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Land Use in Europe from Bronze to Iron Age reconstructed from pollen data

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1. Introduction

Bronze Age is the next phase of human development after Neolithic which ushered in an era of metallurgy. In some parts, copper age is considered as an intermediary between the two, however; there is no consensus among scholars (Pearce, 2019). Bronze Age is considered as the beginning of complex societies and other societal changes for it required transport on a larger scale, calling for specialised labour and eventually stratification of society. It is likely to have a direct impact on subsistence patterns and resource management. Transition essentially means change. In the context of the thesis, change brought about by man is noted; which in turn affected the landscape. This research was conducted to examine if there has been change in land owing to human activities during the transitional phase of Bronze to Iron Age in Europe. Pollen data from existing datasets has been used to address the research question at hand.

Pollen, in addition to geomorphological, sedimentological and geochemical techniques, has been used together with other biological proxies to infer climatic changes over time. It was also used to reconstruct past landscape, vegetational cover and in some cases even subsistence strategies as a result of agricultural and pastoral activities (Mercuri et al., 2010). Pollen data has been analysed using multiple mathematical and computational models. Primarily, identification and cluster analysis is depicted in pollen diagrams. REVEAL, LANDCLIM, LOVE, GLUES are some other projects which are pollen-based. These were attempts to assess climate, environment, land use, human activities based on pollen data obtained.

Triticum, Hordeum, Avena have been regarded as anthropogenic indicators (Birks and Behre, 1988). Pollen grains of these taxa are large and not dispersed easily. Therefore, considered to provide only local signatures. *Secale* is known to have high pollen-productivity and considered a reliable indicator of cultivation. Additionally, *Olea, Juglans, Castanea, Vitis* are also human indicators. *Plantago and Rumex* have been considered as pasture indicators.

Cereals have been cultivated in Europe since Neolithic times (Gauthier and Richard, 2009). Pollen records are supported by macrobotanical and archaeological evidence (Peña-Chocarro, Pérez-Jordà and Morales, 2018). Important archaeobotanical finds in Europe at the transition Bronze to Iron Age have been synthesised.

Major shift in crop husbandry and agricultural strategies during the Bronze Age is noted. This would have an impact on the land in later times as well (Primavera et al., 2017). Many excavations in northwest Portugal support Bronze Age cultivation in the region (Tereso et al., 2016). Northwest Iberia shows macrobotanical remains and archaeological evidence of silos; also hinting towards change in settlement pattern from 3rd millennium BCE. It considers 600-400 BCE as the transition phase (Tereso et al., 2016). Bronze Age in the Balearic Islands is pointed out by Naviform Culture around 4300-3800 cal BP (Burjachs, 2017). The Bronze-Iron Age transition in France in Orent, Auvergne is seen around 2900-2600 BP (Ledger et al., 2015). Lake Bourget (France) shows late Bronze Age around 3300-2800 BP (Gauthier and Richard, 2009). South France, eastern and western Catalonia too have a similar date for this transition of Bronze to Iron Age at 3400-2750 (Alonso and Bouby, 2017). The data from Alps region at Airolo Madrano shows evidence of Late Bronze Age around 3350-3150 BP (Jacquat and Della Casa, 2018). In North Italy (Bergamo) Bronze Age remnants are dated around 3000 BP (Ravazzi et al., 2020). Decline of agropastoral activities is noted at 2700 BP. In the region of Apulia, the end of the Bronze Age is set around 3000 BP (Primavera et al., 2017). It is depicted by Bronze Age archaeobotanical studies involving charcoal and fruit seeds.

In the Czech Republic late Bronze to early Iron Age between 3250-2500 BP highlight climate deterioration (Dreslerova, 2013). At Babikovce catchment, Myjava Hill in Slovakia around 3260-2750 BP, evidences of past soil erosion and gullying are strongly related to agricultural expansion (Dotterwich, 2013). Cultivation of wide variety of crops is characteristic of Bronze Age in Carpathian Basin particularly in Middle and Late Bronze Age. (Marta Dal Corso, 2019). By 2750 BP the society experiences structural changes leading to Iron Age determined as Talayotic culture; witnessing a fall around 2500 BP(Burjachs, 2017). The transition coincides with the 2.8ka event. Authors state that global climatic events directly influence vegetation and evolution of islands (Burjachs, 2017). Increase in extensive herding and agricultural practices was noticed after Late Bronze Age in Greece (Weiberg et al., 2019) .

Most of Europe has different Bronze and Iron Age periods at regional levels. It is due to a variety of cultures which flourished in different regions at different times. The diversity in development and transition can be advantageous for it is an indicator based on local resources, cultures and of course climate which contributes towards shaping the larger picture. However, it prevents creating a standard narrative in terms of archaeological understanding. Taking that into consideration, certain limits have been set in terms of geography and chronology. Portugal in the west and Black Sea in the east along with Germany in the north and Cyprus in the south are the **provisional geographical boundaries**. 3100-2500 cal has been considered as the **chronological extent**. The same has been discussed in detail later.

This research aims to look at the larger picture in terms of land-use. Tree to cereal ratios, in addition to pasture and OJCV data have been used to address the main research question i.e. human impact on land from Bronze to Iron Age. Moreover, change in forest expansion and clearing is also noted. Special emphasis has been laid on cereals as an indication of human settlement. Thus, *Triticum, Hordeum, Avena, Secale* as cereal indicators, *Plantago* and *Rumex* as pastoral indicators and *Olea, Juglans, Castanea, Vitis* as anthropogenic indicators have been stated. More than 500 sites were observed from the Neotoma dataset. But only 250 could make the mark owing to the parameters discussed later. The same has been shown in Figure 1.

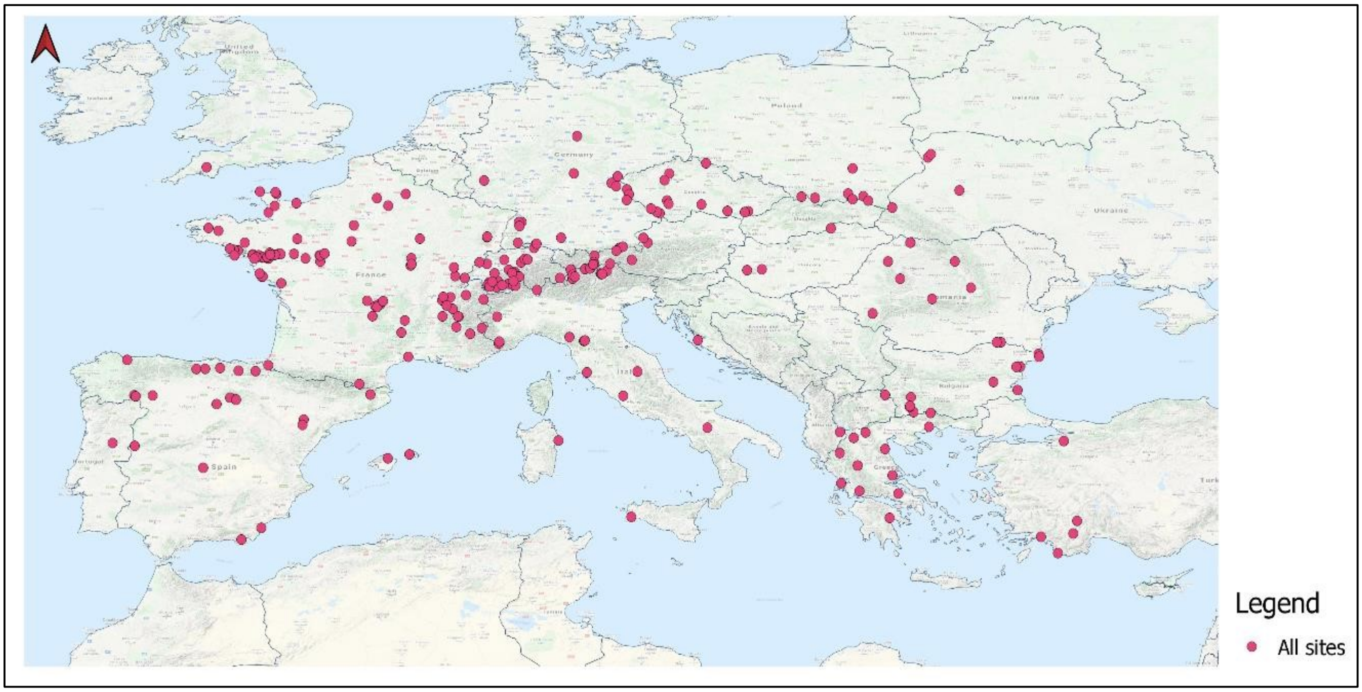


Figure 1. all analysed sites plotted on the map of Europe.

2. Literature review of European pollen data at the Bronze-Iron Age transition

The terrains encompassing the Mediterranean Sea provided land support for past societies which had far-reaching effects. These regions are the result of a unique environment that was changed by human organization over numerous centuries. There has been extensive discussion about the general function of human and natural elements in the Mediterranean landscape. The paper by Deza-Araujo et al. (2020) evaluates human-indicator approaches by using independent archaeological evidence and models. It gives an overview of existing pollen methods and discusses benefits and shortcomings extensively. It is concluded that species indicator approach is the oldest and most widely used. It is advised that study of anthropogenic pollen indicators is essential to boost existing indices of track changes in land-use intensity. More accurate affirmation of long-term dynamics using archaeology will be crucial to synthesise the available archaeological evidence.

a. Mediterranean landscape

Pollen examination permits past vegetation to be depicted, with the indications interpreted through taphonomic and depositional actions. A wide range of strategies has been set up to construct pollen data into significant vegetation units. It is estimated that climate influenced distribution and abundance of plant species, which were then overturned by human impact in the region (Fyfe et al., 2019).

In order to understand at what point in Holocene changes in climate became detectable; Roberts et al. (2011) used certain trees as bio-indicators for typical Mediterranean vegetation. This included olive (*Olea*) and holm oak (*Quercus ilex*). The paper concluded that land cover initially started changing around 6000 BP. However, the situation was paced up by human activity which soon became a significant agent.

A tendency towards desertification in coastal areas with indistinct cause and development is seen in many parts of the Mediterranean. The study by Di Rita et al. (2012) aims to detect the main reasons for landscape change over thousands of years. The results show an overall and progressive trend of anthropization of landscapes shown by changes in vegetational patterns. This is especially true after the Neolithic in different times and modes from site to site. Coastal pollen records show rapid transitions indicating that a significant environmental instability occurred due to natural and human-induced processes.

Discussing vegetational transitions, Fyfe et al. (2018) uses the example of Mediterranean. Indices of human impact are OJC *(Olea, Juglans,* and *Castanea)* and API (Anthropogenic Pollen Indicators) which consist of *Artemisia, Centaurea,* Cichorieae, *Plantago, Urtica,* and *Trifolium*. The approach used involves noting the taxa which are constantly present in the clusters prepared. The preparation of clusters is based on

Ward's method (1963). This is known as phytosociological approach. The core idea is that broadly similar clusters may reflect the characteristics of the vegetation; they may also show real variations in land use intensity. Use of cluster-based analysis to segregate Mediterranean-based vegetation types was used to understand vegetational patterns over the Holocene period (Woodbridge et al., 2018). The analysis was based on modern pollen and fossil pollen datasets. The dynamic nature of the Mediterranean vegetation was established. Decline in closed-vegetation after 3500 BP from the mid-Holocene and increase in human induced vegetation thereafter was stated. The method enables description of vegetation at a sub-continental scale.
Similar conclusion is drawn by Weiberg et al. (2019) for a research in Greece mainly during the Neolithic to Bronze Age transition phase. The paper concludes by elucidating that activities like herding intensified agriculture led to amplified land-use in the Bronze Age. Levels of *Cerealia* decline after 2500 BP indicating that the population was engaged in olive cultivation and herding, as opposed to cereal cultivation. The authors mention that rise in radiocarbon densities in late Bronze Age shows increasing human presence especially, when compared to later Neolithic stages. The site of Palaikastro from eastern Crete shows prominent increase in olive trees (Cañellas-Boltà et al., 2018) in the transitional phase from the final Neolithic to early Minoan age. Palaeoenvironmental records were studied in order to better comprehend landscape history from the Late Neolithic to the Bronze Age. The data proposes agricultural and pastoral activities. Some pollen data also points toward different crops leading to land reconstruction. It marked a landscape shift suggesting continuous occupation. Around 3600 cal BCE, Crete was one of the first regions to produce and manage olives extensively. Expansion for olive tree and management using pruning and mechanical cleaning are the reasons for expansion of the same indicating human exploitation of resources in the region (Cañellas-Boltà et al., 2018) .

Human activities have been assessed with multiple methods using pollen. Certain pollen taxa are consistently used as indicators of human impact, pasture (e.g., *Plantago* and *Rumex*), opening or closing of forests (broadleaved evergreen trees). Some sites corroborate palynological results with other proxies for more effective analysis. However, it must be noted that climate is often considered a major driving force in terms of vegetation, irrespective of other factors in the above research.

Humans transform land and therefore study of demography can provide links to exploitation of land resources. There has been a surge in inter-disciplinary research involving human population and pollen data. Summed probability distribution of radiocarbon dates and settlement data including site counts are used as archaeological proxies for estimating population fluctuations. The research is based on cluster analysis of taxa and community classification. Pollen count data is divided in 200-year intervals across Holocene and percentage of samples assigned to each vegetation type is presented by change in vegetation cluster group (Weiberg et al., 2019; Fyfe et al., 2019; Woodbridge et al., 2019).

One such study from the Levant (Palmisano et al., 2019) determines when and how human impact changed the landcover over the centuries. *Centaurea*, a secondary anthropogenic indicator, can reflect an intense human impact on vegetation such as woodland clearance, increase of pasture lands, building and agricultural activities. Regional patterns showed rise in human activity from 5500-4500 BP reflected through oak and cedar deforestation. Humans were not a main driving force in the evolution of the Holocene landscape, which was mostly affected by abiotic factors. A change in AP% (arboreal pollen) seems to be directly impacted by climate change instead of anthropogenic activities. The period or region may not be directly relevant to the research, but **it reinforces the idea that climate can be a driving force in landscape change**. In order to understand the spread of agriculture spatially, pollen and archaeological data is used to explore the relationship between demography and vegetation change. It is concluded that a drift in human population was vital in moulding land cover in southern Anatolia (Woodbridge et al., 2019). An association of AP% and demographic change has been suggested, with larger populations being directly linked to wetland vegetation and a decline in the abundance of trees. An eminent link between OJC (*Olea, Castanea,* and *Juglans*), API (anthropogenic pollen indicators), grazing indicators and climate records show that people adapted to long-term climate changes through diversification of subsistence strategies. This included sheep herding, control of competing arboreal vegetation and woodland management. These activities influence geomorphology, soil properties, site conditions for vegetation growth and in turn climate.

A similar study to assess long-term changes in human population in land cover in southern France was conducted by Berger et al. (2019). The methodology is very similar to Woodbridge et al. (2019). It includes SPD, cluster analysis; community distribution etc. Changes in vegetation are described based on OJC, AP% and other factors. There is strong correlation between the population proxies and the various land cover indicators of human impact according to the aforesaid studies on the subject. It was not possible to assess agricultural evidence that could have sustained the populations or the size of human population which was affected. There was a decisive increase in pastoral indicators and *Olea* pollen after 2500 BP as the region transitioned into Iron Age.

Investigating the effect of changing demography and consequent land use on vegetation cover of Tyrrhenian central Italy between early Holocene and post Roman period researchers, Stoddart et al. (2019) conclude that land use escalated specially during the Etruscan period and in Roman period. Land-use well before 2900 BP at the Mesolithic-Neolithic transition is observed in the adjoining areas of Tyrrhenian.

Including over seven regions from Iberia to Levant, rise in population from the Neolithic and constant fluctuations thereafter at least till the Roman times are observed (Roberts et al., 2019). One of the aims of this research was to test hypothesis if human populations can change forest cover by farming and related activities. There is significant connection between human population and forest cover based on pollen data in the Mediterranean. However, this connection is not due to trees and shrubs all together, but rather to pollen data depicted by OJCV. Results propose that OJCV gives the best palynological markers of anthropogenic movement in the Mediterranean. Cycles of land-intensification and de-intensification have been noted by the authors. Pollen data, archaeological site surveys and stable isotopes from lakes, caves, marine records were used to assess the degree of land use. It appears that climate has a marked impact which aids or has detrimental effects on social evolution. Past population in the regions of Iberia and Balearic Islands during the Neolithic-Bronze Age transition shows direct relation with alteration of vegetational patterns and in turn landscapes (Fyfe et al., 2019). NAP (non-arboreal pollen) shows more open grounds and increased OJCV suggests tree cropping; both are directly related to higher population in the region of eastern Iberia. Human transformation of land cover is therefore evident. One of the conclusions of this research is that **vegetational richness is directly proportional to the demography of human populations**. However, landscapes remain open after drops in population and vegetation. Soil degradation and increasing aridity of the late Holocene could be the main causes of landscape opening. The research basically highlights the function of climate driving vegetation growth on a greater extent, proving the importance of population changes in shaping the richness of taxa within broad biomes.

Mapping the landscape history of Laguna de Rio Seco from 7800 cal BP, an increase in fire is noted at 3700 BP (Anderson et al., 2011). This is said to be a result of growth of human population on a regional human level. The human impact further increases after 2700 cal BP, with loss of pine forests and augmented pasture lands around the lake in addition to olea cultivation. The region of southern Iberia confirms that even remote sites did not lack direct human influence during the Holocene although, lower impact is noted at higher elevations.

Emphasising the importance of climate as an important factor for altering landscape, the study by Walsh et al. (2019) involved geomorphic data from alluvial, colluvial and lacustrine records to address various landscape settings and human impact. This is considered important because different landscapes respond differently to human-induced erosion depending on timing, duration, intensity and spatial extent of human-impact. Researchers (Gambin et al., 2016, Ravazzi et al., 2020, Mercuri et al., 2010) have suggested that climate change was a catalyst for increased soil erosion in addition to human activities which altered the landscape.

b. Vegetational models and Databases

Computer simulations were used to understand pollen dispersal and deposition (Sugita et al., 1999). They aimed to re-examine the relationship between pollen and landscape openness. Species composition, spatial pattern and structure of vegetation, type and size of study sites, spatial spread of vegetation, differences in air movement and turbulence for pollen transportation, and regional pollen production influence the spatial scale of landscape vegetation. Traditional study of NAP (non-arboreal pollen) is considered inappropriate and inadequate according to the authors, owing to the above factors which are often overlooked.

The procedure of POLLSCAPE (Sugita et al., 1999), based on simulations, is useful for quantifying landscape characteristics. However, it needs to be coupled with vegetational composition and background pollen through time. The main purpose of POLLSCAPE is to study pollen dispersal and deposition in closed forests. It is based on the idea that wind is the major transporter of pollen.

Regional Estimates of VEgetation Abundance from Large Sites model, abbreviated as REVEALS (Sugita, 2007a), was useful to reconstruct past vegetation/land cover using Holocene pollen records at the sub-continental scale of Europe. Pollen counts from several sites were merged to estimate vegetation in given time window. Many factors influence the accuracy of REVEALS. Some of them are type and size of sites, regional chronologies, effectiveness of pollen productivity estimates. REVEALS data can be unreliable for sites with poor chronologies (Trondman et al., 2014).

Projects like GLUES (Global Land Use and technological Evolution Simulator) LOVE (Local Vegetation Estimates) allow vegetation abundance to be inferred from pollen percentages at the regional (10^4-10^5 km^2 area) and local ($\leq 100km^2$) spatial scale (Gaillard et al., 2010).

LandClim is a 'stochastic process-based model' to study specific changes in forests at the landscape scale over long periods with an effective spatial resolution (Trondman et al., 2014). LandClim results are expected to provide crucial data to reassess ALCC (Anthropogenic Land Cover Change) estimates for a better understanding of the land surface-atmosphere interactions.

There have also been initiatives to create databases for environmental studies in Europe and beyond.

Giving an overview of pollen databases in the European context, Davis et al. (2013) mention that 'first dataset was raw-count data and secondary percentage digitised from published pollen diagrams.' The authors then give a brief description of BIOME 6000 project. They further move on to discussing reasons for the requirement of a new database, the European Pollen Database http://www.europeanpollendatabase.net/index.php.

The structure of the article is especially beneficial for a new researcher. It states why representation of vegetation in pollen records can be of utmost importance when studying past vegetation, land-use and ecosystem change. Quantitative estimates of past (anthropogenic) land-cover, reconstruction of past climates, integration with vegetation models and investigation of taphonomic problems are other research questions which can be answered. It is concluded by emphasising quality-based control and mentioned merging it into the global palaeoecological database of Neotoma https://www.neotomadb.org/ .

The ArchaeoGlobe Project is another attempt to create a database with the aid of archaeologists from all over the world in order to understand past land use from 10,000 BP to 1850 CE (Fuller et al., 2019). The research explores the relationships between different modes of land use. More importantly, the project highlights the kind of impact, although limited, foragers may have had on land and exploitation of the same. It maps change in landscape from primitive times and not just after the advent of agriculture. It states that 'existing global reconstructions underestimate the impact of early humans and use on earth's current hemisphere'.

Neotoma (Williams et al., 2018) is an interactive application created by many researchers and scientists at large. It aims to provide resources for research on past environmental changes. Taxon, community diversity, distribution, spatio-temporal dynamics are the factors considered. Wide availability of datasets involving plant, animal and geological entities have been listed. Neotoma is a low-cost solution to harness palaeoenvironmental research with a variety of dataset types. In this thesis, it was decided to use Neotoma as the primary source for obtaining pollen data for purpose of my research.

Vegetational models and pollen databases have therefore been used to answer research questions about climate, human impact and landscape changes. Additionally, local research has been conducted to examine similar research problems.

c. Data from published literature

Published literature was searched to provide insights and data about the topic. The main criteria for this section of literature was references to human activities in Europe as recognized from multiple records, preferably in the transitional phase from Bronze to Iron Age. The sampling interval is often very wide (between 100-1000 years) when represented in pollen diagrams. It is thus very challenging to identify the desired time period and draw conclusions accordingly. An argument maybe that not all literature intends to address this specific time period. Yet, literature has been of significant value to assess human use of land from Bronze to Iron Age. Various proxies other than pollen, including macrobotanical data, geological studies from many sites across Europe have been of advantage for a more holistic picture. Some of them include study of isotopes, molluscs, zooarchaeology, and tephra. A table (*Table.1*) has been included to provide a quick summary of the literature from this section.

Guadiana valley in Portugal shows maximum aridity around 10,200, 7800, 4800, 3100 and 1700 cal BP (Fletcher et al., 2007). From 4040-2830 BP, a decline in *Quercus, Fraxinus* and increase in Ericaceae, *Myrtus, Plantago, Castanea,* and *Vitis* show rise of anthropogenic activities. This is backed by a major decline in *Quercus* forest and riparian woodlands in addition to a major expansion of lowland (*Cistus*) scrub vegetation. Between 2830-1560 cal BP hints towards warm and dry climate owing to a decline in *Pinus*, all types of *Quercus, Olea, Phillyrea*, presence of *Castanea*, and peak values for *Ericaceae* and *Plantago*. Rise of Cistaceae and Ericaceae declare multiplied prevalence of fire in the landscape, reflecting human influence. Decline of pinewood with thickening of *Olea* shows intensified human influence, possibly promoted by prevailing dry climatic conditions.

Study of carpological remains by Tereso et al. (2016) from Bronze Age comprehends farming systems in north-west Iberia. Macrobotanical remains of millet, faba, barley, wheat have been found. Diverse pulses were also recorded. It is noteworthy that these finds are not as common in other parts of Iberia. Increased agricultural practices from Bronze Age led to creation of pits and silos for storage of grain. Further study has verified diversification in settlement around Late Bronze Age (Tereso et al., 2016). A trend in emergence of new productive socio-ecological systems which affected landscape through processes across spatial and temporal scales is observed. Rise in deforestation and soil erosion is mentioned with regards to enhanced and more complex social, economic and ecological schemes (Tereso et al., 2016). Collectively, it is a consequence on the environmental history of the region and archive the alteration of human strategies of resource exploration and exploitation.

Addressing available plant reserves during the Bronze Age and first Iron Age in the northwestern Mediterranean Basin, Alonso et al. (2017) mention widespread presence of millet cultivation in addition to cereals, pulses, oil, spices and fruits. Archaeobotanical samples were collected for 67 sites. Carpological analyses conducted in terms of chronology and geography were based on correspondence analysis factor. This analysis encourages a comprehensive study of all data from all phases. A distinct change in land due to agriculture is seen around the 8th and 7th centuries BCE. The change is mainly driven by cultivation of fruit trees.

Changes in agro-pastoral activities are studied in catchment area of Lake Aydat in France (Miras et al., 2015). It is based on studies of pollen and biomarkers conducted previously. Use of rarefaction analysis ensured approximate measurement of floristic diversity and landscape configuration. Local grazing indicators were considered as a sign of human impact, which started in the Neolithic period. There is definite evidence of human impact in the region in Neolithic and metal ages. Interpreted as an arable weed, *Secale* is regarded as the first evidence of arable agriculture with respect to this site. Eutrophication of the lake (increase in nutrients encouraging dense plant growth), which was more pronounced before 6700 cal BP and continues thereafter in a phased manner. These changes are also evident around 3500-3000 cal BP. Between 3500-3200 cal BP, there is natural decrease in forest cover and dung related fungi. The landscape thereafter changes towards becoming semi-natural, 'grass-rich and patchy.' Supposedly, human impact has a vital role in development of the 'agro-pastoral cultural landscape.'

The past vegetational history of Corsica was explored over the last 6000 years using mollusc identification sedimentology and palynology (Curras et al., 2017). It is stated that there was limited human impact on land till the Bronze Age. Human footprint is observed as early as 3500 cal BCE, however; sharp forest recovery is noted around 2200 BCE indicated by rise in oaks and fall in herbs. A new phase of human activity is then observed around 700 BCE (2700 BP), as indicated by pollen of Cichorioideae, *Plantago lanceolata*, etc. Authors conclude that some human activity was present in a forested landscape in the Late Bronze Age period (1800-1700 BCE). Change in landscape due to human interference can thus be noted. Even if land-use increased through Roman age, it is not reflected in vegetational history later.

Stagno di Sa Curcurica from north-eastern Sardinia shows an increase in trees and shrubs over time supplemented by rise and then fall in anthropogenic indicators like *Olea* and *Vitis* (Beffa et al., 2015). This evidence is extremely important for my thesis as it falls perfectly in the study time interval i.e. 2850-2450 BP at the Bronze-Iron Age transition. Increased olive oil production is observed around 1900 cal BP, indicating expansion of *Olea europaea* due to anthropic activities. These changes were gradual, with centennial-scale atmospheric reorganisations.

An open landscape is observed from 4450 cal BP which supposedly runs parallel to the beginning of Bronze Age in north-western Malta at the site of Bumarrad (Gambin et al., 2016). Fire events seem to take the front stage around 3000 cal BP the region (Gambin et al., 2016). Amplified soil erosion and Bumarrad palaeobay become half the size due to infilling. Grazing activity is thereafter noticed owing to increase of nitrophilous taxa of plants, coprophilous fungi, crop taxa and associated ruderal species indicating human interference. Human impact on the landscape clearly appears over the period, especially after 3000 cal BP.

Assessing marine response to climate changes for the past 500 years from central Mediterranean Sea, Margaritelli et al. (2016) concluded coherence of their research propagating short-term climate variability in the region. Oxygen isotopes and pollen records were used to identify modifications in climate from 5500 cal BP till the present day. The early Bronze Age in the region starts around 3850 cal BP. The authors conclude by stating that archaeological and environmental data agree with one another. It paves the path for enhanced understanding of rise and fall of human cultures. There is no direct mention of human influence on land or humans as catalysts for land change. It hints towards **climate playing a decisive role in terms of landscape**.

A paper which studied seeds, fruits, charcoal from Puglia in south-eastern Italy in Bronze Age aims to identify plant-related changes in subsistence strategies (Primavera et al., 2017). Early to Late Bronze Age sites have been dated to 2000-1000 BCE (4000-3000 BP). There is a drastic metamorphosis in terms of cultivation, seasonal harvesting strategies and storage capabilities, evidently in middle and late Bronze Age (Primavera et al., 2017). The initial alteration was perhaps due to climate but in later stages changes can be attributed to social and political factors. This point is noteworthy in study of land-use of this period as climate social and political factors attributing human presence contributed towards landscape change. Changes and adaptation towards new subsistence strategies because of non-environmental causes have been also considered.

Pollen analysis was conducted in order to assess evergreen vegetation in the vicinity of Lago Alimini Piccolo, eastern Italy (Di Rita and Magri, 2009). Consistent decline in forest cover is related to increase in Mediterranean shrubs and herbs. It may indicate dynamic increase in human undertaking during the Bronze Age. Continuous presence of cereals after 2600 BP validates anthropic activities in the region. Human impact is likely to have played an important role in the increase of shrubs, resulting from oak forest clearance for land use activities. There is no noteworthy data specifically in the transition period.

A study comparing three Iron Age populations in different geographical regions namely, Libyan Sahara, Tuscany and Latium in central Italy explore the hypothesis being that humans affect the surrounding plants (Sadori et al. 2010). The Etruscans from Gulf of Follonica (Tuscany) are of interest to us. There is well-defined indication of human presence, yet the impact is limited. Research so far has indicated that human environmental pressure during the Iron Age shows considerable change in plant cover. It led to modification of native plants and spreading plants of economic interest away from their natural surroundings. A noteworthy mention in this paper states extensive use of *E. arborea* wood in Tuscany around the 6th-5th century BCE.

The paper by Ravazzi et al. (2020) is of immense aid for the current topic. It discusses land-use history in the beginning of Bronze Age in Bergamo located in Italy. In terms of terminology, the paper mentions how emergence of urban centres is directly considered as a feature of the Iron Age. An emergence of early settlement is dated to 1300-1100 BCE. The Final Bronze Age is fixed around 1100-900 BCE, followed by the beginning of Iron Age as urban centres. Pollen analysis and geo-statistics were the basis of this study. This data is valid for northern Italy- especially the region around Alps. The research states that subsistence economy in final Bronze Age on hilltop of Bergamo was a mixed one. Plants and animals were used. Traces of livestock have been found in stratigraphic sequences in form of spores of coprophilous fungi. The most important consequence of this paper was that end of the Bronze Age and onset of the Iron Age in Bergamo saw woodland reclamation around 2700 cal BP. Disturbed occupation and land-use continuity is seen in Bergamo in late Bronze Age and continued for at least five centuries.

Elucidating association of cereals in late Bronze Age and early Iron Age (3250-2400 BP) in Czech Republic, Dreslerova et al. (2013) state that agriculture spread swiftly in this time period. Archaeobotanical record stands as a testimony of agricultural changes with a list of cereals, namely emmer wheat, naked wheat, barley, millet, spelt, oats and rye. Millet was preferred in the start, nevertheless barley eventually dominated the scene. Barley is positively related with higher altitudes as opposed to emmer, millet, and einkorn. An evident decline in climate around the Bronze/Iron Age transition is noted. A gradual rise in agriculture and in turn increased land-use has also been established in the transition from Bronze to Iron Age in the Czech Republic. The relation of climate and agriculture is noteworthy.

The Bogaczewo culture from Great Mazurian Lake District in Poland flourished in central and Eastern Europe tentatively after 450 BCE. Enough archaeological evidence is available to show increased human presence and development of this culture at the beginning of Roman Iron Age (Wacnik et al., 2014). Palynological data shows strengthened anthropogenic transformation of the vegetation which can be correlated effectively with the archaeological data. Livestock was maintained. The statement is based on sustainable production of herbage and cleared woodlands. Increased diversity of herbaceous plants is noteworthy. The cultivated crops included *Triticum, Avena, Hordeum, Secale. Cannabis sativa* was also recorded in addition to *Betula*.

A multiproxy analysis using geochemical and tephra chronological methods was used to reconstruct palaeoclimate of Lake Prespa (Aufebauer et al., 2012) and Lake Ohrid (Vogel et al., 2010) respectively. Early and mid-Holocene sedimentation is shown by considerably warmer climate, ice-free winters, increased productivity of the lakes and maximum values in trees. Effects of human activities in the catchment are observed only after 1900 cal BP. They are reflected in hydrological and environmental conditions. With regards to lake Ohrid, a range of limnological parameters are sensitive to subtle changes in temperature and nutrient supply in vicinity of the lake. The research talks extensively about calcite content of the lake. Around 6.4 ka and 2.4

ka cal BP, the higher calcite is attributed to warm and dry climate. Rapid fall of OM (organic matter) and calcite around 2.4 ka is associated with **anthropogenic deforestation in catchment of Lake Ohrid** which lead to increased surface runoff and erosion. Land in the region of Lake Shkodra, Albania shows changes due to human impact (Sadori et al., 2015). The major changes are recorded at 4000, 3000 and 1500 cal BP. The change resonates with other climate indicators like temperature decreases in north Atlantic cores and forest openings. Pollen analysis ascertains that climate is the not the deciding factor for this change, for it is not seen in isotope results. Lake Prespa, Ohrid and Skhodra eventually show human impact on the basis of geochemical proxies rather than of pollen indicators.

Table 1 an overview of published literature referred.

Sr. No	Region/site	Period	Land	Human presence
1.	Guadiana Valley	4040-2830 cal BP	Decline in forest. Increase in anthropogenic plants	Peaks at 2830-1560 cal BP
2.	Northwest Iberia	Bronze Age (2600 BP)	Cultivation of many cereals, pulses	Present
3.	Iberian Peninsula	7550 cal BP	Limited cultivation	Neolithic present. Bronze-Iron Age limited.
4.	Laguna de Rio Seco	7800 cal BP onwards	Decline in pine forests after 2700 BP	3700 BP indicted by fire. Peak at 2700 BP
5.	67 Sites from Northwestern Mediterranean	2800-2700 BP (Bronze Age)	A distinct change in land driven by growing mainly fruits	Present
6.	Lake Aydat (central France)	Around 3000-3500 cal BP	Forest decline	Local grazing indicators were considered as sign of human impact, nothing from Bronze-Iron Age.
7.	Corsica	2700 BP	Decreasing forested landscape	Present with fluctuations before and after the given date
8.	Stagno di Sa Curcurica		Increase in trees and shrubs affected by *Olea* and *Vitis*.	Increased in 2850-2450 BP Phoenician period
9.	North-Western Malta	4450 cal BP	Size of palaeobay shrinks. Open landscape	Grazing activity. Indicates human presence
10.	Central Mediterranean	3900-1900 BP	Forested landscape. Trees and shrubs	No direct mention
11.	Puglia	4000-3000 BP	Changes over time. Natural, then political	New subsistence strategies, seasonal harvesting etc.

12.	Lago Alimini Piccolo	4000 cal BP-present	change over time in terms of evergreen forests, shrubs, herbs. Unclear whether natural or man-induced changes.	Human activities increase during Bronze Age
13.	Liguria, Italy	7000-5000 cal BP	Forests and anthropogenic disturbance	High during 5837 cal BP and 2515 cal BP
14.	Bergamo	3300-3100 BP	Woodland reclamation around 2700 BCE	Livestock and agriculture
15.	Gulf of Follonica		Change in plant cover; cultivating plants of economic interests	Cultivating plants of economic interests by Iron Age
16.	Czech Republic	3250-2400 BP	Cultivated	Agriculture actively practiced
17.	Great Mazurian Lake District	2450 BP onwards	Increased diversity of herbaceous plants. Cultivated. Livestock maintained	Iron Age established.
18.	Lake Prespa	8200-2400 BP	Lake productivity fluctuates	After 1900 BP
19.	Lake Ohrid	6400-2400 BP	Warm and dry climate	Higher calcite around 2.4 ka associated with anthropogenic interference
20.	Lake Shkodra, Albania	4000-1500 cal BP	Forest openings. Landscape change evident after 1200 CE	No direct mention

Table 1 summary of published literature referred to in this research.

Limited in nature, there has been research on subsistence activities from Bronze to Iron Age in Europe. This research is based on macro and microbotanical analysis. Scattered pollen data as seen in the literature may indicate highly localised land use, as opposed to collective data which shows regional impact. This could prove vital for understanding patterns or land use.

It can be observed that there has been substantial work pointing towards the transition period between Neolithic and Bronze Age. However, there is limited published data in terms of land transformation from Bronze to Iron Age. There is research stating enhanced cultivation in later periods owing to more settled lifestyle based on archaeological evidence (Roberts et al., 2019; Stoddart et al., 2019). Cultural change can be a cause or effect of land-use patterns and in turn climate change. However, there is no comprehensive literature in terms of land use discussing the transition from Bronze to Iron Age. Highly localised research in small pockets often discusses human use of resources during Bronze and Iron Age in specific sites. Yet, <u>no clear impact is generally noted, especially in terms of pollen data in the given time period and geography</u>. This is the research gap examined in the literature.

Finné et al. (2011) provide a holistic and comprehensive picture of the climatic conditions in the eastern Mediterranean over last six millennia and lists several shortcomings and suggestions for palaeo-climatic studies :

- Need to distinguish between climatically and human- induced changes
- **Lack of locally based comparisons of climate and human activities in order to better understand societal response to climate variability**
- Need to obtain sufficiently high dating precision and accuracy
- Need to estimate uncertainties for interpretation of palaeoclimatic signals.

The authors mention that it is challenging to unravel impact of human activity and climate change. Locally based comparisons of climate and human activities could therefore be a solution.

The need to generate a larger picture of human activities in Bronze-Iron Age transition in Europe based on a vast database like Neotoma along with existing local literature is addressed in this research. It can provide insights not only in terms of environment, land cover but also in archaeological aspects like societal responses, development of distinct cultures or the lack of it.

3. Materials and Methods

Geographical extent

Sites which fall under the following longitudes and latitudes have been studied. It is therefore evident that geographical boundaries have been given preference over modern political boundaries.

50°N 14°W	35°N 11°W
45°N 32°E	33°N 29°E

For the purpose of better understanding of the results, 8 regions have been identified which have been discussed later. Longitudes and latitudes have been used to specify the regions. However, adjoining areas of plains, mountains have also been taken into consideration for it can have a significant impact on climate and vegetation of the area.

Chronological extent

The proposed age range for study is 3100 to 2500 cal BP. Three time points (±50 years) at 300 years distance from each other were fixed. Degree of land-use therein was evaluated.

2450 cal BP -2550 cal BP ⇒ 2500 cal BP

2750 cal BP -2850 cal BP ⇒ 2800 cal BP

3050 cal BP -3150 cal BP ⇒ 3100 cal BP

Materials

Neotoma (Williams et al., 2018) is an interactive palaeoecological database created by many researchers and scientists at large. It provides multiple resources for research on palaeo-environmental studies. In my thesis work, Neotoma is the primary source for obtaining pollen data.
Besides, relevant published literature has also been considered.

Methods

a. Parameters for selection of sites

After importing sites providing pollen data from the Neotoma database, the following criteria were considered to select the sites used in this study.

i. Only sites with calibrated radiocarbon dates were selected.

ii. One of the main parameters was the oldest and youngest date available from the site. Calibrated radiocarbon dates from 3200 cal BP and 2400 cal BP have therefore been considered.

iii. Sites from the Neotoma dataset with gaps of more than 300 years in radiocarbon cal BP were not selected for this study. Linear interpolation was used wherever possible to estimate the age of samples not directly radiocarbon dated.

iv. Minimum number of pollen samples for each date (3100 cal BP, 2800 cal BP, 2500 cal BP)was fixed to three.

v. In case of multiple available datasets for a given site, dataset with latest publication was given preference. However, better calibrated dates were chosen over publications in some cases. For example, Straldzha mire in Bulgaria has 3 datasets; two from 2009 and one from 2013. The dataset from 2013 was selected in this case owing to closer dates.

Trees and shrubs (TRSH) were used indicators of arboreal pollen. Arboreal pollen shows forest cover in the given period. Cereals designate direct human interference on the entire ecosystem, as thay are procured mainly via cultivation. *Plantago* and *Rumex* (Behre, 1981) suggest pasture lands.

Including longitude, latitude, site and dataset ID from the Neotoma dataset gives precise details of the sites, referred for the purpose of this study. A complete table of the dataset of selected sites has been included in the Appendix for further reference.

b. Linear interpolation method

This method was used to calculate a more appropriate percentage in absence of analyzed pollen layers in the three time intervals of interest for my thesis (3100±100, 2800±100, and 2500±100 cal BP. Linear interpolation is a mathematical function to formulate new data points based on existing data. It is often used for calculation of ^{14} C dates. It is not considered realistic; however, it is the simplest age model and generally yields useful interpolations. This method has been used in my study to obtain dates closer to the proposed date range. It was significantly of help when age intervals were wide or simply lacked relevant dates.

$$y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$$

The above formula was used to calculate linear interpolation, which has been discussed using an example. Modern technology has enabled calculation on websites. The website used in this research has been provided below.
https://www.ajdesigner.com/phpinterpolation/linear_interpolation_equation.php

Example- Site of Kopais provides calibrated dates based on MADCAP (Giesecke et al., 2014) age model. It provides multiple dates. In order to obtain a close date to 2500 cal BP, existing dates 2435 cal BP and 2589 cal BP were chosen to find the midpoint. These dates have been provided by the researcher. The midpoint was calculated by adding the two dates and then dividing it by 2 i.e. $(\frac{a+b}{2})$

$$\frac{2435 + 2589}{2} = 2512$$

2512 cal BP fits very well in the proposed age range.

Percentages of arboreal pollen (TRSH) were calculated for the given dates. X variables were selected to represent ^{14}C dates in calibrated BP and Y variables represent arboreal pollen(AP) in percentage. The following values were then allocated to respective variables in order to fit the formula.

x_1=2435, y_1=29.59 x_2=2512, y_2=? x_3=2589 , y_3=59.34

$$y_2 = \frac{(2512 - 2435)(59.34 - 29.59)}{2589 - 2435} + 29.59$$

The solution obtained for y_2= 44.46
The answer seems viable for the value is between y1 and y3.
On the same lines, linear interpolation was calculated for necessary categories of pollen data to obtain respective dates.

c. Challenges with ^{14}C dating

The chronological framework is not clear for many of the sites. Most of the radiocarbon dates are not calibrated. Radiocarbon dating depends on availability of organic material in the given sample. Preservation and contamination are the biggest challenges in ^{14}C dating (Valdivia et al., 2020). Funds and time can be major constraints when it comes to dating archaeological material. Bayesian age model is largely used and even recommended for it allows inclusion of relation data obtained from archaeological site and thereby permits calculation of beginning off individual archaeological sequences. Different calibration methods are followed in the Neotoma database with respect to data in hand, namely, Giesecke, Tinner, CAL BP etc. This may question the precision due to variations of such calibration models. Non-calibrated radiocarbon dates have not been considered for the purpose of this study.

Reservoir effect in calibration of ^{14}C dates continue to occupy a major space in academic discussions. The reservoir effect is caused by a superficial age of source reservoir from contemporary atmospheric surface ^{14}C value. Certain segments of soils can store Carbon for long periods, and this may be inaccessible from biological processes arising in soil. It results into soils having extensive radiocarbon ages of thousands of years (Jull et al., 2013). Water rich in dissolved ancient calcium carbonates, commonly known as hard water, is the most common reason for the freshwater reservoir effects (Philippsen, 2013) Molluscs and other encrustations living in water bodies contribute to uptake of C. This may result into depiction of higher C from water bodies as compared to atmospheric C. Atmospheric carbon is obtained from terrestrial plants. The ^{14}C content of mixed layer of ocean is an indication of degree of exchange between atmosphere and surface ocean and upwelling from deeper layers. Large fluctuations due to upwelling of old C from deeper ocean is often observed. This is called Marine reservoir effect (Jull et al., 2013) Radiocarbon dates can be misleading if subordinate effects are not considered. It is thus necessary to consider such small but vital factors. Implementation of effective and standardised calibration models can be a solution to this challenge.

d. Maps

Maps were plotted in QGIS (ver. 3.10.8), based on the longitude and latitude coordinates obtained from datasets of Neotoma. Sites from published literature have also been plotted. The geographical coordinates were not always available in the respective research paper. In these cases thay were obtained from Google maps. The plotting is therefore indicative of the study area and may not necessarily point to the actual archaeological site.

Sites were allocated regional names to slice them into eight groups based on geographical location. This was done arbitrarily, aiming to include sites of a region in one area. In the process, some sites may not come under any of the eight categories.

e. Mathematical calculations

A table comprising all data was prepared. Average values for TRSH and cereals were obtained for each site and pasted in the respective columns. All the mathematical analysis was performed using Microsoft Excel.

a) Average values for each region were counted by noting the cumulative average of TRSH, pastures, cereals and OJCV. Stacked columns for the respective data was inserted to enable visualisation.

b) Some mathematical calculations like value of r, R^2 was assessed to understand correlation and variance respectively. Excel formulas were then used to assess value of r and R^2. It was not possible to plot value of r because the value on a normal distribution curve is too small (0.02). R^2 was presented as scatter diagram and the trendline used to indicate the lack of variance (0.005).

c) To count all the sites comprising data related to anthropogenic indicators; sites with pasture, cereal, OJCV data were grouped together. The number of sites was noted, and a scatter chart was therefore prepared to show human indicators (HI) in comparison to TRSH data.

The results based on aforementioned materials and respective methods are illustrated in the forthcoming chapter.

4. Results and observations

The major aim of my research was to assess human impact on land from Bronze to Iron Age. The examination was based on tree to cereal ratio and change in tree cover. However, data from cultivated trees, pastures and OJCV was also collected since they have been considered as human indicators (HI).

Having collected data from 250 sites in Europe to south of 50°,the sites were divided into eight geographical zones *(Map 1).* The average values of different categories of pollen data were calculated for each zone *(Fig.1),* in order to minimize the local effect of the single sites. Thereafter, difference in TRSH and cereal data was scrutinised and compared.

a. Geographical Regions

The sites from Neotoma were divided into eight zones (*Map 1*) The geographical regions are mere guidelines for the purpose of this research and have been allocated arbitrarily. The only site (Holzmaar) which does not fall under any of the categories; has been ignored for time being.

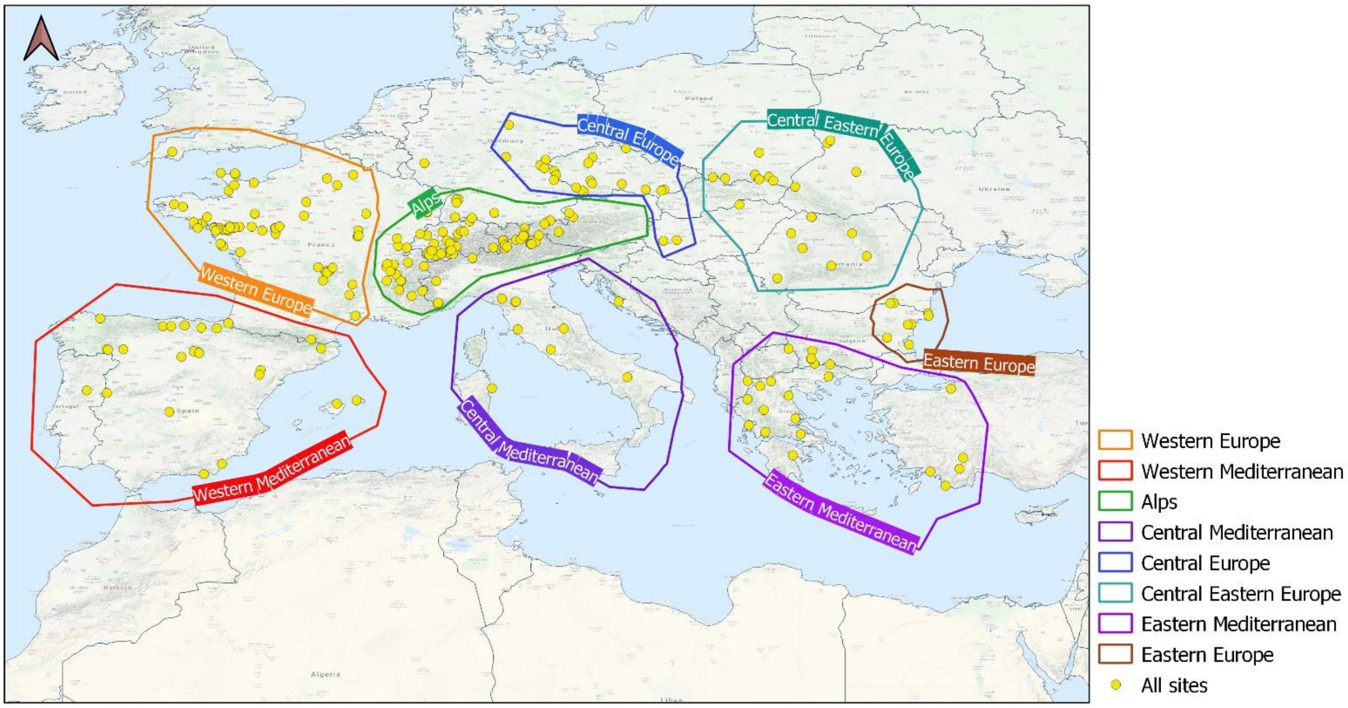


Figure 2 the eight selected European regions selected to examine changes in land use at the Brone to Iron Age transition

Fig 2 shows the eight selected geographical zones. It is noteworthy that the maximum concentration of sites is in the Alps region (80 sites) followed by Western Europe (59), Western Mediterranean (25), Central Eastern Europe (26), Eastern Europe (20), Central Europe (18), Eastern Mediterranean (13) and lowest in the Central Mediterranean (8).

b. Average

Average value of all sites in respective category and chronology was calculated to note the tentative value in respective category and chronology. It provides an insight for better understanding of the data and looking at the larger picture as opposed to scatter diagrams which can help point out exceptional cases of single sites with local disturbance.

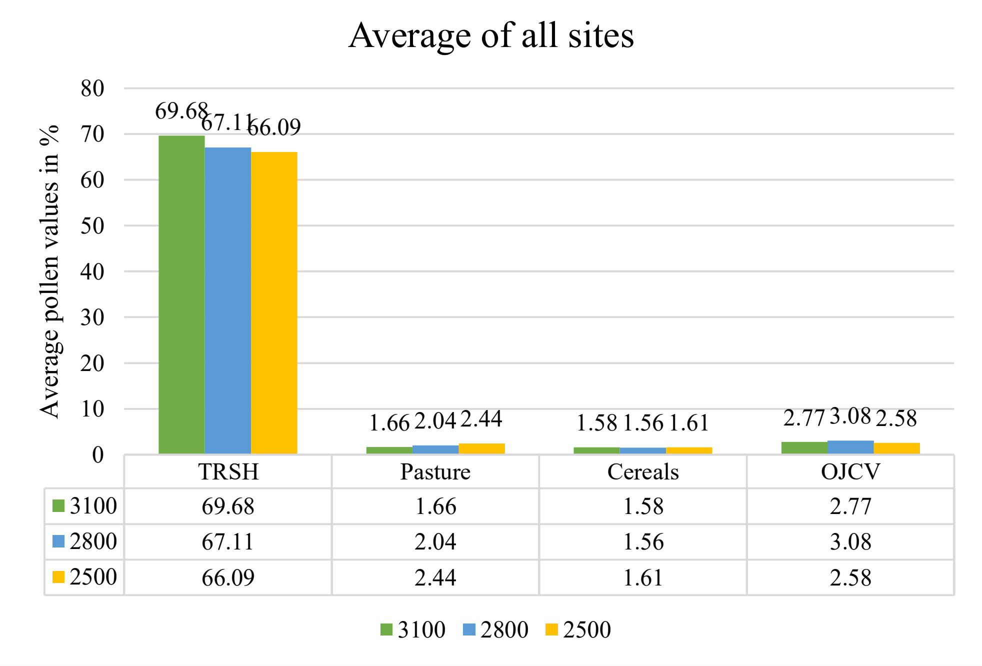


Figure 3 average values of pollen percentages for TRSH, pastures, cereals and OJCV in 3100, 2800, 2500 cal BP

Figure 3 shows average values for TRSH, pastures, cereals and OJCV in all the sites at 3100, 2800, 2500 cal BP. *Plantago* and *Rumex* are pasture indicators. *Triticum, Secale, Avena, Hordeum* are included in cereal indicators. *Olea, Juglans, Castanea,* and *Vitis* are included in OJCV. Minor differences are observed in all the categories across time. The difference in average values for forest cover is negligible (1-2%). With regards to pastures, 3100 cal BP shows lowest average value (1.66%). It increases thereafter reaching its peak in 2500 cal BP (2.44%). It could be indicative of rising extent of human habitation. The cereal data is almost the same in all three time periods (1.58%, 1.56%, 1.61% respectively). OJCV average fluctuates with a small difference of 0.3%. It increases in 2800 cal BP (3.08%) as compared to 3100 cal BP(2.77%). The value drops again around 2500 cal BP (2.58%).

The average data indicates towards a small rise (0-1%) in human indicators which reflect increased use of land from 3100 to 2500 cal BP.

c. TRSH Average

Average values for each time period (3100, 2800 2500 cal BP) were individually calculated for TRSH and cereals. The graph below is a depiction of average values of trees and shrubs from respective region each time window.

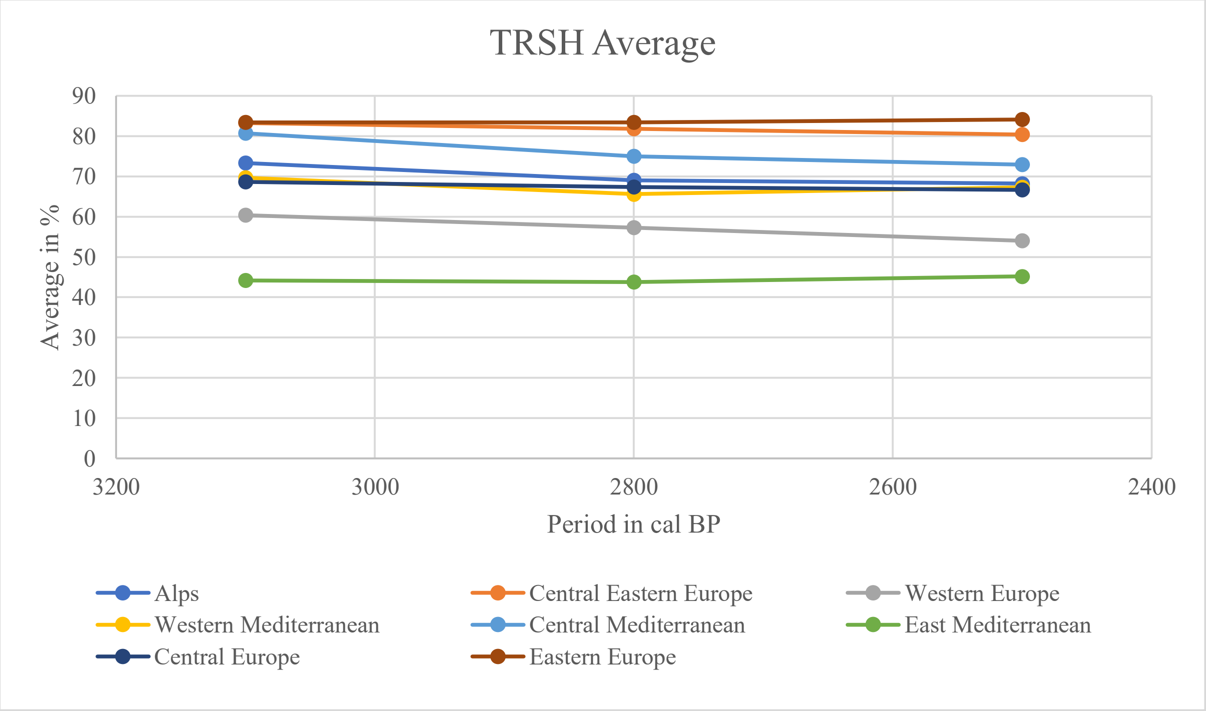
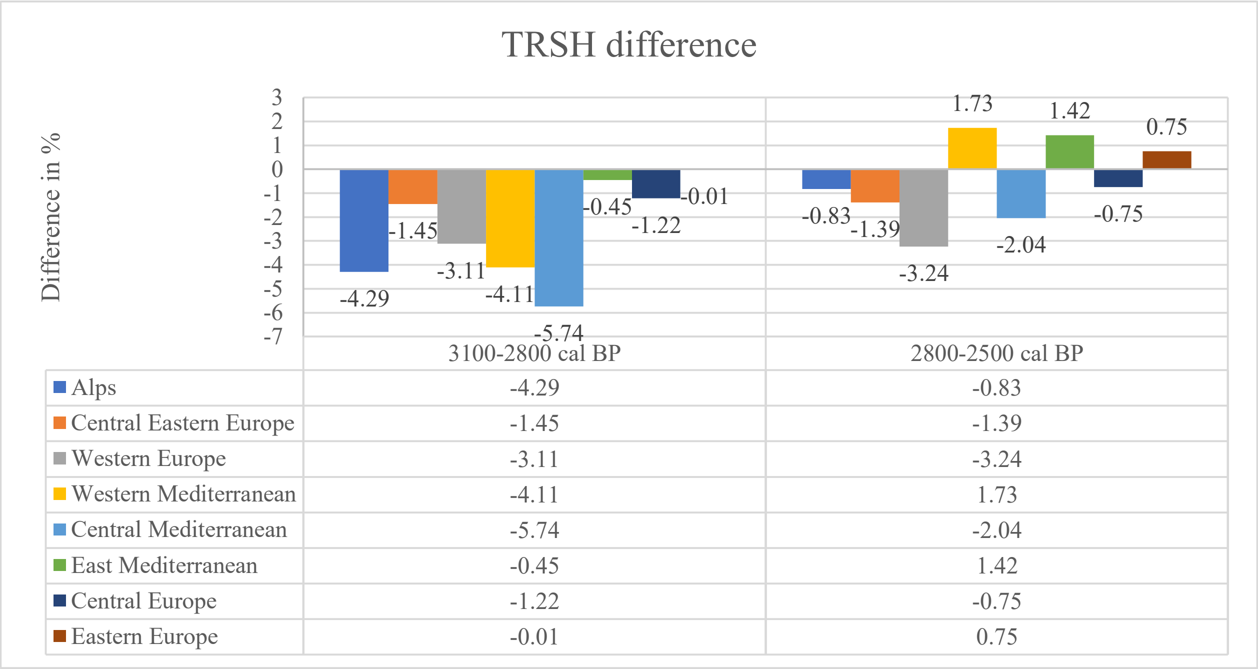


Figure 4. average values of TRSH per selected region

Figure 4 intends to show change in average forest pollen from 3100 to 2500 cal BP Eastern Mediterranean shows relatively low average values at <50% which increases in Western Europe at <60%. Western Mediterranean, Central Europe and Alps show further increase with highest values <75%. Eastern Europe, Central Mediterranean and Central Eastern Europe taken the lead with <85% average pollen percentage.
The differences has been elaborated in Fig 5. The difference in trees over the years was calculated to see if there has been an increase or decrease.



	3100-2800 cal BP	2800-2500 cal BP
Alps	-4.29	-0.83
Central Eastern Europe	-1.45	-1.39
Western Europe	-3.11	-3.24
Western Mediterranean	-4.11	1.73
Central Mediterranean	-5.74	-2.04
East Mediterranean	-0.45	1.42
Central Europe	-1.22	-0.75
Eastern Europe	-0.01	0.75

Figure 5 difference in TRSH percentage from 3100 to 2800 cal BP and 2800 to 2500 cal BP

Fig 5 shows a decrease in TRSH percentages in all regions from 3100 to 2800 cal BP. Maximum decline in forest area is noted in the central Mediterranean (-5.74%) followed by Alps (-4.29%), Western Mediterranean (-4.11%), Western Europe (-3.11%). The difference thereafter is not significant (<-1.45%) in regions of Central Eastern Europe, Central Europe and Eastern Mediterranean. Eastern Europe records practically no difference (-0.01%) in forest cover.

Fig 3. Gives an average value of all the sites. Fig 5 is separated based on the region and hence the fluctuation is more evident; there is no scope to make up for outliers. Hence the difference is much stronger in Fig 5 as compared to Fig 3.

The decrease in forest cover from 2800-2500 cal BP is relatively less important in terms of numbers. The highest drop is noted by Western Europe (-3.24%). However, comparing it will 3100 cal BP, the difference is not very significant (0.13%). Central Mediterranean shows a decline of 2.04% from 2800 to 2500 cal BP. When compared to 3100, difference of 3.7% is noted which is rather significant. Alps show a very small difference (-0.83%) in vegetational cover in 2500 cal BP when compared to 2800. Western Mediterranean in 2500 shows a rise of 1.73%. Central eastern Europe records a decrease of -1.39% respectively which is not very significant (0.06%) in comparison to 3100 cal BP. Central Europe shows -0.75% in 2500 cal BP. The difference when compared to 3100 cal BP is 1.97% which can be considered sizeable. Eastern Mediterranean shows a rise in forest cover by 0.97% for the value of 2500 cal BP stands at 1.42%. Eastern Europe shows a rise of 0.75% in vegetational cover.

d. **Cereal Average**

Cereal data was available from only 7% of the sites collected from Neotoma. Again, they were separated according to the region and average was calculated for all three periods. A visual representation of the same can be seen in the line diagram below.

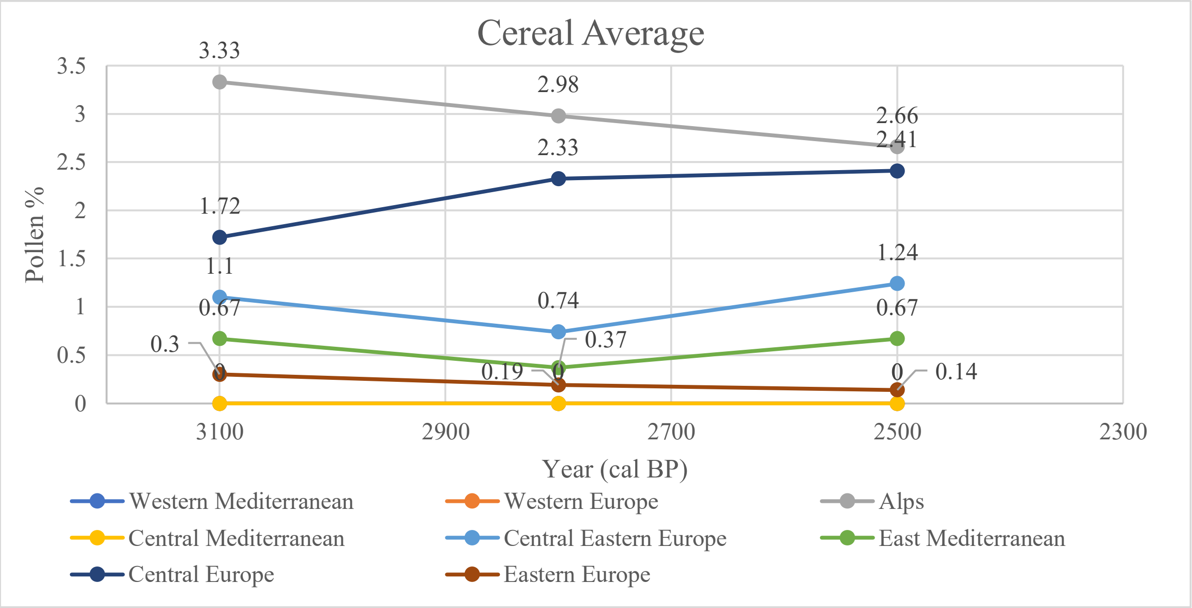
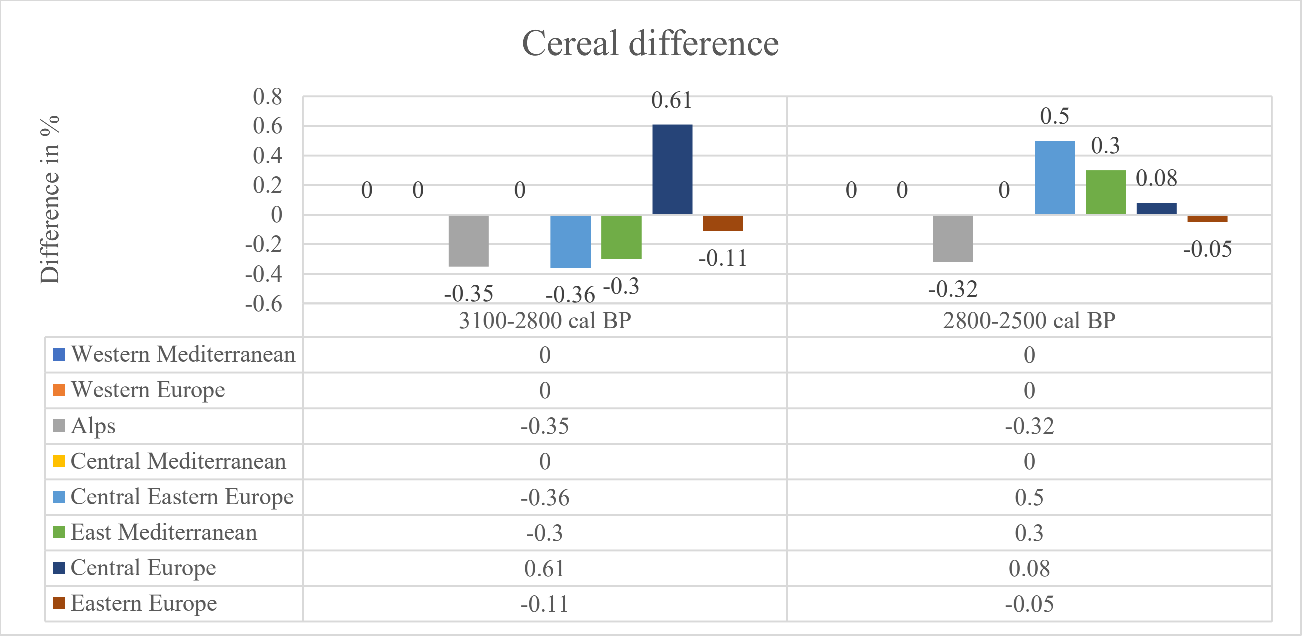


Figure 6 average distribution of cereal data as per the 8 selected regions.

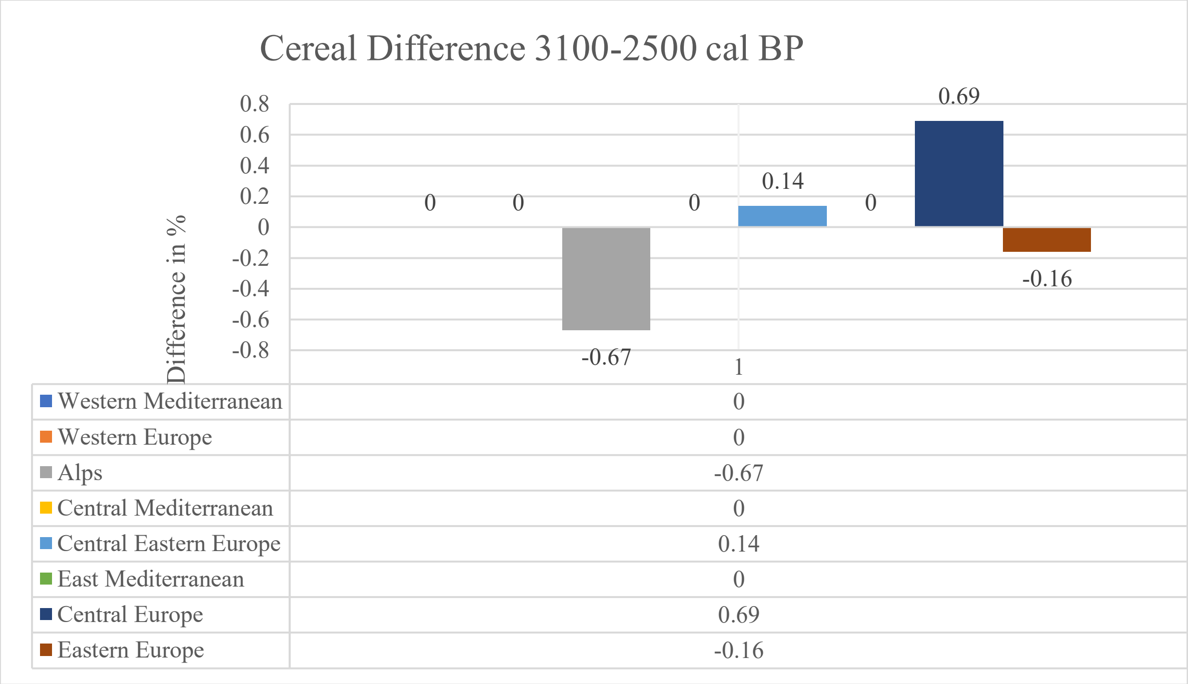
Figures 6 shows the average distribution of cereal data. The purpose of the line chart is to observe shift in numbers from 3100 to 2500 cal BP. The region of the Alps shows a consistent and notable decline in cereals whereas Central Europe shows an increase followed by stable values. Central Eastern Europe is rather interesting for there is a decline and then increase. Eastern Mediterranean has a similar story to tell of decline followed by rise. The cereal data from Central Mediterranean and Eastern Europe is of negligible proportions. The same has been discussed in detail below.
The differences in rise or fall have been discussed below in Fig 7.



	3100-2800 cal BP	2800-2500 cal BP
Western Mediterranean	0	0
Western Europe	0	0
Alps	-0.35	-0.32
Central Mediterranean	0	0
Central Eastern Europe	-0.36	0.5
East Mediterranean	-0.3	0.3
Central Europe	0.61	0.08
Eastern Europe	-0.11	-0.05

Figure 7 difference in cereal data from 3100 to 2800 cal BP and 2800 to 2500 cal BP.

There is decline in the Alps region in cereal data. From 3100 to 2800 cal BP, the decrease is 0.35%, thereafter into 2500, decrease by another 0.03% is noted. Central Eastern Europe initially shows a decline in cereal data at 0.36% in 3100-2800 cal BP. However, there is an increase in pollen data by 0.5%. this results into the same average in 3100 and 2500 cal BP. The Eastern Mediterranean shows a minimum decrease (-0.3%) and then an equal increase (0.3%) in cereal pollen. Central Europe seems to be the only region which shows a consistent growth in cereal data. In 2800, the increase is by 0.61% whereas 2500 cal BP gives a value of 0.08%. The latter value may seem rather small; yet, it indicates towards an increase of cereal pollen. Eastern Europe also shows a regulated decline in cereal pollen. In the first phase (3100-2800 cal BP), there is a decrease by 0.11% and by 0.05% in the second phase (2800-2500 cal BP)



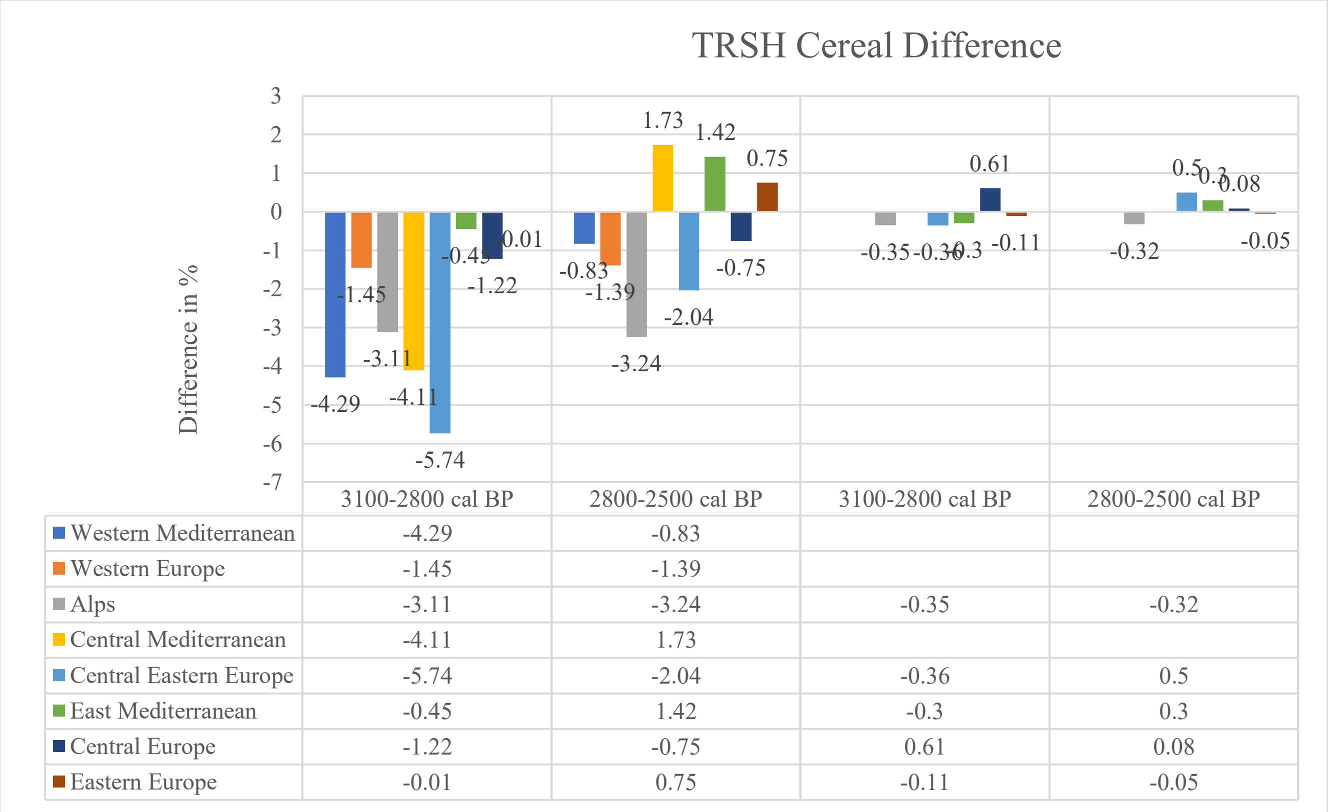
	1
🟦 Western Mediterranean	0
🟧 Western Europe	0
■ Alps	-0.67
🟨 Central Mediterranean	0
🟦 Central Eastern Europe	0.14
🟩 East Mediterranean	0
🟦 Central Europe	0.69
🟫 Eastern Europe	-0.16

Figure 8 difference in cereal pollen percentage from 3100 to 2500 cal BP in the selected regions.

Figure 8 shows the difference in cereal pollen percentage from 3100 cal BP to 2500 cal BP. Alps show a steady fall of 0.67% whereas Central Europe show a rise of 0.69%. Central Eastern Europe too records some increase in cereal pollen at 0.14% and Eastern Europe records a fall at -0.16%. The other regions have not been included for they do not provide cereal data at all or do not show any difference from 3100 to 2500 cal BP.

e. <u>TRSH and Cereals</u>

The graph shows comparison of TRSH and cereal data from Neotoma based on geographical zones. A combined plot of TRSH and cereals has been presented. The purpose is to note the sharp differences in the pollen percentage obtained. It is therefore not possible to observe any trend or pattern in TRSH and cereals over the given period.



	3100-2800 cal BP	2800-2500 cal BP	3100-2800 cal BP	2800-2500 cal BP
🟦 Western Mediterranean	-4.29	-0.83		
🟧 Western Europe	-1.45	-1.39		
⬜ Alps	-3.11	-3.24	-0.35	-0.32
🟨 Central Mediterranean	-4.11	1.73		
🟦 Central Eastern Europe	-5.74	-2.04	-0.36	0.5
🟩 East Mediterranean	-0.45	1.42	-0.3	0.3
🟦 Central Europe	-1.22	-0.75	0.61	0.08
🟫 Eastern Europe	-0.01	0.75	-0.11	-0.05

Figure 9 differences in TRSH and cereals across the studied time periods.

Figure 9 gives a combined picture of differences in TRSH and cereals in two distinct phases of 3100-2800 cal BP and 2800-2500 cal BP. TRSH covers most of the landscape whereas cereals only refer to cultivated land. The values of the two cannot be directly compard. However, my thesis attempts to compare the increase and decrease of the same over the years.

One of the major reasons for such disparity could be small percentage of cereal data and the limited number of sites providing information about the same.

a. <u>Mathematical applications</u>

Pearson's R shows correlation whereas R^2 shows variance in the datasets. Both have been used to show lack of congruence in TRSH and cereal data obtained from the 250 sites.

a) Correlation coefficients are used to examine if there is any relation between two datasets. Having observed the lack of any trend or pattern in TRSH and cereals, correlation coefficient of values of TRSH and cereals was obtained. The value is extremely small at 0.02. The following formula was used for the same.

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[\,n\Sigma x^2 - (\Sigma x)^2\,][\,n\Sigma y^2 - (\Sigma y)^2\,]}}$$

The formula belongs to Pearson's R. It has been used for this research to assess the relation between TRSH and cereals. It is known that a value closer to 1 indicates positive relation between the datasets. This means that, for every positive increase in one of the variables, there is a positive increase in set proportions in the other variable too. On the same lines, a negative relation which is closer to -1 hints towards decrease when one variable increases positively. A value closer to 0 demonstrates that the two variables or datasets may not be related at all. This is the case with our datasets of trees and cereals for the value is as small as -0.02. Since the number is very small, it is challenging to comment on whether trees depend on cereals or the other way around. This is primarily the case, because no relation can be established with the given data.

b) R^2 also known as the coefficient of determination is used to establish percentage of variation where y (TRSH) is explained by x (Cereal) variables. The value is supposed to be between 0 and 1. The closer it is 1, better the variation.

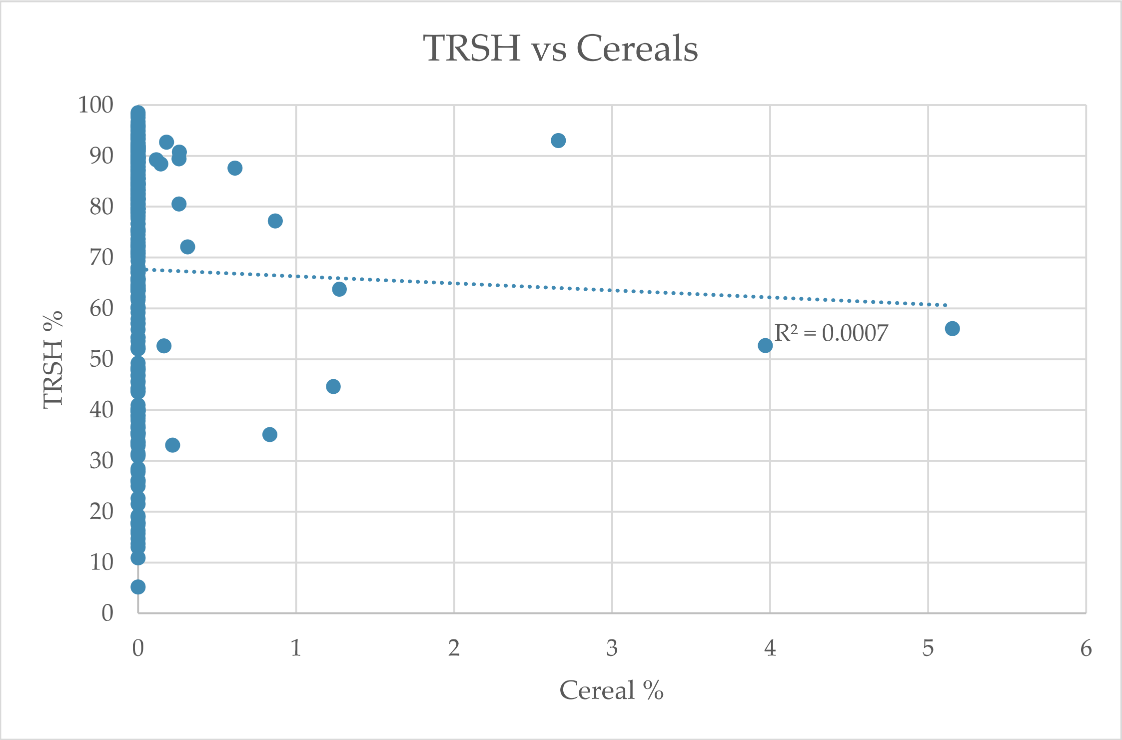
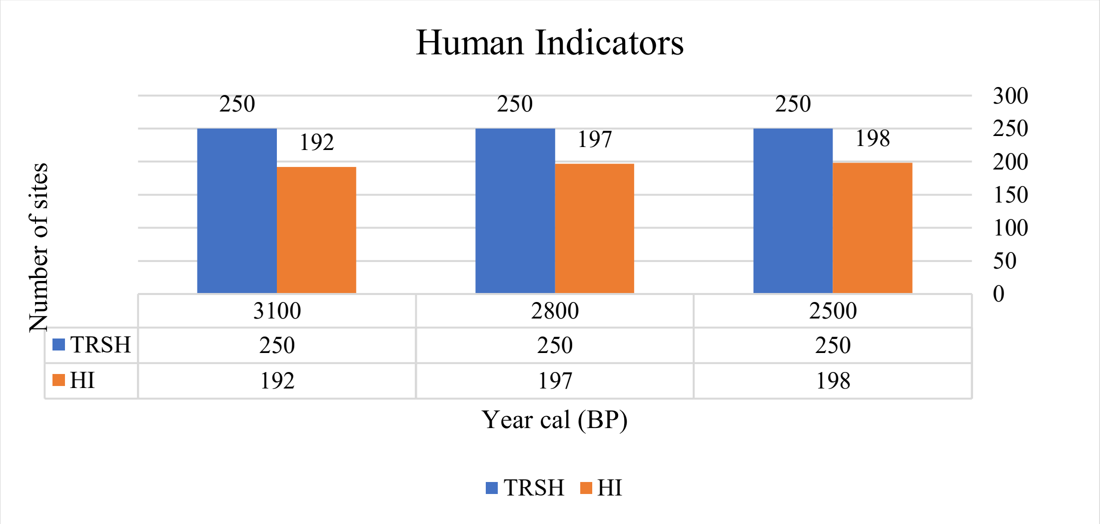


Figure 10 variance beween TRSH and cereal. An outlier number was excluded.

The R^2 value indicated in Fig 10 shows lack of explained variability in the two datasets for the value is extremely small at 0.0007. 0% indicates that the model explains none of the variability of the response data around its mean. 100% indicates that the model explains all the variability of the response data around its mean.

b. Human Indicators

It can be a justified argument that land under cultivation will always be less than forest cover in this time frame. This is a primary reason for selecting anthropogenic indicators like *Plantago, Rumex, Olea, Juglans, Castanea,* and *Vitis*. The sites in pastures with no data for the given period were eliminated along with duplicates in cereal and OJCV. The sum of remainder sites was calculated and is represented below.



	3100	2800	2500
TRSH	250	250	250
HI	192	197	198

Fig 11 number of sites with TRSH pollen and with total human indicators (HI).

Fig 11 shows that the overall proportion of sites providing human indicators rises gradually i.e. 192-197-198 in 3100, 2800 and 2500 cal BP respectively. The number of sites providing data about human indicators was calculated in each period. An average of the HI categories was then taken. The purpose of using the average is to balance out sites which provide data on only one or two parameters like pastures, cereals OJCV.

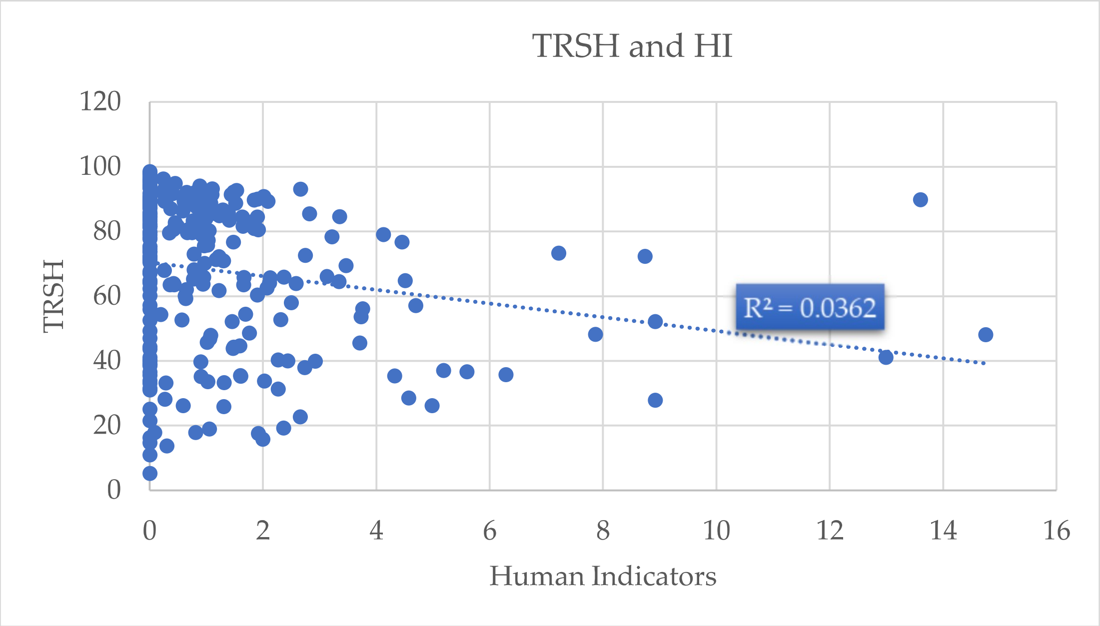


Figure 12 Percentage of human indicators versus TRSH.

The R² value in Fig 12 again is very small at 0.03 indicating negligible explained variability in the datasets.

5. Discussion

This research aspired to address one of the many problems in the study of the relations between vegetation and human activities; the absence of integrated study based on local and individual records at the Bronze to Iron Age transition (Finné et al., 2011). Access to a large dataset like Neotoma enabled this study. The literature review provided an overview of some existing works in the field. It points towards abundant research from Neolithic to Bronze Age change in vegetation and human activities. However, the transition from Bronze to Iron Age has not received much attention from the scholars. Yet, there is sizeable investigation at the local level to understand this transition; although no significant relation between vegetational and human indicators has been observed at a regional scale.

The entire study region was divided into eight zones based on their longitude and latitude. Preference was given to physical features over administrative boundaries for it can have an impact on landscape of the area. This was helpful in later analysis to identify specific patterns or the lack of it.

a. Results

Average values from Neotoma providing information on the four different categories namely TRSH, cereal, pastures and OJCV was calculated to review the data obtained. This was done for all three time periods 3100, 2800, 2500 cal BP. Naturally, TRSH scored the highest, for it indicates forests. The other categories in comparison were in minuscule proportions. Nonetheless, a very small increase (0-1%) is noted in all the anthropogenic indicators- cereals, pastures and OJCV. The increase is proportional to decrease of TRSH average percentage which falls consistently (2-0%) from 3100 to 2500 cal BP indicating forest openings. This surely indicates towards a small but steady rise in human activities from 3100 to 2500 cal BP.

Special emphasis was laid on **tree to cereal ratios**.Average values for each were calculated based on the eight regions and plotted independently. It aimed to merely show transition in tree and cereal data respectively in 3100, 2800 and 2500 cal BP. The differences were also counted to see if there was an increase or decrease in 2800 and 2500 in comparison to the previous period. The average values of TRSH and cereals was compared including their differences. It was not possible to evaluate any relation between the two. Hence, some mathematical applications were used. This included Correlation Coefficient also known as Pearson's R and R^2 to assess variance. Both the tests yielded extremely small numbers -0.02 and 0.005 respectively indicating lack of correlation and variance. One evidently notices the absence of any connection between TRSH and cereals.

One of the reasons for such small numbers could be inadequacy of data obtained from cereals. Only 7% of the sites provided data pertaining to cereals. The pollen count therein was also very small (<5%). This may be a major reason for the lack of any relation between TRSH and cereal.

It brings us to the next part of the results where all **human indicators** (cereal, pastures and OJCV) were plotted against TRSH to observe associations therein. Correlation coefficient in this case was -0.22 which is not very large either. The negative value shows that for increase every increase in one variable (TRSH), the other variable (human indicators) decreases by 0.22. The categories are therefore inversely proportional to one another. **It leads us to conclude that there is no direct relation between forests and anthropogenic indicators of pollen based on the data studied.** It is noteworthy that correlation between cereals and TRSH is -0.02 whereas anthropogenic indicators at large and TRSH is -0.22. Both these values are negatively correlated which proves and that a decrease in one variable (TRSH) can lead to increase in another (cereals/ all anthropogenic indicators). The difference of 0.2 units is not very significant as a number but it encourages inclusion of all HI while calculating human presences and not restricting only to cereals.

However, this figure can be misleading for pastures and OJCV may not always be effective for indicating human presence.

b. Pastures and OJCV as anthropogenic indicators

Certain species have been considered as indicators of human activity. Attempt has been made to re-evaluate the effectiveness of this consideration.

Additional pollen indicator group being ruderal weeds (Polygonaceae, Urticeae, *Plantago lanceolata*) and grazing resistant plants such as *Cirsium, carduus* and different species of *Centaurea* have been calculated in a study in the Levant (Palmisano et al., 2019) . The latter group encompasses together secondary anthropogenic (ruderal weeds) and grazing indicators, an increase of these taxa reflect more generally a more intense human impact on the vegetation such as woodland clearance, increase of pasture lands, building activity (settlements, mining, roads) and agriculture (terracing, abandoned fields, irrigation) (Palmisano et al., 2019). Pollen from *Plantago lanceolata* is considered as a good indicator for human land-use. In central and northern Europe *P. lanceolata* is the only *Plantago* species producing a characteristic pollen type. In southern Europe other *Plantago* species (*lanceolata, altissima, argentea*) produce the same pollen type. This could hinder the understanding of *P. lanceolata* as an anthropogenic indicator (Giesecke et al., 2013).

Animal and human population grew overtime. However, the effect is not necessarily noted in terms of cultivated land. It may have diverted towards pastoral land. Early Iron Age communities may have turned to seasonal mountain pastures and non-local fields