



Land use legacies on forest understory vegetation and soils in the Mediterranean region: Should we use historical maps or *in situ* land use remnants?

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ABSTRACT

How to move forward if we cannot understand our present from our past? The same applies for the study of ecosystems. Evidence of ecological legacies in temperate post-agricultural forests has been provided on soil physico-chemical properties and understory vegetation richness and composition, which led to distinguish ancient and recent forests. However, no land use legacies dating back more than 50 years have been reported in Mediterranean forests. The definition of ancient and recent forests usually relies on a threshold date, most often provided by historical maps. In France, the Etat-Major map is the most precise, with a relatively high resolution and drawn over the whole country with a standardised method. However, the use of historical maps only for studying land use legacies in forest is questionable in a Mediterranean context characterised by a traditional agro-sylvo-pastoral system. Using a historical ecology approach, our purpose was to examine the legacies of various former land uses on soil and understory vegetation in Mediterranean forests and to compare the relevance of two historical sources: 1860 land use map (map-based PLU) and remnants recorded in the field (*in situ* PLU remnants). In the Regional Natural Park of Luberon (French Mediterranean area), we inventoried plant communities and analysed soil physico-chemical properties on 100 plots with various past land uses according to the Etat-Major map (arable, pasture or forest) and *in situ* PLU remnants (terrace, stone removal or no remnants). Compared to ancient forest, former arable land hosted more species and had deeper and nutrient-rich soils while former pasture had shallower and nutrient-poorer soils. Similarly, and compared with no remnants, terraces hosted more species and had deeper and nutrient-rich soils whereas stone removal had shallower and nutrient-poorer soils. Understory species composition significantly varied according to map-based PLU and *in situ* PLU remnants. However, *in situ* PLU remnants were globally a much better indicator of land use legacies on soil and understory plant composition compared to map-based PLU. We thus confirmed the legacies of past land use on Mediterranean forest soil and understory vegetation. We also stressed that historical ecology should rely on both field evidence and historical maps, particularly in Mediterranean landscapes with a complex history of land uses.

1. Introduction

Humans have transformed the land since immemorial times with fire, land clearing for agriculture and landscaping (Kaplan et al., 2009). Even centuries after land use change, former land use can conserve a

long lasting impact on ecosystems (Dupouey et al., 2002a; Plue et al., 2008). Historical ecology, “the study of human impacts on ecosystems and landscapes over time” (Bürgi and Gimmi, 2007; Szabó, 2015; Armstrong et al., 2017), has been a subject of growing interest in the past decades, notably concerning forests (Szabó, 2015). Especially,

Abbreviations: AF, ancient forest; EM, Etat-Major; FAO, Food and Agriculture Organization; IS-PLUR, *in situ* past land use remnants; MB-PLU, map-based past land use; PLU, past land use; PNRL, Regional Natural Park of Luberon; RDA, redundancy analysis; RF, recent forest

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historical ecology has highlighted strong legacies of former land use on current forest ecosystems and stressed that taking into account forest history is crucial for species conservation (Vellend et al., 2013).

Two types of forests are usually distinguished according to their temporal continuity: “ancient forests” which already existed before a threshold date and “recent forests” which have developed on former non-forest soils, mostly cropland or pasture, after this threshold date (Peterken and Game, 1984; Goldberg et al., 2007; Hermy and Verheyen, 2007). The concept of forest continuity relies on the temporal continuity of its use as a forest, i.e. forest stands may have been logged but forest soils must have not been cleared for agricultural use. Historical maps are often used to define the threshold date (e.g. Peterken and Game, 1984; Honnay et al., 1998; Dupouey et al., 2002b; Bergès et al., 2016) and describe forest spatial distribution (Vuorela et al., 2002; Kaim et al., 2016). However, the comparison between ancient and current land use can be difficult not only because map accuracy can strongly vary between ancient and current maps (Vuorela et al., 2002; Leyk et al., 2006), but also because land use or land cover definitions can change over time (Vuorela et al., 2002; Bieling et al., 2013). Moreover, a turnover in land cover might occur between two maps: a forest can be considered ancient because recorded in both historical and current maps, but may have been deforested meanwhile. In France, several historical maps exist but the most reliable is the “Etat-Major” (EM) map (Dupouey et al., 2007): it was drawn at the national scale following a standardised protocol and displays a relatively high resolution and precision compared to other ancient national maps (map scale: 1:40,000; median position error ca. 25 m after geometric correction). This map was drawn from 1818 to 1866, a period which corresponds to the “forest transition”, i.e. the turning point from an overall deforestation to a continuous and massive forest recovery (Mather et al., 1999). Consequently, we can reasonably assume that the forest patches mapped on the EM map were probably already long established, and that little deforestation occurred after this date.

In temperate regions, soil and understory vegetation differences have been highlighted between ancient and recent forests (Flinn and Vellend, 2005; Hermy and Verheyen, 2007). Compared to ancient forests, post-agricultural forests have less acidic soils with lower organic matter (due to matter exportation during agricultural use) but higher nutrient content, such as phosphorous (due to nutrient inputs during agricultural use) (e.g. Koerner et al., 1997; Compton and Boone, 2000; Dupouey et al., 2002a). Species more frequent in ancient forests (ancient forest species) have short distance dispersal mechanisms and no persistent soil seed bank (dispersal limitation, Hermy and Verheyen, 2007). Some of them may also be sensitive to change in soil characteristics or competition with ubiquitous species (environmental filtering). Ancient forest species are thus less able to colonise new forests than other forest species, which makes them more vulnerable to forest habitat loss, even temporary, and represent a conservation issue.

Land use legacies on current forest soils, species richness and composition have been much less explored in Mediterranean forests compared to temperate forests (Amici et al., 2013; Kouba et al., 2015; Basnou et al., 2016). Basnou et al. (2016) found that forest continuity had a weak effect on woody species, while Kouba et al. (2015) highlighted a loss in late-successional species in Mediterranean forests due to intensive and widespread previous agricultural use in this region. Amici et al. (2013) showed that light-demanding species richness decreased with increasing successional age of forest, despite the open forest canopy measured in forests at all successional ages. However, those three studies only concerned the last fifty years and did not go further back in time. Here we focused on the history of Mediterranean forests over the last 150 years.

Research on the soil and understory vegetation differences between ancient and recent forest has little investigated the nature of the land use prior to forest recovery. However, past land uses (PLUs) do not equally influence current forest ecosystems. For instance, Koerner et al. (1997) and Dyer (2010) both highlighted that forests developed on

former pasture show similar pattern with ancient forests, while former crop or garden have a much stronger legacy effect on soil characteristics and plant species richness. Arable soils are altered by ploughing, topography levelling and nutrient inputs, while pasture soils are altered by trampling (Flinn et al., 2005), and may be impoverished by biomass exportation. Due to intense soil tillage and fertilisation, land use legacies of former culture on current soil and understory vegetation are thus hypothesised to be stronger compared to former pasture (Koerner et al., 1997; Compton and Boone, 2000; Wulf, 2004).

The Mediterranean region is characterised by strong biophysical constraints: water limitations due to hot and dry summers and hard calcareous substrates result in a specific agriculture (vineyards, olive trees, lavender). A rugged topography led farmers to cultivate slopes, resulting in the traditional Mediterranean landscape characterised by terraced crops and extensive grazing. The Mediterranean region is also characterised by a former agro-sylvo-pastoral management of the landscape. Herds of sheep and goats were put out to pasture on crops after harvest to enrich soils but also in forest and *garrigue* to complete their diet. Forests were temporarily cleared and cultivated (“essartage”), while boxwood (*Buxus sempervirens*) and litter were used to fertilise crops (Gilbert, 1989; Chalvet, 2006). Potential multiple uses of the land during short periods thus question the relevance of using historical maps in our context. Testimonies of past agricultural use directly detectable in Mediterranean forests are terraces and stone removal remnants, i.e. large piles of stones or stone walls. Terraces testify an ancient established agricultural use whereas stone removal might reveal ancient temporary agricultural use (de Réparaz, 2000) (Appendix A1). Terraces can date back to the Middle Ages, but their largest extension occurred during the eighteenth and nineteenth centuries (Ambroise et al., 1989; Arnaez et al., 2015), so most of cultivated terrace were probably contemporary of the EM map. Stone removal have been practiced for a long time but no information was found about a preferential period of use. In addition, different land uses probably successively occurred on a same plot. Land use legacies on current forest can overlap and three processes may occur: a persistent effect of the last land use before reforestation; a stronger effect of the more impacting land use irrespective of its date and duration (e.g. arable use over pasture); a cumulative effect of the successive former land uses preceding reforestation. In our case, we assumed that if a land use remnant was still visible now, its legacies were persistent and dominant, irrespective of the time since forest recovery and the succession of land use in the past. There was no evidence of former pastoral use in the field, but we hypothesized that pastoral pressure was more intense in pasture identified on the EM map, even though the whole land might have been temporarily grazed in the traditional agro-sylvo-pastoral management system. Thus, the two historical sources might be helpfully combined to better understand the effect of former land use on current soil and vegetation.

Our main objective was to examine the effect of different PLUs on soil physico-chemical properties and understory vegetation of Mediterranean forests and to compare the relevance of two different sources: ancient maps (hereafter map-based PLU) and remnants recorded in the field (hereafter *in situ* PLU remnants). Our general hypothesis was that *in situ* PLU remnants better indicate the effect of PLU on soil and vegetation than map-based PLU. Specifically, we asked the following questions: (1) Can we detect long-term PLU effect in Mediterranean forests using ancient maps (map-based PLU), and do different map-based PLU (arable land, pasture or forest) have a contrasting effect on soil and understory vegetation? (2) What is the effect of *in situ* PLU remnants and what are the legacies of the different *in situ* PLU remnants on current soil and vegetation? (3) Do map-based PLU and *in situ* PLU remnants legacies concern the same soil and vegetation components; do they have the same magnitude and direction; and are their effects additive?

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