

## Complex Rangeland Systems: Integrated Social-Ecological Approaches to Silvopastoralism

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### ABSTRACT

Crossing disciplinary boundaries, particularly between social and ecological sciences, challenges those seeking to contribute to solving complex and multidimensional environmental problems on rangelands. In this Special Issue we present a set of 13 papers that to varying degrees attempt to integrate, or bring together, diverse approaches across disciplines to understand silvopastoral systems. The papers are about rangelands in numerous countries and regions, including Spain, Estonia, Greece, Germany, Hungary, Italy, Portugal, Romania, the United States, Latin America, and Sweden. Silvopastoral systems provide ecosystem goods and services important to communities, cultures, and society. Management deliberately exploits the diversity fostered by rangeland systems that mix woody species with a well-developed herbaceous understory, offering a greater diversity of products, species, vegetation structural characteristics, and habitat components than either grassland or forest. Biodiversity often peaks at the intermediate levels of tree and shrub cover characteristic of silvopastoral systems. We introduce the papers grouped by four overarching topics: 1) typologies and scales, 2) social-ecological interactions, 3) integrated management, and 4) multiple knowledge systems. Unfortunately, silvopastoral systems often run afoul of ongoing intensification and simplification trends in agricultural production that reduce their economic and ecological resilience. Privately owned systems, the most common in this issue, are subject to the need for owner income. Finding ways to support the benefits of these systems for the public is difficult, as management traditions must be conserved as well as the land. We hope this issue illustrates the value of multifunctional systems and offers insights into how they work.

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### Introduction

Crossing disciplinary boundaries challenges those who would like to solve complex and multidimensional environmental problems on rangelands. This Special Issue attempts to integrate, or bring together, diverse approaches across disciplines and countries to understand silvopastoral systems. In particular, it aims to explore the added value of integrated social-ecological perspectives for the analysis and management of silvopastoral systems. Insisting on dialogue between social and ecological sciences, the contributions in this Special Issue largely draw on the concept of social-ecological systems. The studied settings are predominantly outside of the United States and include numerous countries and regions, including Spain, Estonia, Greece, Germany, Hungary, Italy, Portugal, Romania, Latin America, and Sweden, offering an opportunity to draw insights from diverse international experiences, and to potentially apply what has been learned in the research and management of rangelands abroad to those in the United States. Most

of the papers focus on silvopastoral systems, in which trees and grass, human needs and ecological outcomes, and traditional and current-day agriculture interact, creating many tradeoffs that must be navigated by the manager. Almost all the articles are about privately held land, woodlands created or manipulated to provide income and amenities for their owners. Ideally, however, these working landscapes offer more than “food and fiber,” they are rangelands that produce ecosystem services of considerable value to society. One of the reasons silvopastoral systems were chosen for this exploration of integrated social-ecological systems is because the outcomes of the relationships between people and the ecosystem are often blatantly obvious, writ large in the pattern, species composition, and ages of the trees. Here we introduce the concept of a silvopastoral system, confess to difficulties with translation and use of terms, discuss common themes that emerge in the issue, and introduce each contribution.

### Silvopastoral Systems

Silvopastoral systems are a form of agroforestry that include grazing by livestock as an important component of the agroecosystem. Agroforestry deliberately integrates woody vegetation (trees or shrubs) with

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**Figure 1.** Portuguese montado (Photograph courtesy of Lynn Huntsinger).

crop and/or animal production and benefits from the resulting ecological and economic interactions (Mosquera-Losada et al., 2009). Wood and livestock are the two main commodity products. Silvopastoral systems manage trees to maintain a developed understory providing livestock forage (Cubbage et al., 2012). A classic example, which features prominently in this Special Issue, is the dehesa and montado of the southwestern Iberian Peninsula (Bugalho et al., 2011; Campos et al., 2013) (Fig. 1). In this Mediterranean climate zone woodlands are managed with a well-spaced oak overstory producing multiple products and abundant mast, and an annual grassland understory is grazed by several kinds of livestock. But silvopastoral woodlands occur in multiple geographies around the world and can include everything from northern conifer woodlands to southern tropical savanna when managed for livestock production.

We hope our readers recognize the difficulties of translating across so many boundaries, and accept a necessarily diverse and possibly imprecise use of terms. In Europe, silvopastoral systems are now most commonly referred to as wood pastures (Bergmeier et al., 2010; Plieninger et al., 2015), perhaps because of their two main products, wood for fuel and wood products, and pasture for livestock. For practitioners in the United States, pasture suggests an improved site, often irrigated, with intensively managed livestock, at times referred to as “tame pasture.” Further confounding the definition, wood pastures are commonly part of what is called “farming” in Europe. Wood pastures are in fact not irrigated, grazing is extensive, and a major source of income is livestock products. As a result, in the United States they would be called ranches that use woodland or savanna rangelands. “Rangelands,” as defined in the United States, are not necessarily used for grazing but most simply are grasslands, woodlands, and savannas (Booker et al., 2013). Historically, the wooded rangelands of Europe have been more intensively managed than those in the United States. It is our contention that what is termed in Europe wood pasture could in the North American context be translated as grazed wooded (or hardwood) rangelands, grazed semi-open woodland rangelands, or woodland and savanna rangeland used for grazing. In each, herbaceous vegetation growing seminaturally is the fundamental resource of livestock production. Both in the Old World and the New supplemental feeding, mechanical interventions, and periodic use of tame and even irrigated pastures or stall feeding are common practices but are used to facilitate rather than replace extensive grazing on natural or naturalized vegetation.

And of the trees? They seldom produce high value timber, as this tends to be managed with forestry as the main economic activity.

Instead, they may produce firewood, charcoal, fruit, fodder, game, or mushrooms for the market. In Iberia, they may produce cork, a high-profit use, but harvested in cycles of many years (Croitoru, 2007). In the United States, the trees in pinyon-juniper woodlands produce valuable pinyon nuts and juniper berries used for gin. For all, the canopy layer influences the quality and quantity of herbaceous understory, and the dynamics of the understory influence water dynamics for the trees and the potential for tree regeneration and recruitment. Layered onto these natural processes are the impacts of people, livestock, and wildlife. In California’s oak woodland rangelands, ranchers believe that forage production and quality are enhanced by the right tree canopy for the location, generally around 50% cover, and they do not tend to thin oaks when cover is sparser (Huntsinger et al., 2010). In most of these systems, people are active managers and even creators of the ecosystem (Huntsinger and Oviedo, 2014). Even California’s hardwood rangelands, often believed to be “natural,” are increasingly understood to have been shaped by the management of indigenous Californians, settlers, and ranchers (Alagona et al., 2013). Silvopastoral systems can offer an opportunity to study the impacts of long-term management, because the results are reflected in the ages and distribution of the trees. This issue includes a variety of such systems, from the dehesa and montado of Spain and Portugal, to the hardwood rangelands of California, and to the ancient oak pastures of Romania (Fig. 2).

### Management

The geographical location of a silvopastoral system, together with management traditions and capacities, shape the configuration and the market and nonmarket goods that can be produced, including wildlife habitat, wood and livestock products, carbon sequestration, game, viewshed, and watershed. This form of “diversified farming” (Sayre et al., 2012) can make an agricultural operation more economically resilient, with some product flows prospering when others decline due to climatic or market factors. Due to their complex structure and traditional low intensity management, wood pastures are often recognized as a high nature value (HNV) farming systems in Europe (Plieninger and Bieling, 2013). This acknowledges that diverse traditional silvopastoral management practices create and maintain a landscape that provides a broad spectrum of ecosystem services important to owners, cultures, and society (Torralba et al., 2016; Torralba et al., 2018).

In Europe, the cultural resonance of wood pasture runs deep (Rotherham, 2007). California’s oaks are emblematic of the beautiful



**Figure 2.** Wood pasture with ancient oaks in southern Transylvania, Romania (Photograph courtesy of Tibor Hartel).

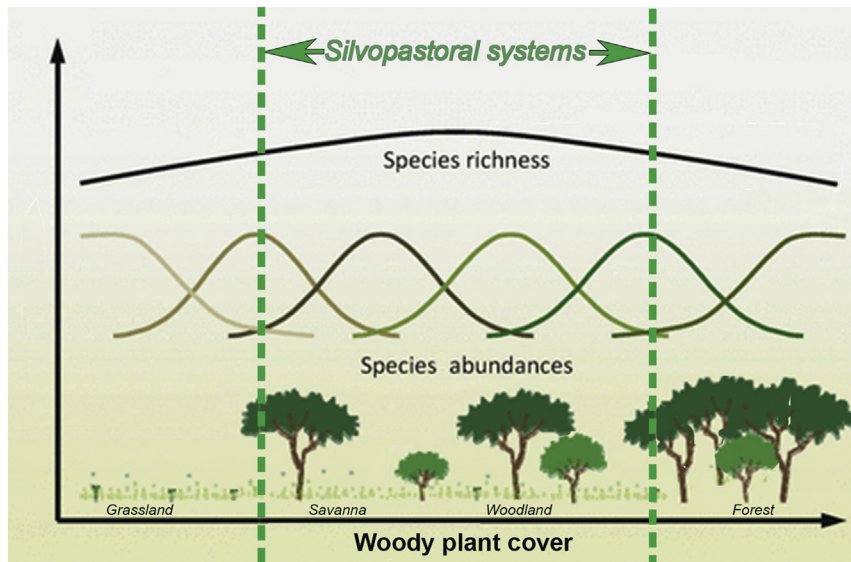
landscapes of the state (Fig. 3), and hardwood rangeland ecosystem services are widely recognized, but the role of management is less understood. For example, it is common for the public and conservationists

to call the unconverted woodlands of ranches surrounding urban areas “open space.” Some ranchers take offense because they think it implies nobody is stewarding this land—it makes ranchers, and their management practices, invisible (Huntsinger and Sayre, 2017). Similarly, the Native Californians who had such a powerful role shaping the woodlands over millennia using fire also are often invisible to the public and environmental scientists. However, exclusion of management activities in California, depending on the area, can have many of the same impacts of land abandonment in Europe, if over much longer time scales: increased cover of trees and shrubs and loss of grassland, and consequently, changes in wildlife habitat and fire risk.

Worldwide, silvopastoral systems share many common features and threats. Changing fire regimes, insufficient or excessive tree regeneration, wildlife population dynamics, climate change, changing hydrologic regimes, livestock production economics, land abandonment, agricultural intensification, and conversion to exurban residences are all part of the picture (Underwood et al., 2009). Unfortunately, a dependence on management can put a silvopastoral landscape under pressure when human goals and economies change (Manning et al., 2006). The traditional management practices that once created the open woodlands of Europe and North America are lost or on the wane, putting these systems at risk (Hartel and Plieninger, 2014). Their products are diverse but relatively sparse, and on sites suitable for cropping cannot compete with intensified monocultural agriculture in earning a cash income. Too often government policy aimed at increasing agricultural productivity leaves silvopastoral systems vulnerable, or conservation policy that excludes active management and use leads to vegetation change contrary to conservation objectives. In California, misguided state outreach programs for livestock producers in the first half of the 20th century encouraged the removal of oaks, which was thought to increase forage production. For Europe, wood pasture is often excluded from agricultural subsidies supporting tilled croplands and other types of farming. Even conservation legislation (e.g., the Habitats Directive of the European Union) can be unsupportive of wood pastures, scorning them as degraded forms of natural woodland habitats (Bergmeier et al., 2010). In California, there are no specific national policies for oak woodland protection, and, as another U.S. example, on federal lands in the Intermountain West pinyon juniper woodlands are sometimes subjected to efforts to completely remove the trees.



**Figure 3.** Oak woodlands in California's north central Sierra Nevada foothills (Photograph courtesy of Lynn Huntsinger).



**Figure 4.** Conceptual model of changes in species abundances and richness on rangelands with increasing cover of woody plants. Species richness is likely to be highest where both tree and grassland-associated species co-occur, with the endpoints varied, depending on geography and management (adapted from Archer et al., 2017). Silvopastoral systems are high diversity points on the gradient between forest and grassland, with the canopy managed to be open enough to support a well-developed understory.

#### *Taking Advantage of Physical and Ecological Diversity*

There are many woodland and savanna ecological interactions and synergies that are deliberately taken advantage of in managed silvopastoral systems. For example, in a drought, the woody species of a silvopastoral system access water deep in the soil profile and provide forage and mast for livestock. In fact, it has been proposed that in the dehesa and montado systems of Iberia, the spacing of trees reflects not only the need for a developed herbaceous understory, but a “hydrological equilibrium” where competition between tree roots for water is minimized (Joffre et al., 1999). A mix of woody and herbaceous species offers a greater diversity of species, vegetation structural and functional characteristics, and habitat components than either a grassland or a forest. From the perspective of vegetation structure, adding trees to a grassland system, or grassland to a woodland system, is transformative: grasslands or forests become shrub or tree savannas and woodlands.

These changes bring in new species that increase biodiversity directly. Subsequently, modification of soil properties, vegetation structure, and microclimate may facilitate establishment by other novel plant and animal species. Maximum diversity in silvopastoral configurations occurs often where woody and herbaceous plants are both well represented or where gains in new woody and herbaceous species outweigh losses of the initial grassland or forest-obligate species (Perevolotovskiy and Seligman, 1998; Hartel et al., 2013; Archer et al., 2017) (Fig. 4). If the system changes to either end of the tree cover gradient, diversity of plant and animal species is likely reduced (Fig. 5), so management focuses on keeping a mix that maintains a diverse ecological balance among species and a subsequent mix of ecosystem service flows.

An open woodland or savanna, especially with grazing as part of the system, has a further benefit of contemporary significance: adding woody species to a grassland increases carbon sequestration on a site (Nair et al., 2009). Because of the spacing of trees or shrubs, and the



**Figure 5.** Romanian ancient pasture invaded by hornbeam when active management ceased 30 to 50 years ago. The large old oak is more than 200 years old and was once part of a silvopastoral system. Abandonment has caused the woodland to undergo a state change to hornbeam forest and the old oak has died (Photograph courtesy of Tibor Hartel).

grazing of the understory, such systems can be relatively fire resistant (Mirazo-Ruiz, 2011).

### *Social-Ecological Systems Approaches*

Our topic of silvopastoral systems is broad and generously inclusive. One challenge is in the meaning of integration: What are we integrating here? Is it trees and grass? Social science and ecological science? Science and management? Human decisions and ecosystem function? “Yes,” is the answer to all. Our authors take different approaches for a variety of reasons. Their backgrounds and training, the composition of the team, the available data, and the methods possible in each place all shape the work that becomes a paper and part of this Special Issue. Many frame their work using the social-ecological systems model, a model that is sometimes challenged for placing too much emphasis on ecological concepts and neglecting the importance of justice, power dynamics, history, and social science in general (Hruska et al., 2017). Yet it is terribly attractive to those who want to cross disciplinary borders and at the least avoid neglecting social or ecological aspects of a problem that may ultimately hold the key to understanding the dynamics of the situation.

Overall, topics chosen by social scientists are only sometimes centered on an ecosystem type. More commonly they address a political or social system not directly linked to a particular ecosystem, but more to a particular social or political setting. The environmental boundaries that an ecologist might use to evaluate a silvopastoral system may not concern a social scientist. A social science study may evaluate governance or political systems that apply to a bewildering and extensive variety of ecological contexts, and while this may not pose a problem when studying social change or economic development, for an ecologist it may lack needed specifics about ecosystem components. Many of our authors have attempted to reconcile these often ill-matched systems and explore them as one integrated social-ecological system with the tools, expertise, and data available to them. As a result, these papers offer a spectrum of approaches, and we hope you appreciate the varying capacity for integration, and the various system aspects that are integrated (or not) by the researchers in this Special Issue.

### **Contributions**

This Special Issue was developed as a result of the first World Conference on Silvopastoral Systems that took place in Évora, Portugal in September 2016. The issue includes 13 papers offering perspectives from rangeland ecology and management, but also from social-ecological systems studies, woodland ecology, conservation biology, human geography, and political ecology. The studies mainly refer to Europe and North America, though one contribution (Soler et al. 2018) is from a South American perspective. Although the studies address diverse silvopastoral systems, spatial scales, social-ecological characteristics, and research questions, overarching topics can be identified: 1) typologies and scales, 2) social-ecological interactions, 3) integrated management, and 4) multiple knowledge systems.

### *Typologies and Scales*

Silvopastoral systems occur in many places around the globe. Understanding their distribution and ecological relationships can help with developing strategies for conservation and explaining their value. Landscape configuration, as well as vegetation structure and function on individual sites, must be understood for comprehensive management and policy strategies. Both papers that attempt such large-scale approaches are from Europe: Would the archetypes and classification parameters developed by the authors be generalizable to other continents as well?

Röllig et al. (2018) show the differences and similarities among such systems across Europe and identify threats for persistence in the future. Using a dataset of 13 693 trees from 390 plots in wood pastures from eight European countries (Estonia, Greece, Germany, Hungary, Italy,

Portugal, Romania, and Sweden), they classify wood pastures, revealing a gradient from dense wood pastures with high levels of regeneration (Estonia) to sparse wood pastures with large trees but a lack of regeneration (Romania), and develop a typology of five different types of wood pastures. In some locations, the trend to higher tree density was a threat to the biodiversity of the systems, and in others, a lack of recruitment of new trees into the canopy was a trajectory toward treeless grassland. Each requires different management approaches.

Hartel et al. (2018) characterize the social-ecological contexts of European silvopastoralism, developing four typologies for silvopastoral systems that include social and ecological components. The archetypes include landscape physiognomy, ecosystem services, and management-related synergies and trade-offs in ecosystem services supply. The socio-economic aspirations of the owner (oriented toward conventional or sustainable production) and the available financial capital for using management technologies in the woodlands are critical factors.

### *Social-Ecological Interactions*

The interaction between social and ecological systems is new territory for many researchers. As pointed out by Sherren and Darnhofer (2018), projects tend to emphasize one side or the other, depending on the interests, skills, and funding of the researchers (Hruska et al., 2017). Social science at times calls for a qualitative approach, while ecological research usually draws on quantitative methods. The spatial and temporal scale of each type of research often differs. Like the systems themselves, studying silvopastoral systems is complex and rich with possibility. Four papers are centered on different forms of interactions and integration: two integrate social and ecological research, while one is a work of ecological research (focusing on overstory–understory interactions), and two others come from a social science or humanities perspective (one centering on local social networks, another one on spatial interactions between remote places).

Torralba et al. (2018) take an integrative approach, examining the role of management in the coproduction of ecosystem services from the Spanish silvopastoral systems known as dehesa. They explore the relationship between biophysical and sociocultural factors and dehesa management practices. They identified four main social-ecological dehesa types as defined by their characteristics and management. In their study area, interactions between the studied system characteristics covary consistently, generating bundles of ecosystem services associated with intensity of management.

Surová et al. (2018) examine how Iberian silvopastoral systems contribute to society's well-being. An integrated social-ecological perspective is used to examine one case study in Portugal and one in Spain, assessing their contribution relative to other landscape types in the studied areas. Members of rural communities, public authorities, land managers, and researchers identify similar benefits and challenges in montado and dehesa, with numerous sociocultural and environmental benefits, but also at economic risk because of low income generation, and the authors call for policies that address socioeconomic issues hindering their potential contribution to human society well-being.

Tölgyesi et al. (2018) approach silvopastoral systems from an ecological perspective, surveying a wood pasture along a gradient from open pasture to forest edge. They find that the scattered trees and shrubs of the studied silvopastoral system have additive facilitative effects on their understory, probably through modifying the microenvironment and grazing pressure, leading to the formation of temporary diversity hot spots with distinct vegetation. Shrubs may also provide a refuge for seedling trees, and the authors suggest that some shrub encroachment should be allowed in Romanian silvopastoral systems.

Palomo-Campesino et al. (2018) reveal competing visions for the future of silvopastoralism and identify profitability, conservation, and modernization as the central themes that concern stakeholders. Overall, the linkages among stakeholders are characterized by high levels of cohesion and communication exchange, and a low level of conflict.

Starrs (2018) takes a geographical approach in his paper examining the role of stock driveways in the history of Spanish and US rangelands. He discusses them as relicts of previous regimes of land tenure and community that still form a valuable set of connections on the landscape. He argues that transhumance, sometimes carried out over long distances, generates sizable benefits to grazing animals, grazed lands, herders, and the larger society, by keeping corridors open for wildlife and for still-developing uses. Stock driveways are often held dear by neighbors whose folklore and daily life cherishes the change of pace involved in seasonal movement between the varied ecotones offered by lowlands and uplands. In the American West, where transhumance, if still practiced, often relies on near-distance movement or shipping by truck, the use of public land stock driveways was largely abandoned 40 years ago, foregoing sizable benefits.

### Integrated Management

Silvopastoral systems require multidisciplinary, integrated management: as the name implies, livestock, trees, and the herbaceous understory are managed, but with distinct practices and science for each realm. Neither fish nor fowl, silvopastoral systems can fall through the cracks when it comes to conservation policy and common management imperatives, because they are neither grasslands nor forests, and management is complex, entwined with cultural values, and does not seek to maximize either forage or tree production, but rather a synergistic mix of products. By their very nature, silvopastoral systems resist a single product focus, including managing solely for carbon sequestration. Their value is diversity, at multiple levels, and that brings conflict with an economic imperative that stresses intensification and homogenization—how can these systems be conserved despite these trends?

Approaching an ecological problem with social science techniques, Shapero et al. (2018) examine a perhaps universal problem on rangelands, invasive species, and show that the social dimensions of the problem can have a powerful influence on conservation initiatives. They find that the three main types of landowners in the hardwood woodlands and grasslands of Mediterranean California, ranchers, land trusts, and public agencies, have differing views of what constitutes an invasive or pest species, and of how urgently those should be managed.

Pinto-Correia et al. (2018) examine how changes in management threaten the biodiversity of Portuguese silvopastoral systems known as *montado*. Trends in agricultural production drive simplification of these oak and annual grassland rangelands, reducing multifunctionality. The authors conduct an integrated analysis of the relationship between grazing intensity and biodiversity in *montados* of similar biophysical and structural characteristics, combining ecological surveys with manager interviews.

Although not focusing on silvopastoral systems specifically, Wilmer et al. (2018b) study management strategies and decision-making of ranchers in eastern Colorado and Wyoming, combining interviews and ecological monitoring. Having long term goals, flexibility, and learning to adapt are important themes in management, with ranchers able to change grazing strategies more rapidly than stocking rates. The authors discuss conceptual frameworks for decision-making on ranches that are relevant to all rangelands, including silvopastoral systems. They suggest an adaptive decision-making framework for rangeland social-ecological systems that is able to integrate cross-scale interactions between ranch-scale decision-making and broader social, economic, and political dynamics.

### Multiple Knowledge Systems

The management of complex systems is widely believed to benefit from the use of diverse sources of knowledge. Our view is that learning how silvopastoral systems work and developing effective conservation programs and policies must draw on traditional and scientific knowledge, ecological and social science, and local and landscape information

(Tengö et al., 2014). Often the gathering of this information, and identifying realistic solutions, is best done with the participation of stakeholders as well as scientists. Integrating the experiential knowledge of managers and the scientific information garnered by researchers can be difficult, especially where the norm is constant adaptation to external forces and internal change. Research teams with representation from both types of knowledge systems are typically best suited to approach the task. This is not the same as the huge research-team approach so common with government-supported research in the 1990s and onward, where each member of a team produces a separate—but disconnected—contribution, and there is no effective integration of research conclusions into a practical, applied, and coherent form.

Sherren and Darnhofer (2018) point to an important paradox: integrating social and ecological approaches is often believed important to sustainable management of natural resources. However, their analysis of the content of three problem-based journals shows that—if social sciences are included at all—they are typically subservient to natural sciences, and it is quantitative approaches that are generally privileged.

Soler et al. (2018) present a sweeping review and analysis of knowledge production for South American silvopastoralism that examines how different sociopolitical factors such as sources of funding, institutional priorities, and international cooperation can bias the direction and objectives of scientific research. Who funds studies and who is involved can have a profound effect on the focus of the research conducted and the forms of knowledge included.

Wilmer et al. (2018b) write about science-management partnerships on the western Great Plains, where management objectives for livestock production, grassland bird conservation, and vegetation structure and composition converge (Fig. 6). Based on a 10-year collaborative management experiment initiated in 2012 to foster science-management partnerships using a participatory, multistakeholder approach, they evaluate a decision-making process that emerged after 4 years. This study reveals that drawing on multiple knowledge systems requires the development of trust-based relationships and understanding of the different perspectives and backgrounds of knowledge contributors.

### Conclusions

Silvopastoral systems exploit the variety fostered by mixes of woody species with a well-developed herbaceous understory, offering a greater diversity of species, vegetation structural characteristics, and habitat components than either a grassland or a forest. Livestock and trees are both units of production but also management tools used to shape the system, and many have been managed together for centuries. Unfortunately, silvopastoral systems often run afoul of intensification and simplification



**Figure 6.** A horned lark (*Eremophila alpestris*) perched on a fence in The Pawnee National Grasslands of the western Great Plains of the United States. This ground-nesting grassland bird is one of several in need of conservation in the region (Photograph courtesy of Nicole Kaplan).

trends in production. Privately owned systems, the most common in this issue, are subject to the need for owner income, and finding ways to support the benefits of these systems for the public is made more difficult because management as well as land must be conserved (Fig. 5). They are true “working landscapes”—a term coined in the United States to describe systems that coproduce widely valued commodities and ecosystem services. Their multifunctional character should not be neglected in policy, conservation, or environmental initiatives, and this requires careful consideration of tradeoffs and interactions between ecosystem and social system components. For example, increasing carbon sequestration is a worthy and attractive goal, but shifting to single purpose management for carbon may lead to tradeoffs with other benefits in ways costly in ecological, financial, or social terms. We hope this issue shows the value of multifunctional systems and offers insights into how they work. In a silvopastoral system we find an echo of Johan Rockström’s (2015) words: “The value of biodiversity is that it makes our ecosystems more resilient, which is a prerequisite for stable societies; its wanton destruction is akin to setting fire to our lifeboat.”

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