Rangeland Ecology & Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Post Hoc Assessment of Stand Structure Across European Wood-Pastures: Implications for Land Use Policy☆

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ARTICLE INFO

Article history:
Received 27 February 2017
Received in revised form 9 April 2018
Accepted 9 April 2018
Available online xxxx

Key Words:
agroforestry
scattered trees
silvopastoral systems
social-ecological systems
tree density
woodland
savanna

ABSTRACT

Europe's woodland and savanna rangelands, often part of silvopastoral systems known as *wood-pastures*, are deteriorating because of abandonment that leads to return to a forested state or lack of tree regeneration from overgrazing or tree and shrub removal. Despite numerous local studies, there has been no broader survey of the stand structure of European wood-pastures showing which systems are at risk of losing their semiopen character. This overview aims to 1) show some of the differences and similarities in wood-pastures from landscapes across Europe and 2) identify which of these wood-pastures are at risk of losing their semiopen character. We collated a dataset of 13 693 trees from 390 plots in wood-pastures from eight different European regions (western Estonia, eastern Greece, northern Germany, Hungary, northern Italy, southern Portugal, central Romania, and southern Sweden), including tree diameters at breast height, tree density, management type, and tree species composition. On the basis of their structural characteristics, we classified wood-pastures using principal component analysis (PCA) and cluster analysis. The PCA showed a gradient from dense wood-pastures with high levels of regeneration (e.g., in Estonia) to sparse wood-pastures with large trees but a lack of regeneration (e.g., in Romania). Along this gradient, we identified three main groups of wood-pastures: 1) sparse wood-pastures with mostly big trees; 2) dense wood-pastures composed of small trees, and 3) wood-pastures containing a wide range of tree ages. Our results show a large structural gradient in European wood-pastures, as well as regeneration problems varying in their severity, highlighting the importance of social-ecological context for wood-pasture conditions. To maintain the ecological and cultural integrity of European wood-pastures, we suggest 1) more comprehensively considering them in European policies such as the Common Agricultural Policy and EU Habitats Directive, while 2) taking into account their structural characteristics and social-ecological backgrounds.

Introduction

Woodland and savannah, rangelands with a semiopen tree canopy, represent the largest percentage of the world's rangelands (McKell et al., 1972; Platou and Tueller, 1988). In Europe they are typically part of silvopastoral systems known as *wood-pasture* (Bergmeier et al., 2010). The most well-known European wood-pastures are the Mediterranean oak woodlands of the Iberian Peninsula, generally referred to as *dehesas* or *montados*, but wood-pastures can be found in many other parts of Europe. Wood-pastures are permanent grassland combined with

☆ The study was partly supported by grants IUT34-7 from the Estonian Research Council (Estonia), FCT-MEC Postdoctoral grant (SFRH/BPD/97166/2013) (Portugal), the European Community's Seventh Framework Programme, Grant Agreement 613520 (Project AGFORWARD), and the Leuphana University Lüneburg.

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https://doi.org/10.1016/j.rama.2018.04.004
1550-7424/

scattered trees or groups of trees or shrubs, often with large old trees functioning as keystone structures, and often forming ecotones between grasslands and forest (Bergmeier et al., 2010; Lindenmayer et al., 2014).

Human impact has shaped the structure of wood-pastures in Europe for thousands of years (Hartel and Plieninger, 2014; Jørgensen and Quelch, 2014; Hartel et al., 2015). Since their origin in the early Holocene (Bergmeier et al., 2010), wood-pastures have developed as social-ecological systems from forest-based livestock grazing to semiopen landscape elements, shaped by not only biogeographic and environmental conditions, such as climate, elevation, and soil, but also the needs of local people (Chételat et al., 2013; Huber et al., 2013; Bergmeier and Roellig, 2014; Hartel and Plieninger, 2014). The resulting mosaics of grassland with shrubs and trees of different ages, as well as variable light and shade conditions, provide important habitat for a wide range of plant, invertebrate, bird, and mammal species, many of which are threatened at local or landscape scales (Bergmeier and Roellig, 2014; Falk, 2014; Garbarino and Bergmeier, 2014; Hartel et al., 2014; Roellig et al., 2014). Moreover, wood-pastures can contribute to landscape connectivity (Fischer and Lindenmayer, 2002) and adaptation to climate change (Manning et al., 2006, 2009) as well as retain cultural values, including heritage, traditional knowledge, aesthetic, and recreational values (Sutcliffe et al., 2014; Varga and Molnár, 2014; Plieninger et al., 2015).

Despite their shared origin in forest-based livestock grazing, today wood-pastures across Europe are highly varied because of differences in past and present practices in grazing and tree management (Hartel et al., 2013; Bergmeier and Roellig, 2014; Plieninger et al., 2015). Therefore the structure of wood-pastures differs in tree species composition, density, distribution, and the age distribution of trees (approximated by the distribution of stem diameter classes) (Garbarino and Bergmeier, 2014; Hartel et al., 2015). Tree density can range from only a few trees per hectare (ha) to up to 500 per ha (Garbarino et al., 2011; Hartel et al., 2013). Abandoned wood-pastures with dense shrub regeneration can reach densities of woody vegetation that are higher by yet another order of magnitude (Varga et al., 2015; Roellig et al., 2016). The spatial arrangement of trees also differs significantly across Europe (Garbarino and Bergmeier, 2014). In the absence of tree management and under low grazing pressure, trees can form a nearly closed canopy. Wood-pastures with long-term traditional management, on the other hand, typically exhibit a relatively sparse distribution of trees, and where trees are planted (e.g., on the Iberian peninsula), their distribution can have close to a regular pattern (Pulido et al., 2001; Plieninger and Schaar, 2008). The time since wood-pasture establishment, together with the management and distribution of trees, also influences the distribution of stem diameter classes (Plieninger et al., 2003; Fischer et al., 2009). While natural and seminatural forest typically show a high proportion of young trees, the diameter distribution of trees in wood-pastures often follows a bell curve (Pulido et al., 2001; Plieninger et al., 2003; Fischer et al., 2009). Long-term intensive grazing and tree removal have led to a shift towards larger size classes, indicating a lack of regeneration (Bauer and Bergmeier, 2011; Plieninger et al., 2011). In abandoned wood-pastures, larger trees surviving from the former land use tend to become crowded by younger trees, resulting in an increase in the lower diameter classes (Plieninger et al., 2003; Rapp and Schmidt, 2006; Varga et al., 2015).

Despite their cultural and ecological importance, wood-pastures are facing multiple threats (Bergmeier and Roellig, 2014). A lack of regeneration due to overgrazing and the removal of wooded structures, as well as forest regrowth due to abandonment and subsequent shrub-encroachment, are two main threats to their persistence (Bergmeier and Roellig, 2014). A key challenge is that the management of wood-pastures is often not economically profitable anymore (Plieninger et al., 2015). Traditional management is typically labor intensive but economically less feasible than other grazing systems (Bergmeier et al., 2010; Roellig et al., 2016). Another major influence on wood-pastures are national and European Union (EU) land use policies. These policies often do not formally recognize wood-pastures, and even if they do, they are very insufficient or they treat wood-pastures as homogenous systems across Europe, ignoring the actual and historic variability of these habitats (Peeters, 2012; Beaufoy, 2014; Jakobsson and Lindborg, 2015). For example, wood-pastures with > 100 trees per ha are usually not eligible for the subsidies for agricultural land (single-area support payments [SAPs]) of the EU's Common Agricultural Policy (CAP) (Beaufoy et al., 2015). Furthermore, nature conservation policies such as the EU Habitats Directive recognize only four types of wood-pastures (e.g., *Fennoscandian* wooded pastures, *Juniperus communis* formations on heath or calcareous grasslands, *Arborescent matorral* with juniper, and *Dehesa* with evergreen oaks). Other wood-pasture types receive neither formal recognition nor protection at EU level (Bergmeier et al., 2010; Plieninger et al., 2015).

Despite a considerable number of local studies on the stand structure of wood-pastures (Plieninger, 2007; Plieninger et al., 2003; Pulido et al., 2001), there has been no comprehensive overview of the stand structure of wood-pastures in Europe showing which systems are most at risk of losing their semiopen character. To provide such an overview, in this study we aim to 1) show some of the differences and similarities in wood-pastures from different landscapes across Europe in terms of their tree species composition and stand structure, and on this basis 2) identify which of these wood-pastures are at risk of losing their semiopen character. To achieve these aims we compiled data on tree structures in wood-pastures from different landscapes across Europe.

Methods

Data Collection

To describe different wood-pasture systems across Europe we conducted a post hoc comparison largely drawing on existing datasets. To make sure data were comparable, existing data sets needed to have a minimum set of common descriptors including information on plot size, numbers of trees per plot (to calculate the tree density), diameters at breast height (DBH), and species (at least genus) for all surveyed trees within the plot. Management type (grazed or ungrazed) and geographical coordinates were also collected. Following these criteria, we collected a large dataset of 390 plots located in wood-pastures, broadly distributed throughout different parts of Europe (western Estonia, northern Germany, eastern Greece, northern Italy, southern Portugal, central Romania and southern Sweden, Hungary) (Fig. 1).

Data Limitations

Because our analysis is based on a post hoc comparison, the plots are not strictly representative of European wood-pastures and some regions known for their wood-pastures are missing (e.g., Spain, France, and England) because available data did not meet the above criteria. Notably for our data, sampling methods differed between plots and involved random to systematic sampling, in temporary or permanent plots. The plots always represented a subset of a wood-pasture, often placed subjectively in the center of a wood-pasture or in an area of representative tree cover (Table 1). To account for variable plot sizes, a standardized trees-per-ha density variable was developed for each wood-pasture. In addition, we calculated all structural variables (see later) per plot. Varying plot sizes were required to appropriately cover the different structural characteristics of a given wood-pasture. We caution that these inherent limitations to our post hoc comparison be kept in mind. Notwithstanding these limitations, our resulting dataset covered a wide sociogeographical range across Europe and, to the best of our knowledge, is the first of its kind that integrates quantitative data across multiple countries and datasets.

Tree Data

In each plot all trees that reached breast height were measured and identified. Because of the differences in sampling design, some of the

Please cite this article as: Roellig, M., et al., Post Hoc Assessment of Stand Structure Across European Wood-Pastures: Implications for Land Use Policy, Rangeland Ecology & Management (2018), https://doi.org/10.1016/j.rama.2018.04.004