocene land-cover and land use change in Europe over different cultural ERs (WPs 2-3), b) the production of policy documents, white papers and future strategies (WPs 3- 4) (Fig. 1).

Ongoing discussions in Work Packages and Atlas and Policy groups between ESRs and supervisors in the 1st year of TERRANOVA, have highlighted so far the importance of policy output to be incorporated in the digital atlas.

Table 1: Overview of Work Packages in TERRANOVA.

Work package		Start Month	End Month	Activity type in t	Lead Beneficiary		ESRs
#	Title				#	Short name	
1	Training a new generation of ESRs	7	42	Training	8	CNRS	1-15
2	Exploring past environments and energy regimes	7	42	Research	7	AU	1-6
3	Rethinking human-environment interaction	7	42	Research	1	VUA	7-10
4	Designing landscape management and tools for policy	7	42	Research	3	MLU	11-15
5	Maximising outreach and dissemination	7	42	Dissemination	4	UU	1-15
6	Managing and coordinating TERRANOVA	1	48	Management	1	VUA	-

2.2.   ROLE OF THIS DELIVERABLE IN PROJECT

TERRANOVA will produce an unprecedented atlas with layers of reconstructed human-environment relations, land use dynamics, climate change, fauna history and species pools from the Eemian time-period up until the present day. This information will be integrated in a separate layer outlining scenarios of future landscape management, which will include areas of Europe with potential for ecological restoration based on rewilding principles.

Our approach to rewilding focuses on key components of natural ecosystem dynamics, such as trophic complexity, stochastic disturbances and dispersal among habitats. Rewilding actions resulting in restoration of these processes, and their dynamic interactions, we consider crucial for promoting functioning and sustainable ecosystems.

Table 2: Overview of the 15 ESR projects, grouped in the 3 Work Packages. All projects study one or more of four energy regimes (ER) and are divided between Atlas and Policy groups.

ESR	ER 1	ER 2	ER 3	ER 4	WP 2: **RECONSTRUCTING** PAST ENVIRONMENTS AND ENERGY REGIMES	ATLAS	POLICY
ESR 1	■	■			Natural Baselines in European Interglacial Landscapes	■	
ESR 2			■		Balancing culture in the North European landscape evolution and integrated legacies	■	
ESR 3	■	■	■		Modelling human-environment interactions in landscape change (ABM)	■	
ESR 4	■				Balancing culture in southwest European landscape evolution and integrated legacies	■	
ESR 5	■				Balancing culture in southeast European landscape evolution and integrated legacies	■	
ESR 6	■	■			Pollen-based quantitative reconstructions of past natural and anthropogenic landscape openess in two European field laboratories	■	
					WP 3: **RETHINKING** HUMAN-ENVIRONMENT INTERACTION		
ESR 7				■	Modelling land cover change in Europe over the current and previous energy regimes: The combined effects of climate and anthropogenic activities on the development of European landscapes	■	
ESR 8				■	Macro-scale perspectives on past and potential future megafaunas across Europe and their ecological impacts	■	■
ESR 9	■				Modelling and characterization of climate, environment and human impact during the four energy regimes	■	■
ESR 10			■		Trade-offs between agriculture and nature in landscape development		■
					WP 4: **REDESIGNING** LANDSCAPE MANAGEMENT TOOLS FOR POLICY		
ESR 11			■		What is the socio-economic value of rewilding?		■
ESR 12			■		Investigating the potential of natural restoration and rewilding in the European landscape		■
ESR 13				■	Defining a framework for Rewilding Europe landscapes in the Anthropocene		■
ESR 14				■	Managing trade-offs in agricultural landscapes transitions: protecting cultural heritage versus rewilding		■
ESR 15				■	A long-term view of nature and culture in decision-making		■

2.3 APPROACH

The research described here encompasses an interdisciplinary endeavour in combining data from the sciences and humanities in a combined digital atlas of landscape evolution.

2.4 STRUCTURE OF THIS DOCUMENT

The deliverable introduces the reader into TERRANOVA its scope and outlook. The next step is to explain the role of the digital atlas within TERRANOVA. Following the results of one year of atlas building research are presented. The deliverable is concluded in presenting the next steps to take to produce a final digital atlas of European landscape evolution and future landscape management.

3 CURRENT STATE OF THE DIGITAL ATLAS

The first step towards the interdisciplinary assembly of the digital atlas generation consisted of establishing the basis of regular communication and data exchange between the contributors to the atlas. At the moment, regular exchanges between the different working groups involved are being held through various communication platforms, as outlined in the TERRANOVA Communication and Dissemination Plan. Updated data is being shared upon receiving a request from an internal collaborator or a team member involved in digital atlas generation. Experience to date has proved information and data exchange to be reasonably efficient, with some room for improvement in the data sharing process.

The second step of the atlas generation workflow consisted of assembling the input data from various contributors into a common geo-database. All ESRs involved in data collection for the digital atlas have been actively participating in creation of the first version of the digital atlas. Several example datasets have been delivered to form a database of ancient landscapes, energy regimes and climate scenarios. All the collected data have been revised, classified, geographically referenced and integrated in a common geo-database in order to ensure data uniformity and compatibility. Following the INSPIRE specifications for geographic data and maps, linked to standardisation agreements within the European Commission, the TERRANOVA atlas database uses the European Terrestrial Reference System 1989 (ETRS89-LAEA) based on the GRS80 ellipsoid. The database consist of local data from research laboratories as well as modeled data on a continental scale.

The atlas database is currently formed by **four main data types**:

1. **Archaeological data.** This data mainly consist of point data in field research laboratories studied within the TERRANOVA framework. Each point typically represents a single archaeological site with extended attributes, such as carbon dating information, type of remains, archaeological culture, age, etc. This data type mainly consists of previously published data that is currently being digitized and put together to create a geo-referenced library of existing archaeological knowledge for TERRANOVA field laboratories in Northern, Southeastern and Southwestern Europe (Figure 2).
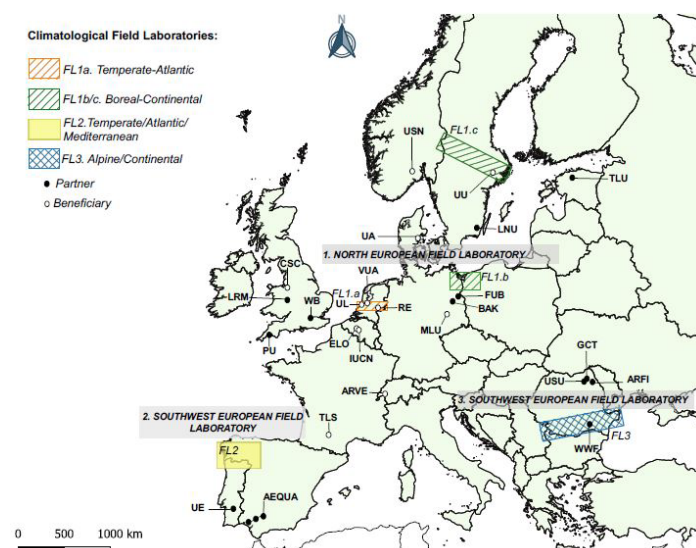

Figure 2. Europe showing locations of field laboratories (FL) (rectangles) in Southwest Europe (FL2), in Southeast Europe (FL3), and in Northern Europe in The Netherlands (FL1a), Germany (FL1b), and Sweden (F1Lc). Image source: TERRANOVA Grant Agreement. Note: FL position and extent may be changed throughout the course of the project.

Figure 3 shows the archaeological sites where the TERRANOVA project is making further investigation in the view of increased archaeological knowledge on defined processes. These sites have information which can provide us with better understanding of *e.g.* evidence of fire use (charcoal, burnt bone), transition to agriculture (pottery, agricultural tools) etc. This database is still growing, including more sites and time periods, which will lead to better understanding of societal processes and create a robust database suitable for use in continental-scale datasets evaluation and modelling.

Figure 3. Available archaeological sites dated mid-Holocene, studied in the framework of the TERRANOVA ITN

• Mid-Holocene archaeological sites

2. **Climate data.** This data currently consists of modeled climate variables for the mid-Holocene and pre-industrial time periods in Europe simulated by the climate model of intermediate complexity iLOVECLIM. The data is being represented in two grid resolutions, standard iLOVECLIM grid (5.6° x 5.6°) and downscaled grid (0.25° x 0.25°). Figure 4 shows outputs for 6000 BP equilibrium from standard and downscaled iLOVECLIM model simulations.
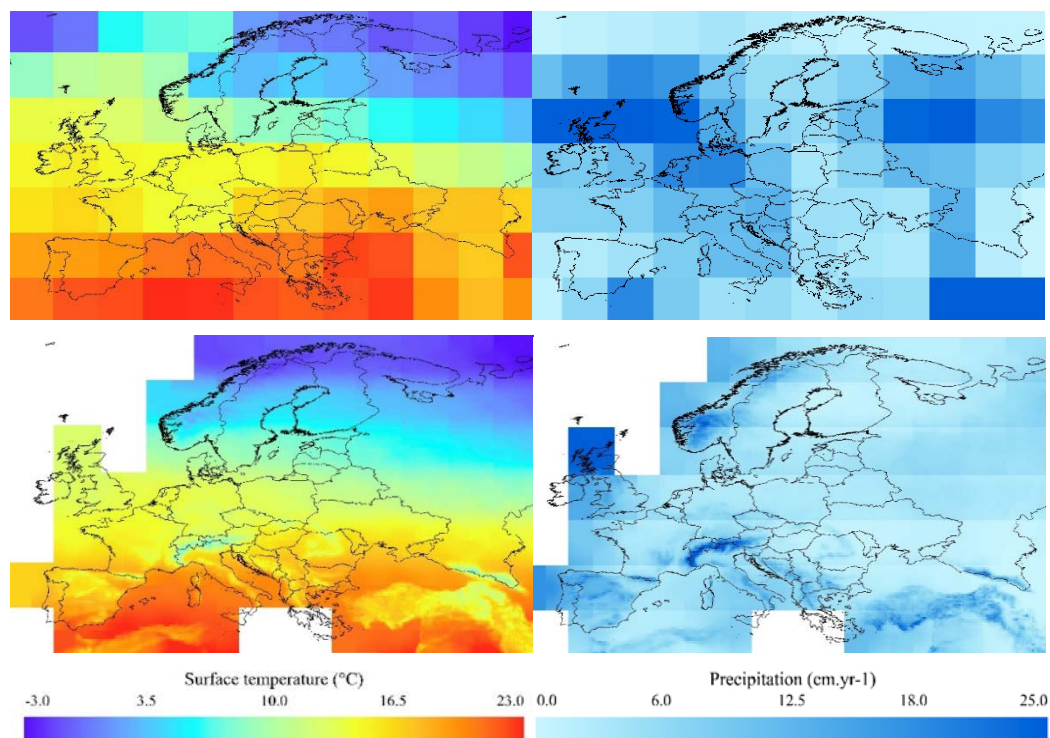

Figure 4. iLOVECLIM output for 6k equilibrium. Temperature (left) and precipitation (right) maps for Europe from standard (top) and downscaled (bottom) runs

3. **Land cover data.** This data consists of three parts:

3.1. Climate forced land cover. This part consists of vegetation maps generated from the output of two dynamic vegetation models (DVMs) of different complexity, VECODE and CARAIB. Vegetation distribution in these models is based on climatic parameters, derived from the iLOVECLIM model. Figure 5 presents maps of dominant biomes and plant functional types in Europe simulated using modeled mid-Holocene climate. We note that 'subtropical forest' doesn't coincide with the natural vegetation in the region. , This is likely the result of a bias in the climatic runs underlying the vegetation resulted presented, currently under investigation. It will not be present in the final product since a bias correction approach will be implemented for the final result.

Figure 5. Dominant biomes (top) and plant functional types (bottom) in Europe modeled by the CARAIB digital vegetation model
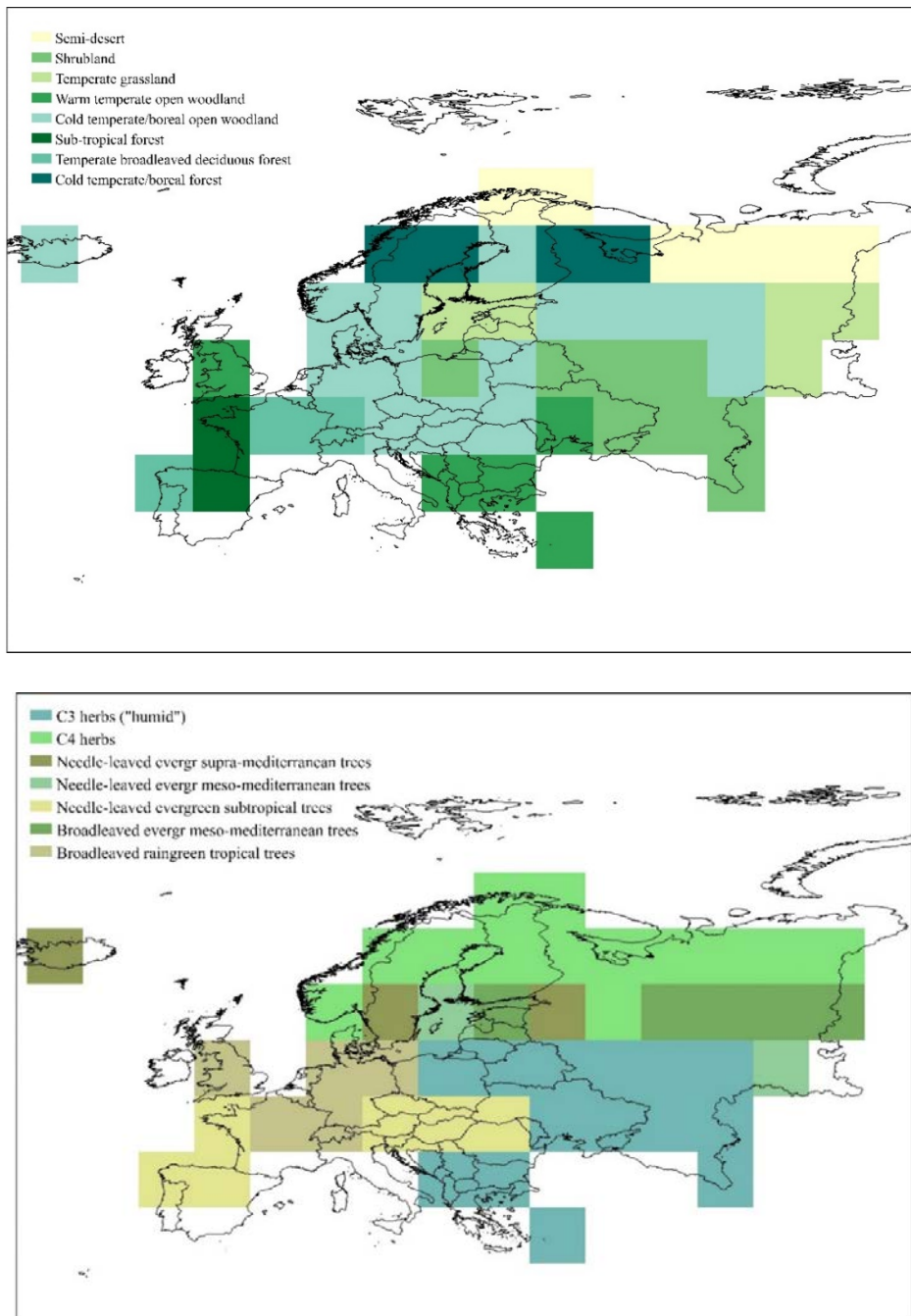
3.2. Population forced land cover. This part consists of maps produced using algorithms of agent-based modeling (ABM), which simulates human-made land cover changes based on archaeology-derived population estimates. Figure 6 shows an example ABM output for 6k for the Iberian peninsula, which reflect human-modified landscapes. This is an example model, based on non-specific population data.

No human activity — Woodland
Temperate forest — Shrubland
Grassland — Recently burned areas which did not have time to recover
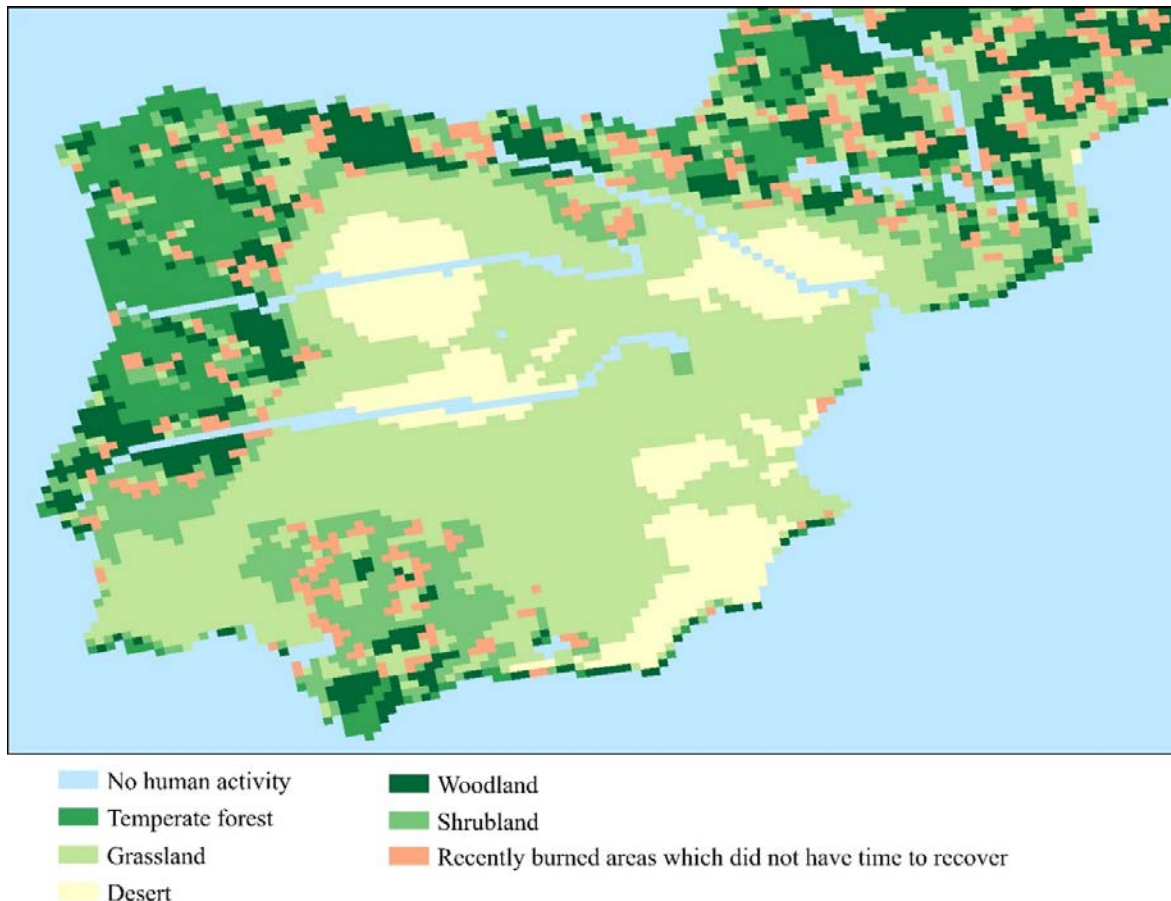Desert

Figure 6 . Influence of anthropogenic burning on land cover in mid-Holocene Europe. Vegetation cover simulated with human burning. Results are based on worldclim climate data, Copernicus elevation maps and present-day hydrology

3.3 Pollen-based reconstructions. Two datasets, one for the Holocene and one for the Eemian, consist of gridded reconstructions of regional vegetation plant cover at a 1° x 1° spatial scale using the REVEALS model to convert pollen percentage into plant percentage cover. The Holocene REVEALS reconstructions are based on ca. 1500 pollen records across Europe. Gridded maps of past plant cover for 31 plant taxa and several Plant functional types and three groups of plant taxa, i.e. evergreen trees, summer-green trees, and open land taxa (including the two subgroups grassland and cultivated land) are produced for continuous 500-year time windows between 11700-11200 BP and 1200-700 BP, and the three recent time windows 700-350, 350-100, and 100-present. Fig.7 shows the spatial scale covered by the Holocene pollen-based reconstruction. Maps of past vegetation cover representative of the "high vegetation", mesocratic phase of the Eemian interglacial (~ 112 000 ~ 125 000 BP) will be produced at a European scale.
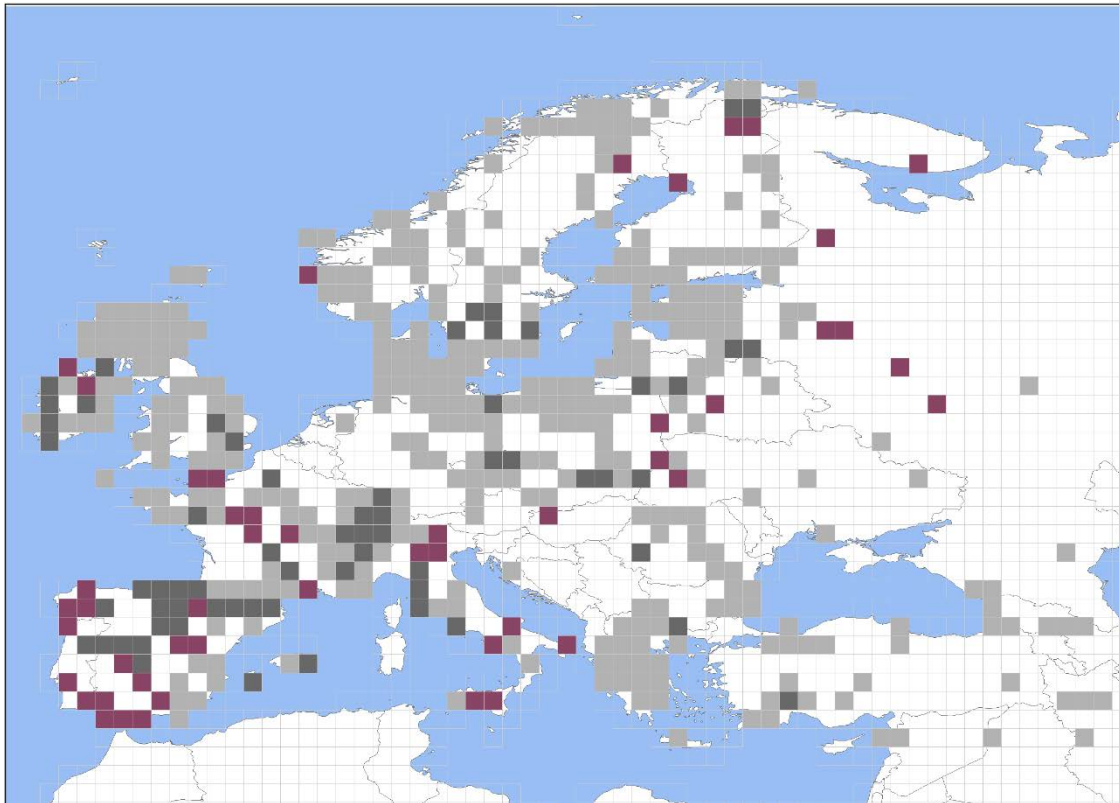
Figure 7. Map of Europe showing the grid used for pollen-based REVEALS estimates of plant cover and the grid cells (1 degree) with pollen records used for the REVEALS reconstructions. Light grey: LandClim II* project grid cells with pollen records; dark grey cells: LandClim II project grid cells with pollen records and additional, new TERRANOVA pollen record(s); purple: TERRANOVA new grid cells with new pollen records. ALL light grey, dark grey and purple grid cells will be included in the final TERRANOVA REVEALS reconstruction of plant cover for 31 tree and herb taxa, and three groups of taxa, evergreen trees, summer-green trees and open land taxa. *LandClim II is a Swedish project coordinated by M.J. Gaillard. The LandClim II REVEALS reconstruction will be published in Githumbi, E. et al. (paper in prep.)

4. **Megafauna distribution.** These data consist of habitat suitability maps for megafauna species (mammals > 10 kg) in Europe during the Eemian Interglacial (MIS 5e), on a 5km x 5km grid resolution. The dataset is created based on simulated climate of selected time period using a species distribution modelling framework, and spatial filtering using topography and potential Neanderthal impact determining megafauna extinction at the local scale.

Currently several datasets, such as pollen and megafauna reconstructions, are expected to be published, and thus, corresponding layers are not yet available outside of the TERRANOVA project working group. Most of the publicly available layers currently consists of previously published data (archaeological data from TERRANOVA research laboratories) and modeled data.

TERRANOVA framework is based on the concept of cultural energy regimes (ERs), separated by transition periods, which correspond to major changes in socio-metabolic regimes. Therefore, the atlas geodatabase includes preliminary maps for ER transitions in Europe, derived from previously published data (HYDE 3.2)[5]. Maps representing transitions from one ER to another are shown on the figure 8 (transition between ER 1 and 2) and figure 9 (transition between ER 2 and 3).
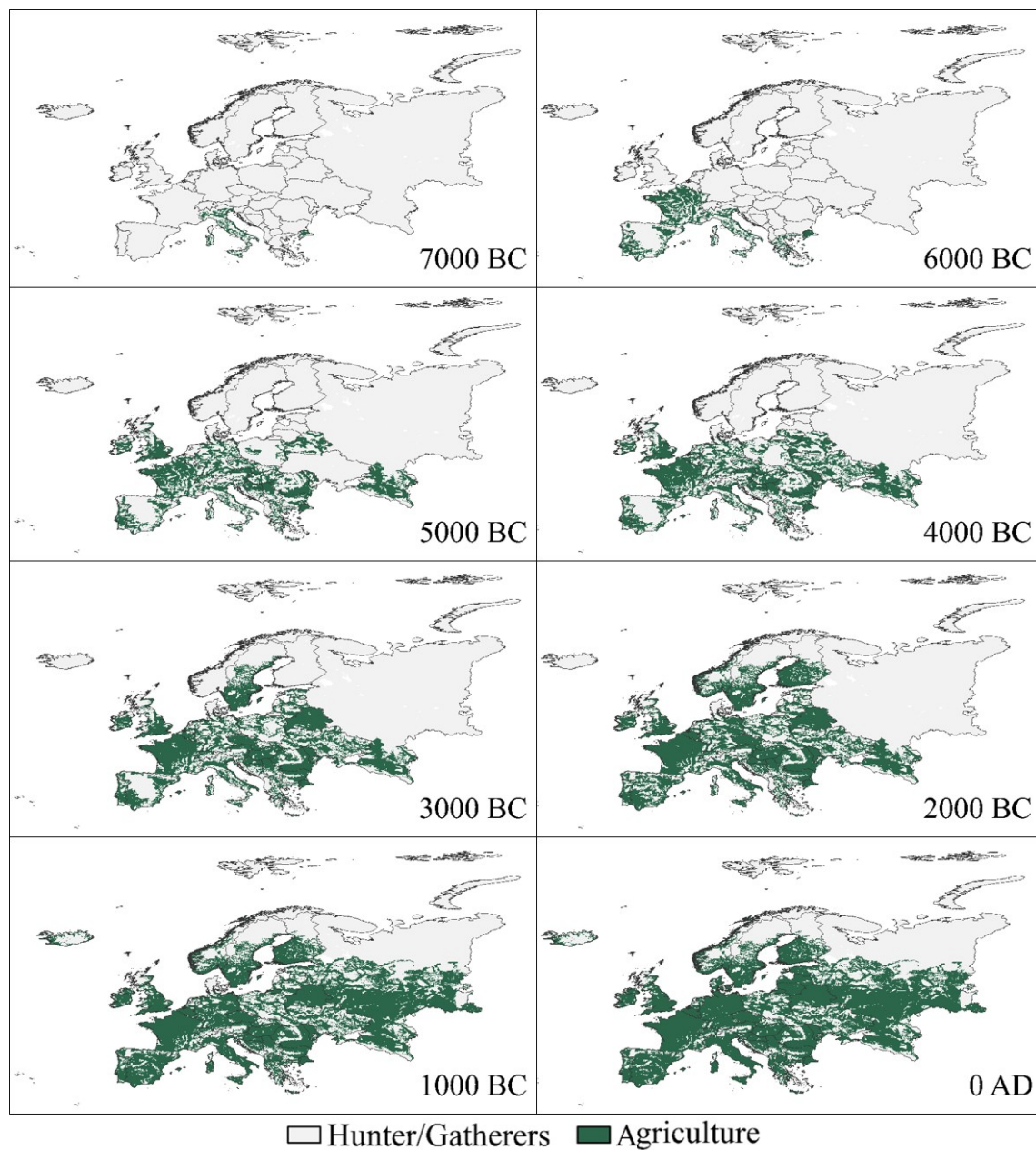
[5] Klein Goldewijk 2017

Figure 8. Extent of the transition from the ER1 (Hunter/Gatherers) to the ER2
(Agricultural/Timber) for the given time steps. The maps are derived from the HYDE 3.2 dataset[5]
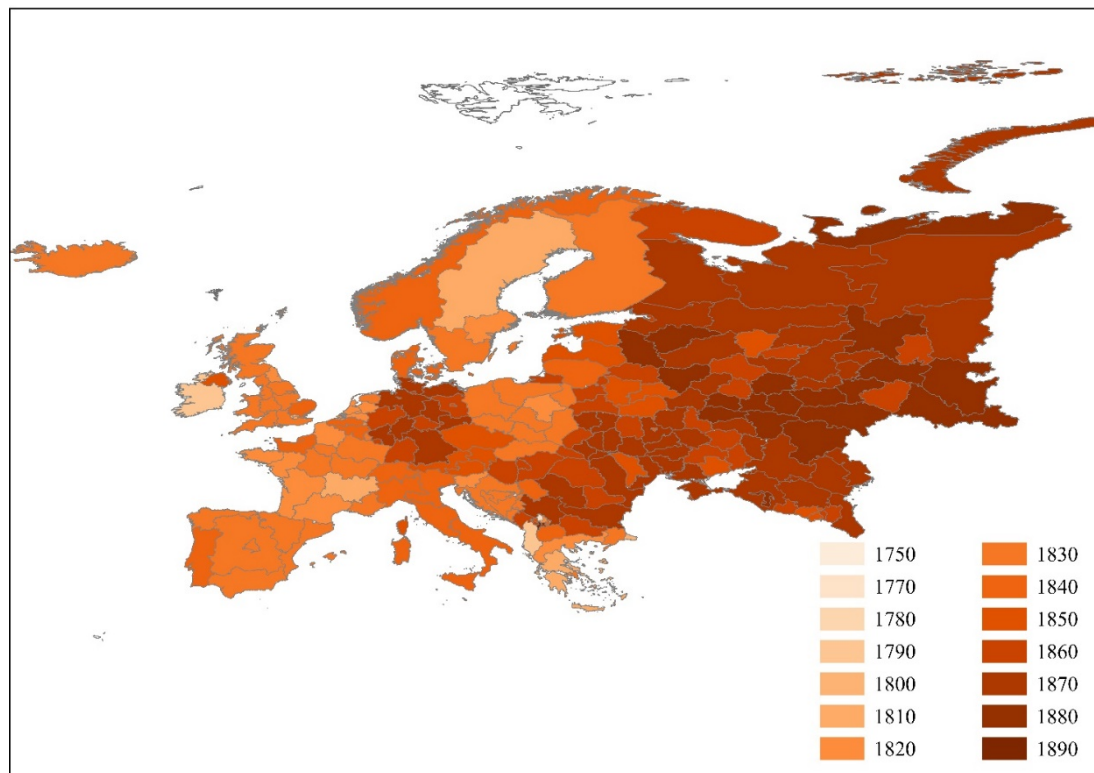
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[5] Klein Goldewijk 2017

Figure 9. Transition from the ER2 (Agricultural/Timber) to the ER3 (Industrial). The map is derived from the HYDE 3.2 dataset [6].

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[6] *Klein Goldewijk 2017*

4   NEXT STEPS TO TAKE FOR FINAL PUBLICATION OF DIGITAL ATLAS FOR LANDSCAPE EVOLUTION

Atlas building phase

At the moment, most of the data within the atlas geo-database is preliminary and non-specific. During the next 6-24 months it will be gradually extended and improved. Some of the foreseen changes include:

-        Archaeological knowledge database of the TERRANOVA project is currently being created. During the next several months it is expected to become larger and more consistent. This will create a robust and consistent archaeological geo-database for Northern, Southeastern and Southwestern Europe;

-        Several layers with publically available existing datasets, *e. g.* ArchaeoGlobe maps, will be added to the atlas;

-        Several equilibrium and transient climate simulations using iLOVECILM will be performed, which will create a set of geographically referenced climate information suitable for studying climate processes during the Holocene. These maps will be used for investigating other processes, such as land cover changes, within the TERRANOVA framework;

-        Future variations of climate forced vegetation simulations with the CARAIB dynamical vegetation model will include prescribed land use, extracted from pollen-based gridded reconstructions of regional vegetation cover. This will provide a better understanding of relationship between human activity, climate and land cover change in the European Holocene;

-        Future ABM improvements will include the use of model-based reconstructions for Europe to create maps similar to Figure 1 on a European scale. In combination with climate, vegetation and pollen-based reconstructions these maps will provide an insight on usage of fire by early humans and its impact on Holocene climate and land cover;

-        The database of pollen records used in TERRANOVA project will still be extended in the coming months. The expected pollen-based gridded reconstruction of regional vegetation cover will be available for a number for ca. 500 1x1° grid cells across Europe. Spatial interpolation will be used to fill the gaps between observations to produce continuous land-cover maps for continuous 500-year time windows between 11700-11200 BP to 1200-700 BP and for the three recent time windows 700-350, 350-100, and 100-present . The REVEALS vegetation cover (both natural/climate-induced and human-induced) will be compared with i) the climate-forced (natural) vegetation cover by the CARAIB dynamic vegetation model to infer anthropogenic land-cover changes over the Holocene, ii) archaeological data to evaluate the impact of human activity on past land-cover changes. Additionally, pollen-based gridded reconstructions of vegetation cover during the mesocratic phase of the Eemian interglacial will be produced for comparison with the Holocene vegetation cover;

-        Pollen based reconstructions may also be used to generate wall-to-wall maps by developing a predictive model of vegetation cover based on pollen-based reconstructions and potential drivers (climate, human population etc.), *e. g.* using co-kriging.

-        Technical specifications for data gathering and imaging atlas layers will be further explored in the next half year of the project phase of TERRANOVA, including the data catalog utility GeoFlow as well as the mapping platform GeoBon in association with CNRS and MLU.

WP4 connection (Policy)

In addition to the 'regular' Atlas disciplinary data as described above a series of future policy oriented layers will be added to the digital atlas:

-        A map of contemporary habitats distribution of megafauna at a resolution of 10 km including predicted changes in the habitat distribution for the different species and the potential for functional trophic complexity in Europe over the last three decades."

-        Another type of data will include scenarios of predicted ecosystem service impacts of three possible land conversions: intensification, extensification and abandonment. It will be

centered on the predicted impact on various landscape functions and services, such as carbon capture and biodiversity. Additionally, it is expected to generate priority maps for each of these services/functions and a set of optimal landscape configuration maps, generated for different goals. This data will have a potential to be used by the policy-oriented part of the TERRANOVA, focused on land management and policy guidelines for decision makers;

-        Maps of the transitions between the ERs can be used for comparison with archaeological data and for climate/vegetation modelling purposes. However, in the future they will be replaced by the synthesis of a set of archaeological and modelled data, collected within the TERRANOVA project, which will be made publically available in a form of open access digital atlas of on landscape evolution, ancient land cover and climate scenarios.

Atlas publication

Additionally, as data generated by various working groups will be published, more atlas layers are expected to become available. By the end of the TERRANOVA project, the digital Atlas will go online, and will contain several ready-to-use data generated layers in an open source format, with papers and additional raw data for researchers to build upon.

5 CONCLUSION

TERRANOVA the European landscape learning initiative has proceeded well in time and invested within novel interdisciplinary initial collaborations to produce the preliminary digital atlas of landscape evolution.

It is expected, according to the Grant Agreement, that data acquisition will continue and increase over the next two years, during seminars and several network-wide meetings, including with policy makers and NGO's, in order to build into a useful tool for future landscape managers.

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