Quaternary International xxx (2016) 1–10

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

# The old charcoal kiln sites in Central Italian forest landscapes

Elisa Carrari [a, *], Evy Ampoorter [b], Francesca Bottalico [c], Gherardo Chirici [c], Andrea Coppi [d], Davide Travaglini [c], Kris Verheyen [b], Federico Selvi [a]

[a] University of Firenze, Dept. of AgriFood Production and Environmental Sciences, Laboratories of Applied and Environmental Botany, P.le Cascine 28, 50144 Firenze, Italy
[b] Ghent University, Department of Forest and Water Management, Forest & Nature Lab (ForNaLab), Geraardsbergsesteenweg 267, B-9090 Gontrode, Belgium
[c] University of Firenze, Department of Agricultural, Food and Forestry Systems, Via San Bonaventura, 13, Firenze 50145, Italy
[d] University of Firenze, Department of Biology, Botanical Laboratories, Via G. La Pira 4, 50121 Firenze, Italy

ARTICLE INFO

*Article history:*
Received 9 May 2016
Received in revised form
19 October 2016
Accepted 21 October 2016
Available online xxx

*Keywords:*
Airborne Laser Scanning
Charcoal hearths
Charcoal-enriched soil
Inventory
Legacy effects
Traditional forest uses

ABSTRACT

Production of wood charcoal in the Mediterranean countries started over two millennia ago and vanished almost completely only in the last century. The legacy of this activity are thousands of abandoned charcoal kiln platforms, in which soil and vegetation characteristics are deeply affected. Understanding the consequences of such effects at the forest level demands a better knowledge of the density, distribution and morphology of these sites, as well as the influence of forest type and local geomorphological characteristics. We examined these aspects using field surveys and Airborne Laser Scanning (ALS) data in 1-ha sample quadrats distributed along an altitudinal gradient in three major forest types of Central Italy, namely evergreen sclerophyllous forest, oak-dominated thermophilous deciduous forest and montane beech forest. We found on average 5.5 kiln sites per ha. The highest overall surface proportion covered by charcoal platforms was recorded in oak-dominated forests, due to their generally larger size. In beech forests, kiln platforms were more numerous than in the other two forest types, but smaller. Density was intermediate in the sclerophyllous forests, where the overall proportion of surface was lowest. The charcoal-enriched soil layer was usually single and continuous (e.g. not interrupted by mineral layers). The thickness of this layer was similar in the three forest types, but increased with slope inclination. Several features of our kiln platforms such as density and shape were distinct from others in Central and Northern Europe, probably reflecting different forest histories and purposes for which they were built. Using ALS, we could detect all kiln platforms in beech forest on steep slopes and approximately 75% of the kilns in oak forests on hilly terrain. Hence, all further ecologically- or archaeologically-oriented study in our region at the landscape level will benefit from the use of hillshade and/or slope images from ALS data.



## 1. Introduction

Based on artworks of ca. 38.000 years ago found in the caves of southern France, it appears that wood charcoal has been one of the first synthetic materials produced by man (Antal, 2003). With the beginning of iron metallurgy (Bonhôte et al., 2000; Ludemann, 2006), it then became one of the main sources of energy until the 19th century (Bonhôte et al., 2000; Fabre and Auffray, 2002; Pèlachs et al., 2009; Deforce et al., 2012; Paradis-Grenouillet, 2012; Rouaud and Allée, 2013). Its production is a very ancient form of anthropogenic forest use in the temperate regions, and was continued to satisfy the needs of the human populations in most European countries, especially for metal processing in foundries. Production of charcoal is based on the pyrolysis of wood at low temperature (from 400 °C to 600 °C) without oxygen, and was realized in special wood kilns covered by a mixture of soil and plant material (Landi and Piussi, 1988; Bonhôte et al., 2000; Ludemann, 2003; Powell, 2008; Deforce et al., 2012; Paradis-Grenouillet, 2012). In hill and mountains areas, kilns were usually prepared along footpaths in

* Corresponding author.
*E-mail addresses:* elisa.carrari@unifi.it (E. Carrari), evy.ampoorter@ugent.be (E. Ampoorter), francesca.bottalico@unifi.it (F. Bottalico), gherardo.chirici@unifi.it (G. Chirici), andrea.coppi@unifi.it (A. Coppi), davide.travaglini@unifi.it (D. Travaglini), kris.verheyen@ugent.be (K. Verheyen), federico.selvi@unifi.it (F. Selvi).

http://dx.doi.org/10.1016/j.quaint.2016.10.027
1040-6182/

sites where it was possible to cut the stools in the adjacent stands and concentrate the wood in small, terrace-like platforms prepared for this purpose (Cantiani, 1955). In the Mediterranean region, various evergreen and deciduous tree species were used for charcoal production, such as oaks (*Quercus cerris, Q. pubescens* and others, except for *Q. suber*), ash (*Fraxinus ornus*), hop-hornbeam (*Ostrya carpinifolia*) and various secondary woody species that occur especially in thermophilous deciduous forests, such as *Sorbus* sp., *Acer* sp. and others (Carrari et al., 2016a). Large sclerophyllous shrubs such as the green olive trees (*Phillyrea* sp.), the strawberry tree (*Arbutus unedo*), and the heath tree (*Erica arborea*) were also used for this purpose. According to Mariotti Lippi et al. (2000), the latter species was one of the most important sources for charcoal production in S Tuscany during the Etruscan period (IV–V century b.C.).

While in most northern and central European countries the use of wood charcoal was abandoned in the 19th century due to the rapidly increasing and widespread use of coal (Deforce et al., 2012), the importance of this material in the Mediterranean area even increased during the industrial revolution, as other fuel sources were largely lacking. In Italy, its production and use mostly vanished only during the fifties, though it is still in practice today in some remote mountain areas (Landi and Piussi, 1988).

The main legacy of this traditional activity are thousands of abandoned charcoal kiln sites disseminated in present-day forests (Acovitsioti-Hameau and Hameau, 1996; Bonhôte et al., 2000; Davasse, 2000; Montanari et al., 2000; Blondel, 2006; Pèlachs et al., 2009; Paradis-Grenouiller et al., 2011). Thanks to the resistance to microbiological decomposition of charred organic material, these sites are rich in centuries-old charcoal remains (Robin et al., 2015). This provides an opportunity for the reconstruction of former woodland composition and management practices on a stand scale, using anthracological analysis and radiocarbon dating (Montanari et al., 2000; Ludemann, 2003; Ludemann et al., 2004; Nelle, 2003; Nelle et al., 2010; Pèlachs et al., 2009; Knapp et al., 2013, 2015). Other previous studies, however, showed that this practice has probably caused long-lasting ecological effects on the structure, composition and functioning of the soil and vegetation. A first important effect is the strongly increased amount of total carbon in the topsoil layers, suggesting that these sites can contribute significantly to the overall capacity of carbon stock at the forest-level (Criscuoli et al., 2014). Nutrient availability and pH are also often increased, which may lead to compositional differences in the understorey vegetation with respect to the adjacent stands (Wittig et al., 1999; Carrari et al., 2016c). In addition, the altered processes of tree recolonization in kiln sites abandoned since even decades may lead to long-lasting negative effects on forest recovery (Mikan and Abrams, 1995, 1996; Young et al., 1996; Carrari et al., 2016b).

Evaluating the magnitude of these effects and the contribution of charcoal kiln sites to the long-term carbon stock in the soil at the forest-level demands a better knowledge of their spatial distribution, density and overall surface (Schmidt et al., 2016), as well as of the characteristics of the charcoal-enriched soil layer. Previous inventory studies provided data for Germany and the Alpine area (i.e. Hesse, 2010; Ludemann, 2011; Schmidt et al., 2016), Belgium (i.e. Deforce et al., 2012; Hardy and Dufey, 2015) and Norway (i.e. Raab et al., 2015), while in S Europe most of this studies focused only on the Pyrenees (Bonhôte et al., 2000; Davasse, 2000; Pèlachs et al., 2009; Py-Saragaglia et al., 2015) and in S France (Vaschalde et al., 2008; Allée et al., 2010; Paradis-Grenouiller et al., 2011). Hence, no evidence exists for other Mediterranean regions (i.e. Italy), where factors like the frequently rough geomorphology of hilly or mountainous areas, the often heterogeneous forest environment, as well as the diversity of local traditions have probably affected the spatial distribution and the morphology of the kiln sites to a considerable extent.

Accordingly, the aims of this work were: 1) to provide a characterization of the charcoal kiln sites in the forest landscapes of a Mediterranean area (central Italy), and 2) to examine the effects of forest type and major geomorphological traits on the spatial distribution and morphology of these sites. To this purpose, we used a traditional field-based inventory and Airborne Laser Scanning (ALS) data. The latter was already successfully adopted in forest areas of C and N Europe (i.e. Ludemann, 2003; Schmidt et al., 2016), but still not in areas of S Europe. By comparing results from the field and the ALS data, it was possible to test the efficacy of the latter for kiln site detection in territories covered by oak forests with a multiple-layered structure and a massive shrub layer, or in beech forests occurring on the steep slopes of the Apennine mountain chain.

## 2. Regional setting

The study was performed in the forests of Tuscany (central Italy), located between 42.867017° N and 43.983427° N and 10.468035° E and 11.817308° E (Fig. 1; geographical details in Table 1).

The territory of Tuscany is characterized by three major climate and forest types, spread along an altitudinal gradient from sea level to over 1400 m: 1) meso-Mediterranean along the Tyrrhenian coast, where woodlands are mainly formed by evergreen sclerophylls and especially *Q. ilex*; 2) supra-Mediterranean on the hill systems in the central part of the region, largely covered by thermophilous mixed forests dominated by various species of deciduous oaks (mainly *Q. cerris*, *Q. pubescens, Q. petraea*); 3) montane-suboceanic on the Apennine range and Mount Amiata, where beech (*Fagus sylvatica*) and mixed beech-silver fir (*Abies alba*) forests usually occur above 900–1000 m. Mean annual rainfall and temperature in the study area vary from 650 mm and 15 °C respectively along the coast, to 1450 mm and 10.9 °C respectively on the Apennines and Mount Amiata (period 1961–1990, source: Servizio Meteorologico dell'Aeronautica Militare). The study area is characterized by a variety of geolithological formations and soil conditions, but cambisols are the prevalent soil type according to the Soil Atlas of Europe (European Soil Bureau Network, 2005).

Tuscany had an utmost importance for charcoal production because of the presence of the main Etruscan civilization. The great ability of this population in metallurgy is widely known, as well their practice to use charcoal for copper production at least since 800 b.C. (Chiarantini et al., 2009). Hence, the forests of the present study area were an inexhaustible source of all types of wood needed for the metallurgic activity since that time and they can be considered "Metallurgical Forests", as defined in Paradis-Grenouillet (2012). The activity continued, despite some fluctuations, also during the Middle age and even increased in the nineteenth century (Arrigoni et al., 1985). In later times, production of wood charcoal was such a deeply rooted practice in C Italy that it remained a major source of energy for heating and cooking, as well as for the production of high quality steel in small blast furnaces until the years 1950 and 1960 (S.I.L.T.E.M, 1946). Based on local historical documents and common knowledge, the forests investigated here have provided wood charcoal for centuries and abandoned for this purpose only about 60 years ago, as in other parts of Tuscany (Landi and Piussi, 1988; Arrigoni et al., 1985).

## 3. Material and methods

### 3.1. Selection of quadrats

For each forest type, here after indicated as "sclerophyll", "oak"

Please cite this article in press as: Carrari, E., et al., The old charcoal kiln sites in Central Italian forest landscapes, Quaternary International (2016), http://dx.doi.org/10.1016/j.quaint.2016.10.027