Local Ecological Knowledge and the Sustainable Co-Management of Sierra Nevada's Social-Ecological System

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Abstract

Local ecological knowledge systems have been the basis of Sierra Nevada's social-ecological system, which has co-evolved over more than ten centuries until nowadays, based on the knowledge, practices, and innovations deriving from the relationship between people and the ecosystems on which they depend. In Sierra Nevada, this co-evolution is greatly influenced by the traditional water management system, generating a "cultural landscape." However, during the twentieth-century Sierra Nevada's social-ecological system was affected by diverse drivers of change such as climate change, rural exodus, land-use change, and conservation government policies, which are threatening its stability and the transmission of the related local ecological knowledge. Local ecological knowledge on water management, traditional agricultural systems, and knowledge related to grazing and cattle raising should be included in the co-management of the territory and representatives of this knowledge should be involved and collaborate with administration and researchers developing adaptive plants to reduce negative impacts of global change.

Keywords

Adaptive co-management • Drivers of change • Global environmental change • Social-ecological system • Traditional water management

1 The Contribution of Local Knowledge Systems to the Sustainable Co-Management of Social-Ecological Systems

During the last decades, researchers and natural resource managers have increasingly been using local knowledge and involving Indigenous Peoples and Local Communities (IPLC) in monitoring, conservation, and ecosystems' restoration efforts (Reyes-García et al. 2021). Overall, including local knowledge and promoting stakeholders' participation has resulted in better outcomes and acceptance of conservation action than when conservation is imposed by external agents. Moreover, such efforts have also had positive outcomes in the livelihood of local communities, thus being a very successful practice (Danielsen et al. 2007; Reed et al. 2016). In this line, in some research fields—such as biodiversity and ecosystem services conservation or ecosystems assessment (McElwee et al. 2020)—there have been efforts to generate new knowledge based on insights that come from different knowledge systems, i.e., science and local ecological knowledge. In fact, some global efforts, such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), have adopted participatory mechanisms and institutional arrangements for including IPLC and their views in the assessment (Hill et al. 2020). Overall, this trend recognizes the value of local knowledge systems for sustainable

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ecosystem management. A similar approach is gaining ground in other research topics, such as climate change research (Díaz et al. 2019; Reyes-García et al. 2019b)

We use the term "local ecological knowledge" (LEK) to refer to the worldviews, knowledge, practices, and innovations deriving from the relationship between people and nature (Berkes 2017). Other authors have used different terms to refer to these knowledge systems, like traditional ecological knowledge (TEK) (Johannes 1993; Berkes 2018), indigenous knowledge (IK) (Bicker et al. 2003; Ellen 2007), or indigenous and local knowledge (ILK) (Thaman et al. 2013), depending on the studied communities and contexts. The term captures knowledge about the natural world, techniques and technologies of resource management, local institutions governing social relations and relationships to nature, and ethical or spiritual values. LEK is situated in social-ecological contexts and is continuously evolving through the combination of written, oral, tacit, practical, and scientific knowledge obtained from various sources and validated by experimentation and direct interaction with nature (Hill et al. 2020). The application of LEK has resulted in the maintenance of the ecological integrity of many aquatic and terrestrial ecosystems (Cámara-Leret et al. 2019). Indeed, it is argued that the diversity and sophistication of LEK systems have been essential to manage the health of local and regional ecosystems and are now essential to confront societal pressures and environmental burdens (Lyver et al. 2019; Reyes-García et al. 2021).

One of the pathways through which LEK contributes to sustainable resource management is through customary governance and management practices based on formal and informal institutional and social arrangements that create and maintain biodiversity (Lepofsky 2009). Many examples exist showing that ILK-based environmental management (e.g., traditional agriculture, aquaculture, fishery, and community forestry) contribute to biodiversity maintenance in production landscapes (Aumeeruddy-Thomas et al. 2017; Zimmerer and de Haan 2019), ecosystem restoration (Reyes-García et al. 2019a), pollution buffering (Fernández-Llamazares et al. 2020), and nutrient cycling, among other positive environmental benefits. Examples of these practices include resource use agreements and collective rules governing common-pool natural resources, such as forests or waters (Ostrom 1990; Berkes 2018). Other examples of these management practices include religious beliefs and caring for intangible elements inhabiting nature and embodied in sacred forests, landscapes, lakes, springs rivers or marine areas (Berkes 2018), taboos overuse and conservation of specific species (Rafidison et al. 2020), harvesting restrictions based on spatial or temporal considerations, or selective harvesting and grazing, often to deliberately create small-scale disturbances to increase landscape heterogeneity and overall biodiversity (Bird 2015; Molnár et al. 2020). As a result of the application of management systems based on LEK, much of today's world's wild and domesticated biodiversity lies in areas traditionally owned, managed, used, and/or occupied by IPLC (Brondizio and Le Tourneau 2016). In Europe, some of these managed ecosystems are local "hotspots" of native biodiversity, including mountain hay meadows in central Europe (Babai and Molnár 2014), *dehesa* oak and cereal tree savannahs in southern Spain (Acha and Newing 2015), temperate deciduous forest in northern Spain (Guadilla-Sáez et al. 2019), or high mountain meadows (*borreguiles*) in Sierra Nevada (Blanca et al. 2001).

Beyond biodiversity-rich landscapes, management practices based on the co-evolution of natural and social systems have also resulted in complex social-ecological systems or "bio-geo-physical" units with associated social actors and institutions (Ostrom 2009). In such complex and interrelated systems, changes in the social component of the system affect the ecological component, and vice versa. Thus, changes in customary management practices can result in degradation and resource depletion, especially when local norms face the pressure of commodity and extractive industries, demands from international or urban markets for local products, and coaptation from individuals and firms pursuing resource extraction (Natcher and Brunet 2020). This is particularly the case in industrialized countries, where global dynamics, including loss of traditional livelihoods (Biró et al. 2014), landscape homogenization, new technology, or administrative regulations affect traditional biodiversity management practices (Gómez-Baggethun et al. 2013; Hernández-Morcillo et al. 2014).

In this chapter, we use the perspective of the social-ecological system to analyze the contribution of LEK to ecosystem management in Sierra Nevada. Sierra Nevada is characterized by the historical co-evolution of local communities and ecosystems, resulting in a complex social-ecological system. In that sense, Sierra Nevada can be considered a "cultural landscape" or a singular space resulting from a long and intimate relationship between peoples and their natural environment and where LEK could play a fundamental role in the future of the region, being the nexus between social and natural systems. Our chapter draws both on the literature on LEK, traditional livelihood practices, environmental research conducted on Sierra Nevada, and on our own data and personal observations while working in the area. We note that Sierra Nevada is an extensive mountain region with more than 2000 km^2 and more than 60 villages. This means that there may be variations in the environmental and social conditions, resulting in variations in the knowledge developed in different areas. Despite these differences, in this chapter, we consider Sierra Nevada as a unique social-ecological system. The chapter starts by exploring the historical roots of local ecosystem

management, then moves to describe the most important drivers affecting Sierra Nevada's social-ecological system and local knowledge, and ends addressing the current and the possible future contributions of LEK to Sierra Nevada management and conservation.

2 Understanding the Historical Roots of Sierra Nevada's Social-Ecological System: Water Management as a Landscape Architect

As in other Mediterranean ecosystems (Blondel 2006), one of the most important pathways through which humans have impacted Sierra Nevada's social-ecological system has been through water management. In chapter "Singular Cultural Landscapes of the Sierra Nevada", Civantos and colleagues describe how, for centuries, human interventions have modified Sierra Nevada through the development of diverse water infrastructures like *acequias de careo*, *partidores*, *aliviaderos*, and *cimbras, minas or qanats*, to channel, guide, and harvest water running down the slopes of the mountain (Fig. 1). This complex water management system has sculpted unique cultural landscape structures around water management. Local water management systems made possible the permanent occupation of the territory because water distribution allowed the development of agriculture and livestock maintenance (Martos-Rosillo et al. 2019). Water distribution through local management systems also contributed to Sierra Nevada's singular biodiversity, as water management helps regulate the impact of the hydrological cycle in the ecosystem through the recharge of aquifers (Pulido-Bosch and Sbih 1995; Martos-Rosillo et al. 2019). Water management allows the establishment of a variety of habitats that, otherwise, would have not existed, such as chestnut clusters along high mountain acequias. The green cover that grows along the water channels also helps retain soil and prevents erosion and water filtrations feed water sources for animal and human uses (Jódar et al. 2017; Martos Rosillo et al. 2018). In the words of an *acequiero* (person in each irrigation community in charge of controlling, managing, and distributing water through the acequias) of one of the irrigation communities in Órgiva:

> *Sierra Nevada is a sponge that catches the water up high, in the upper parts in winter and spring, to prevent it from going quickly to the sea. It then releases it, little by little, in the lower areas, with water infiltrating and re-emerging on several occasions, thus giving life for several months, especially in summer, to the areas where it passes.*

Beyond their economic and ecological importance, traditional water management and harvesting techniques have also been crucial for structuring Sierra Nevada's social system (Guzmán Álvarez et al. 2010). Like other societies which have developed complex irrigation systems, in Sierra Nevada, local knowledge on water management is considered part of the local identity and cultural heritage. Moreover, water management rules determine social interactions (Fernald et al. 2015). Water in Sierra Nevada is managed through a complex system organized around irrigation communities formed by the owners of irrigated lands which have centuries of family history in common (Espinar Moreno 1989). The irrigation communities of the Sierra Nevada villages have been the basis of the structure of their social organization until a few decades ago, since irrigation communities determined the amount of water that corresponded to each member, which is directly related to the irrigated land surface of each member, and therefore largely determined a family's yield and earnings. Many irrigation communities were formally established during the twentieth century, although their existence is intrinsically linked to the creation of water infrastructures (Cressier 1995), and there are references to some irrigation communities dating back to the thirteenth century, which indicates the long-term importance of this social structure (Espinar Moreno 1989).

To manage water, irrigation communities engage in collective action, including a multiplicity of activities that involve social interactions as much as interactions with the environment, such as cleaning, maintaining, and restoring water channels (Fig. 1b). All these interactions raise conflicts related to irrigation water and the consequent emergence of rules for water distribution (Gálvez-García 2015). These rules, refined over time, are usually very precise and consider both biophysical factors (e.g., water evapotranspiration at different times of the year, or the time that takes the water to arrive from one plot to the next one, which is related to the characteristics of the soil of each portion of terrain), and social factors (e.g., watering order and weekly need of water of each community member), to have an equitable distribution of water. These rules also regulate the possibility to lend, borrow, exchange, or even sell water between members (Guzmán Álvarez 2010b).

Overall, local knowledge on water management has allowed the intense modification of the landscape, contributing to creating a particular social-ecological system that proved to be extremely resilient over centuries (Cressier 1995). Water management allowed the development of agricultural and livestock activities in the area, which together formed a biodiversity-rich productive landscape. Traditional agricultural practices, based on heterogeneous plots of crops for self-consumption and the use of agricultural plots at different altitudes to cultivate a larger variety of crops, together with traditional grazing practices and trasterminancia movement of extensive cattle ranching

Fig. 1 **a** *Acequia de careo* without water to carry out repair works. **b** Members of Bérchules' irrigation community cleaning an *acequia de careo*. **c** *Aliviadero* on the side. **d** *Aliviadero* overflow and flow limiter. **e** *Partidor* of *acequia de careo* of the Poqueira ravine. **f** Water catchment for an *acequia de careo*. **g** *Acequia de careo* of Bérchules

favoring the dispersion of seeds, played a fundamental role in the high levels of Sierra Nevada's biodiversity (Martin Civantos 2011; Ramos Font et al. 2015; Martos Rosillo et al. 2018). Having to conduct repair and maintenance activities in the entire network of *acequias*, from the top of the mountain to the middle and bottom of the valleys, where communities are located, has made local communities excellent sentinels of their territory. Local inhabitants in Sierra Nevada are able to quickly identify changes in the system and react to them, thus maintaining operational multifunctional cultural landscapes (Vahí Serrano and Prados Velasco 2011). Thus, through social interactions oriented to operationalize management rules to successfully maintain water infrastructures, irrigation communities have also contributed to maintaining the social structure, as well as favored the transmission of local knowledge on water management (Ruiz-Ballesteros and Gálvez-García 2014).

3 The Twentieth and Twenty-First Centuries: Big Transformations Driving Social-Ecological System Decay and LEK Erosion

Since the mid-twentieth century, major transformations have led to a complete reconfiguration of Sierra Nevada territory and social-ecological system. Important drivers of change affecting Sierra Nevada in the twentieth century include technological and social change driven by market pressures, population dynamics, government policies, and climate change. These changes have led to the overall reconfiguration of the social-ecological system, resulting in the loss of wild and cultivated biodiversity, but also deterioration and abandonment of traditional water management systems, with an overall impact on Sierra Nevada ecosystems (Zamora et al. 2016) and the erosion of local knowledge systems (Iniesta-Arandia et al. 2014).

A major driver of change in Sierra Nevada's social-ecological system has been ***technological and social changes driven by market pressures***. After the Spanish Civil War (1936–39), inequalities in access to land intensified in the region, driving peasants to self-exploitation (Soto Fernández et al. 2007). According to oral testimonies, in La Taha, for example, the rent paid for the land was frequently two-thirds of the harvest, sometimes even three-fourths. Thus, post-war times were very hard in this region, with most families conducting subsistence activities, often being plunged into poverty. In this scenario, the local economic system relied more on the exchange of products and work than on money circulation. For example, during fieldwork, local people told us about the "*tornapeón*," a type of community work, through which peasants helped each other by alternatively working on the fields that needed more work (Gálvez-García 2015). The opening of the Spanish economy to international markets in the 1960s gave way to a more market-oriented economy. The modernization of agriculture made traditional mountain agricultural systems non-profitable economically, as the mechanization of agricultural processes in mountain areas, where small plots with difficult access predominate, is costly or not possible (Fig. 2).

While the drift of farmers toward commercial agriculture, based on the logic of the optimization of economic benefits and cost reduction, has not been unilateral in Sierra Nevada, it has gradually gained terrain over the years, with peasants adopting the new agricultural practices and technologies required for the production standards of agro-food industries and discontinuing the practice of traditional activities (Fig. 3a). As in many areas of the world (Martin et al. 2019; Labeyrie et al. 2021), the shift from traditional livelihoods has resulted in the abandonment of local livestock breeds, and many traditional landraces better adapted to local conditions, particularly rainfed crops grown in high mountain areas such as varieties of legumes, cereals, and potatoes. In some cases, local varieties have been substituted by varieties with a market value, but most often, the cultivation of such crops has been abandoned altogether, as farmers in the low areas have shifted to the monoculture of almond and olives trees, crops that required low workforce. Nowadays, local landraces such as green beans *martillosa, agostiza* or *colorá*, remain only in the memory of the elders. Only in some areas, a few varieties are kept for domestic use. These include *uva de barco,* a grape variety that was highly valued at the beginning of the twentieth century, becoming listed on Wall Street (Alonso et al. 2006), which still can be found in small familiar plots in Ohanes and other villages around, *patatas de la sierra* (Fig. 3b), a potato landrace typical in villages whose territory includes the highest areas of the mountain like Güejar Sierra, Monachil, Jérez del Marquesado, or Capilleira and Trevelez in the Alpujarras area, *frigüelos* (beans) from the Alpujarras, local varieties of tomatoes, or lettuce *pico de pájaro*. Similarly, the *pajuna,* a local cow breed, declined dramatically, and currently only a few ranchers have this breed, although efforts are underway to recover it (Horcada-Ibáñez et al. 2016).

Other activities traditionally conducted by people living in Sierra Nevada have also been replaced or abandoned by the adoption of new technologies, further contributing to eroding local knowledge systems. For example, vegetable fibers traditionally used to craft agricultural accessories, such as esparto grass, wicker, or straw, are not used anymore as they have been substituted by plastic fibers (Fig. 3d). Similarly, the extraction of essential oils, like thyme, has also been abandoned, and handmade wool looms have disappeared. In some cases, this has caused the decrease of abundance of some of these vegetal species which in turn are

Fig. 2 Terraced slopes divided into small cultivation plots

important nurse plants for other species (Padilla and Pugnaire 2006). In other cases, the abandonment of the practices has resulted in other environmental impacts, such as shepherds throwing wool in the forest, due to its lack of economic value (Personal observation).

A second driver of change in Sierra Nevada's social-ecological system is ***population dynamic***s linked to technological changes occurring in the primary sector. In areas like Sierra Nevada, the disarticulation of traditional economic activities and a loss of competitiveness in the global markets has resulted in an intense rural exodus and the masculinization of agriculture (Rodríguez Martínez 2001). During the second mid of the twentieth century many people moved away from rural areas in general, and mountain areas in particular, where their work was neither recognized nor valued. There was also a change in people's social expectations, particularly among young people, who saw new economic possibilities in cities. All in all, and except for some municipalities near the city of Granada such as Gójar, Monachil, La Zubia, Dúrcal, and Padul, from the second half of the twentieth century, the municipalities of Sierra Nevada have experienced a population decrease (Prados Velasco and Valle Ramos 2010). Overall, the population in the area went from more than 133,000 inhabitants in 1940 to less than 87,000 in 2000, the population also experiencing an important aging process (Fig. 3 e). These population dynamics have greatly affected LEK systems, as LEK transmission channels broke with the young generations moving to cities.

It should be noted that, despite the general trend of population decrease, nowadays, some areas of the Alpujarras, the Marquesado del Zenete, or the Andaráx Valley show a population growth due to the arrival of the new population (Prados Velasco and Valle Ramos 2010). However, this new migration process does not necessarily reinforce the conservation and maintenance of the LEK, since the new inhabitants do not share the same worldview as local populations. In some areas (like Andarax Valley), the newly arrived population has imported intensive agricultural techniques, thus further contributing to the erosion of LEK systems.

A third driver of change affecting Sierra Nevada social-ecological system and associated LEK refers to ***government policies*** that have largely contributed to the transformation of the territory through land-use change, but which have also impacted LEK use and transmission.

Fig. 3 **a** Shepherd milking in a traditional way, **b** Farmer with *patatas de la sierra*, **c** Shepherd with his flock, **d** Traditional braiding with esparto, **e** Old farmer using a traditional tool

Government policies affecting land use include the increase of forest extension resulting from *pinus* reforestations campaigns and the reduction of agro-pastoral activities associated with the creation first of the Natural Park (1989) and then of the National Park (1999). In the 1950's, when the area was still suffering the effects of the Spanish Civil War and experiencing a high migration rate, the state bought large extensions of land to councils and private owners to implement reforestation plans with the goals to reduce soil erosion and produce wood. Since 1956, government reforestation plans have resulted in a change in the vegetation cover in 42% of the territory of Sierra Nevada (Zamora et al. 2016). Decades later, other government policies, i.e., the declaration of Natural Park (1989) and National park (1999), generated additional changes by modifying and restricting the local population's access to several areas and resources

(Mena et al. 2014). Restricted activities included the collection of aromatic and medicinal plants, grazing in the areas of high peaks, as well as hunting of wild game species. These restrictions have affected the transmission of LEK related to such resources. For example, before such restrictions, it was common that families to have two residences, one in the village, which they occupied during the winter, and another in the high mountain area, sometimes a simple cabin, which they occupied during the summer months to take advantage of the pastures for cattle and agriculture of high mountain crops. The restriction of cultivating and grazing in high mountain areas, together with the changes in the professional interests of the new generations, has caused farmers, herders, and ranchers to change their habits and ways of working, including sharing tasks that facilitate knowledge transmission (Personal communication from local elders). Thus, families have ceased to cultivate in the high areas far from the nuclei of the villages, and groups of herders have ceased to share long periods of time in high mountain areas. Nowadays, lonely shepherds carry out daily grazing trips around the village (Fig. 3c) or leave the cattle to graze alone in the areas of high peaks, visiting it weekly or fortnightly.

Government policies also affect LEK through policies that put LEK-based traditional resource management systems in an administrative limbo. On one hand, legislation oriented to impose certain commercial standards in products has made it almost impossible to maintain a livelihood based on traditional practices. For example, the certification of seeds, the commercial preferences of crops and landraces that large trading companies buy, and the reduction in production prices due to agricultural and livestock technification, threaten the continuity of small producers who maintain traditional practices and associated knowledge.

On the other side, the multiplicity of rules imposed by different branches of the administration puts farmers between a rock and a hard place. Traditional resource management systems typically have a multifunctional nature (i.e., they provide multiple socioeconomic and environmental benefits), which hinders their classification in compartmentalized administrations. For example, irrigation communities are under the jurisdiction of the Andalusian Environment and Water Agency, which is part of the Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development. This Ministry has historically been oriented to modern and intensive agriculture, deploying plans for the technification of irrigation. But a good extension of the area in Sierra Nevada has been declared as a National Park, thus falling under the National Parks Autonomous Agency, which has an environmental focus. The implementation of policies from the two agencies translates into local communities receiving subsidies for opposite purposes. Thus, in recent years, the National Park has invested a large proportion of its budget in repairs of different stretches of the traditional irrigation system. At the same time, the Regional Ministry of Agriculture Livestock, Fisheries, and Sustainable Development offered financial aid to irrigation communities of Sierra Nevada to modernize agricultural areas by implementing drip irrigation systems. Traditional water management infrastructures and drip irrigation systems encapsulate opposing mindsets about water management: one is configured to redistribute water in a system where water is not an exclusively human good and the other is used with a purely instrumentalist mindset trying to maximize the benefits of a scarce resource. Such contradictory policies affect the social-ecological networks where irrigation systems are embedded and, as a consequence, irrigation communities become weak and fragmented, some of them being absorbed by local and regional governments losing part of their agency (Ruiz-Ballesteros and Gálvez-García 2014). The loss of norms and local institutions for self-governance, like irrigation communities, diminishes the local capacity of response against global challenges such as water scarcity, biodiversity loss, fires, or plagues, and reduces the local capacity for collective action.

Another driver of change in the Sierra Nevada's social-ecological system has been ***climate change***, which is affecting mountain regions with great intensity around the world (Zamora et al. 2017). In the Mediterranean region, the increase of the minimum and maximum temperatures and reduction of the amount of rainfall and snowfalls are reducing water availability, impacting ecosystems in multiple ways, and affecting negatively traditional livelihoods (Jiménez Olivencia 2010; Morales et al. 2019; Ruiz-Morales et al. 2020). Recent research in Sierra Nevada shows that local populations are aware of a great diversity of climate change impacts affecting the region, showing differences between the different geographical zones of Sierra Nevada. Climate change impacts related to temperatures, precipitation and droughts, rivers' flow, snow cover and snowfields, the abundance of wild fauna and crop's diseases and pests were the most frequently perceived, although the perception of impacts changes according to geographical zones and informants' characteristics (García-del-Amo et al. 2021). Moreover, Sierra Nevada inhabitants perceive climate change as the main driver of change acting in the region, particularly affecting their socioeconomic system through its cascading effects from the climatic, physical, and biological systems. For example, local inhabitants argue that changes in water availability, changes in pasture and crop productivity, and changes in crop diseases and pests have a high repercussion on Sierra Nevada's resilience. In addition, part of this LEK has had no time to adapt to the new uncertain context. For instance, making predictions about weather or water availability becomes much more difficult for peasants and herders.

Changes in the social-ecological system have made reliance on LEK less necessary for daily survival, affecting the *social recognition* of this knowledge system by local communities, including knowledge holders themselves. LEK is, by definition, a dynamic knowledge system that needs shared action contexts to stay alive (Berkes 2018), for which the lack of practical use has hampered LEK intergenerational transmission and renovation. In Sierra Nevada, the interruption of LEK transmission is often promoted by LEK knowledge holders who argue that they have worked hard "to give a better future to their children," offering them the possibility to study and engage in economic activities in the industry or service sectors (Guzmán Álvarez 2010a). These changes in values have also impacted the local identity and the prestige and consideration given to specific activities. For example, herders, who were traditionally considered important LEK-holders, have lost their social recognition in comparison to the "entrepreneurs"' of stabled cattle farms. A paradigmatic example can be found in the "*cabañuelas*," a traditional local weather predictions system. In some villages of Sierra Nevada, people who performed *cabañuelas* went from being one of the most respected and admired figures in the community to being socially downplayed, as the practice lost its social recognition and was considered outdated.

Altogether, the drivers of change described above threaten the continuity of the social-ecological system and the transmission of associated LEK, making the twenty-first-century scenario profoundly challenging for mountain communities.

4 LEK Role in Preserving the Current Social-Ecological System of Sierra Nevada

Despite the many changes described above, LEK systems continue to play a role in preserving Sierra Nevada's social-ecological system. In this section, we examine how LEK continues contributing to the preservation of the Sierra Nevada's social-ecological system through traditional water management, agriculture, and extensive cattle raising.

Local knowledge on water management is essential for the proper functioning of Sierra Nevada's social-ecological system. As mentioned, the network of traditional water infrastructure favors aquifer recharge and helps conserve soil's phreatic level (Jódar et al. 2017; Martos-Rosillo et al. 2019) providing water for agriculture and human consumption for the local communities located on the slopes of the mountain. But water infrastructures are not operational without the associated local knowledge and enough members to maintain them. Water management is also at the basis of the local fabric and, even today, local knowledge on water management continues to help solve water-related conflicts between different social actors (peasants, herders, local population, and touristic properties) particularly during periods of water scarcity. Irrigation communities can predict the availability of water during the dry season, and measure and distribute water most fairly and efficiently. In addition, their practices and norms are flexible enough to allow the adaptation to unexpected events. For example, during the drought of 2012, the irrigation community of *La Taha*, in the High Alpujarra, managed water scarcity modifying the established irrigation turns, but also introducing temporary changes in the distribution between villages to take advantage of the available water (Gálvez-García 2015). Moreover, in several communities in Sierra Nevada, irrigation communities still have many active members and can create social pressure in defence of rights. This was seen, for example, when the regional administration announced a plan to transfer the water from Trevélez River to the coast for touristic and agricultural uses. The opposition of irrigation communities of Trevélez, Busquístar, Pórtugos, and La Taha, supported by local herders and neighbors' associations put a halt to the government plan. On the contrary, the lack of active irrigation communities in some villages of Sierra Nevada has generated important social conflicts. In those villages, the high percentage of abandoned fields and the reduced number of peasants have resulted in the appropriation of the local irrigation system by the local administration, which always prioritizes human consumption, particularly during the dry summer months (Personal observation in La Taha and Ohanes). This decision goes to the detriment of farmers, who maintain the water management system throughout the year, but are not entitled to manage water in the most critical period of the agricultural cycle.

The maintenance of ***traditional agricultural systems***, and particularly local landraces and associated knowledge, contributes to preserving the resilience of the social-ecological systems against future threats (Martin et al. 2019; Labeyrie et al. 2021). Although agriculture is no longer the main economic engine of Sierra Nevada, it continues to play an important role in the maintenance of its social and ecological fabric, particularly subsistence agriculture (Fig. 4). Nowadays, local landraces are not usually found in commercial channels, but some small farmers still cultivate local varieties, preserving part of the agricultural genetic pool that existed in the region. In the testimonies, we have mentioned the bigger resistance of local varieties to pests, as the example of cherry trees or apple trees in the High Alpujarra. The altitudinal gradient of the area allowed to intercrop different varieties and types of crops, which have fewer pests than in lower areas. However, nowadays, due to climate change effects, agricultural seasons are longer, extending the cropping seasons. However, higher temperatures are

Fig. 4 Local farmers applying traditional irrigation techniques, *riego a manta*

allowing the survival of some pests even at high elevations, adding an extra difficulty to Sierra Nevada farmers.

LEK associated with ***grazing and extensive cattle raising*** also contributes to maintaining the stability of the social-ecological system of Sierra Nevada. Researchers have shown that the practice of grazing and extensive cattle raising favors the maintenance of high mountain pastures in Sierra Nevada, as well as the provision of the ecosystem services generated (Varela and Robles-Cruz 2016). Similarly, sustainable grazing pressure prevents soil erosion, maintaining its fertility, and controlling the biomass amount, acting as traditional wildfire prevention (Ruiz-Mirazo and Robles 2012; Varela et al. 2018). Traditional grazing practices have played a fundamental role in preserving the biodiversity of Sierra Nevada, favoring the dispersal of endozoochory seeds of high mountain pastures (Ramos Font et al. 2015), without negatively affecting endangered protected species (Robles et al. 2016). Moreover, the practice of grazing the Mediterranean scrub spp. is even beneficial for human health, as it improves the quality of goat milk (Gutiérrez-Peña et al. 2013). Currently, the number of shepherds and cattle in the area is much lower than it was several decades ago (Ruiz-Morales et al. 2020), which impacts the general configuration of the social-ecological system. Shepherds, during grazing practices, interact with different elements of the ecosystems, contributing to the preservation of the multifunctionality of heterogeneous cultural landscapes (Mena et al. 2014). Like traditional water management, grazing practices rely on LEK and the close and continuous relationship of shepherds with the different elements of the ecosystems. For example, shepherds know which natural springs have water in the different seasons; they also know the order in which livestock should be taken to the different pastures, so the feeder lasts longer; the date and the area in which the different pastures are available; the wild species with high nutritional value like *mierga, albejana, jaramargo, trigillos, or ballicos*; the toxic species in the region, like the *gayomba*; the plant species that have veterinary properties but that can harm animals when eaten in excess, like the *ajedrea* or clovers, or even the wild edible plants they can consume when traveling like *hinojos, collejas*, mushrooms species, and wild berries. As with agricultural varieties, there are still people who have local livestock breeds such as the *pajuna* cow, which is adapted to the scarce local resources, and better support the inclemency of the extreme climates of the region (Ruiz-Morales et al. 2020).

In recent years, the importance of LEK systems in the maintenance of Sierra Nevada's social-ecological system has been increasingly acknowledged at several levels. Within academia, a research group from the University of Granada, has co-led since 2014 an interdisciplinary European FP-7 project, Mediterranean Mountainous Landscapes (MeMoLa) to enhance the importance of the multifunctionality of

cultural mountain landscapes. Participants in the project include several research groups, the Natural Park administration, local and national civil associations, and some irrigation communities. This project studied the importance of LEK in the recognition of soil quality to improve the distribution of crops and landraces, conducted hydrological research to study the ecological benefits of traditional water management systems, carried out educational activities, and proposed modifications in the hydrological policies, giving visibility to the problems of the irrigation communities of Sierra Nevada. For example, one of the outcomes of this project has been a proposal to reconsider the high mountain irrigation communities using *acequias de careo* as an exceptional case by the Hydrographic Confederation, due to their ecological contribution. They have also promoted the involvement of university students in the annual cleaning and reparation of irrigation ditches, thus favoring the exchange of knowledge and the approach of the students to the irrigation communities' reality (Fig. 5).

At the level of the administration, there have also been efforts to promote the maintenance of traditional practices and associated knowledge. A paradigmatic example of this effort has been the creation of a shepherds' school (www.escueladepastoresdeandalucia.es), currently in its tenth edition. This initiative encourages the maintenance of traditional practices by offering training to young people interested in extensive livestock farming. Training includes issues such as the ecological importance of extensive livestock farming and its impact on ecosystems (Ruiz-Morales et al. 2020). The shepherds' school also aims to revalue the social recognition of this profession, which has serious problems of generational renewal. The administration has also recognized as autochthonous the "*pajuna*" breed, conducting analysis to study its quality (Horcada-Ibáñez et al. 2016) and promoting its commercialization and production. Also at the administration level, managers of Sierra Nevada Natural and National park are conducting an adaptive management project (Adaptamed) for the development of adaptation measures for climate change impacts, in which they recognize the ecological value of historical irrigation systems and associated LEK. This project, which will include local irrigation communities, ranchers, and shepherds in workshops and meetings for decision-making, will be an exceptional opportunity to integrate local communities and their LEK in the co-management of the territory, increasing their active role in governance. These actions help to revitalize LEK in Sierra Nevada in a practical way, by recovering its daily use.

Finally, LEK is also experiencing some revitalization through the influence of the arrival of a new population to the area. In the last decades, the neo-rural population, also known as amenity migrants, has brought to the area new practices and needs that have generated different types of impacts. Despite their diversity, this movement has been able to organize itself to improve the commercialization of local products. This is the case of the cooperative *Las Torcas* in the Alpujarra, or *Valle y Vega*, linked to the valley floor of Lecrín Valley and the valley floor of Granada at the foot of the mountain. This new population has introduced new practices and knowledge (i.e., the use of *consuelda* or *cola de caballo* to combat pests, biodynamic agriculture, sprinkler irrigation), but they have also contributed to the maintenance of local knowledge systems. For example, the neo-rural community is responsible for the reintroduction of seeds that were locally lost (e.g., the *pico de pájaro* lettuce in High Alpujarra) and there are examples where they participated in the local work to clean annually the acequias, becoming new repositories of local water management

Fig. 5 Group of students helping to clean and repair an *acequia de careo* (MeMoLa project)

knowledge. Many of the amenity migrants of the mountain villages start their gardens using the knowledge they acquire from locals, enriching it with their own background. For instance, the Hortigas Agroecological Cooperative, formed by urban migrants, without agricultural background, learned from the local residents of Dúrcal, including the elders. These exchanges favor the transmission of their LEK to new populations, who modify it with their own knowledge systems, in this case, agro-ecological knowledge. This cooperative, with more than 100 members, has been operating for 15 years, linking people from the city of Granada, usually students, with Dúrcal farmers. Since the members of the cooperative have to work the gardens at least once a month, this dynamic favors the transmission of knowledge. Overall, the interactions of the neo-rural population with the local communities have in many cases contributed to the valorization of LEK and the development of other agroecological initiatives.

5 The Future of LEK in the Context of Global Environmental Change

LEK systems are not ethereal, so LEK cannot be collected and conserved for future adaptation and implementation. Rather LEK is embodied in knowledge holders, as part of their heritage and culture. LEK is only alive when used by local communities to continue to live in a specific environment. Therefore, although LEK is always changing and facing new challenges, to survive it must preserve its usefulness for the local population—not only in an economic way, but also performing symbolic, identity, and social roles.

Traditional agricultural and livestock farming practices, and traditional irrigation infrastructures and their associated knowledge have proven to be fundamental for the maintenance of the resilience of Sierra Nevada's social-ecological system, and therefore could also be beneficial for the conservation of their ecosystems against current impacts and future threats. Therefore local and regional administrations need to take additional steps on the process of integrating this knowledge system in the management of the territory. Indeed, co-management, i.e., management involving local communities and administration, is becoming a common practice growingly implemented in protected areas and indigenous territories (Krupnik et al. 2010; Armitage et al. 2011; Danielsen et al. 2014; Reed et al. 2016). The co-management approach would imply that the local population of Sierra Nevada should be a fundamental stakeholder, involved in all the decisions about the future of their territory becoming more involved in the management of the territory and natural resources. In particular, since the traditional water management system is the backbone of Sierra Nevada, and the LEK associated is fundamental to preserve the ecological stability of the region (Jódar et al. 2017; Martos-Rosillo et al. 2019), this centuries-old knowledge on how, where, when, or how much water needs to be redistributed along the slopes of Sierra Nevada to have correct functioning of the ecosystems of different bioclimatic zones should be integrated with the co-management of Sierra Nevada. For example, during our ethnographic work, several people mentioned local priorities such as investment in infrastructures of water-supply for livestock on the high-lands during the summer or the maintenance of irrigation systems, beyond the current focus on the *acequias de careo* located on the top of the mountain but also in the lower areas of irrigation systems and hydraulic infrastructures (*cimbras*, *minas* or *qanats*, *partidores*, *albercas*, or fountains), with higher repercussion on the irrigation communities. A co-management system should be able to consider such local priorities at the same level as the priorities determined by the administration. Irrigation communities should be key actors when assessing the management of hydric resources. Moreover, their inclusion through a collaborative network would favor communication between the different irrigating communities and the exchange of knowledge, strengthening the ties between them and enriching their collective LEK.

In the same way, shepherds and ranchers should be effectively integrated and take part in adaptive management plans of high-mountain meadows of Sierra Nevada and wildfire prevention systems (Ruiz-Mirazo and Robles 2012; Varela et al. 2018). Livestock can prevent the rewilding of the territory, which can happen in national parks after removing traditional livestock practices (Guadilla-Sáez et al. 2019), and plays a fundamental role in preserving the biodiversity of Sierra Nevada, hence shepherds and ranchers should be engaged in biodiversity conservation and seed dispersion plans (Ramos Font et al. 2015; Robles et al. 2016). The Andalusian Shepherds School presents a great opportunity to create this change of vision in the management of the territory, involving the local population, adding value, and revitalizing the LEK of their communities, also creating a change in the social perception of these traditional activities (Ruiz-Morales et al. 2020). A similar role can be played by other initiatives led by extensive livestock farming women, who are trying to give visibility and revalue the historical role of women in livestock contexts and their current contributions to this sector (Fernández-Giménez et al. 2019).

To ensure the maintenance of these traditional practices and associated LEK, local communities need to continue benefiting, both economically and socially, from their knowledge (Foley and McCay 2014; Oosterveer et al. 2014). However, maintaining the benefits generated by LEK will be difficult if there is no social recognition and appreciation of

the value of LEK and its bearers. The high physical effort of products derived from traditional practices and their low profitability results in a lack of generational uptake, as the new generations do not prioritize traditional livelihoods (Fig. 6). Beyond the theoretical recognition of LEK and its holders, substantial support from administrations that add economic value to products derived from traditional practices is needed. For example, the current legislation has different quality standards (Protected Designation of Origin, Protected Geographical Indication, Traditional Specialty Guaranteed, and Artisanal Food certificate) which currently only include a few products from Sierra Nevada. This legislation could be modified to revalue processed and raw agricultural and livestock products coming from traditional practices and local varieties and breeds of local communities and small producers or rural areas (Ruiz Morales et al. 2012). The Artisanal Food certificate recognizes the traditional artisanal exceptionality, allowing it to carry out product elaboration following different procedures from the rest of the production companies in the same sector, as is the case of artisan cheeses (Decree 352/2011). Similarly, being within a protected area could be recognized with the quality recognition of natural parks of Andalusia, which encourages the sustainable development of local populations around protected areas.

Such changes in legislation could be accompanied by other actions, to enable small farmers to commercialize the local agricultural varieties they still have. The promotion of the Andalusian seed network and the recognition and cataloging of the autochthonous fruit and vegetable varieties of Sierra Nevada, which currently includes 18 local varieties, will favor their social demand and conservation. Due to the proximity between producer and consumer, local consumption groups and short consumption channels have always been seen as good ways to commercialize local products (Vara-Sanchez et al. 2021), so legally favoring this type of channel is essential. In the same way, information and educational campaigns explaining the added value of artisanal products, such as the ecological and social benefits of consuming local agricultural varieties, could increase consumers' awareness. Cooperativism among small producers is essential to create alternatives in the primary and secondary sectors, which are highly industrialized and technified. In this line, different cooperatives of women shepherds are trying to revitalize the Merino wool sector in Spain, with historical worldwide recognition. These cooperatives

Fig. 6 Ranchers of different generations grouping cows

highlight the importance of women's LEK in this sector, from the breeding and production of the animals to the processing, transformation, and final distribution of wool (Herrero 2020), which should be another alternative to explore in Sierra Nevada.

In general, public administrations could support the maintenance and regeneration of LEK by encouraging short marketing channels and supporting the organization of small independent farmers in truly democratic cooperatives. The maintenance of LEK associated with local landraces and autochthonous livestock breeds, as well as the traditional processing of primary products, can increase the food sovereignty of the Sierra Nevada communities (Pimbert 2006). The use of LEK can also increase the economic possibilities for the population and open new opportunities for young and women in rural regions, creating social and economic resilience, and reducing their dependence on other sectors such as tourism or the demands of the global market that do not usually favor the added value of the associated LEK.

Finally, academia is also in a process of increasingly valuing LEK, in some cases promoting the co-production of new actionable knowledge that brings together scientific knowledge and LEK to address current sustainability challenges (Tengö et al. 2017; Norström et al. 2020). Currently, researchers are working on the co-production of knowledge in fields like agroecology, biodiversity conservation, or natural resources management (Altieri 2002; Armitage et al. 2011). Nowadays, there is also a great concern about the need to also include the LEK of IPLC in climate change research (Krupnik et al. 2010; Berkes 2017; Díaz et al. 2019). In that sense, there is extensive literature showing the variety of climate change impacts in the climatic, physical, biological, and human systems perceived by local communities, and the level of detail that those communities are able to detect describing those impacts (Reyes-García et al. 2019a). Moreover, a recent study has shown similar results with local communities of Sierra Nevada, who are direct witnesses of climate change impacts on their social-ecological system, for which their knowledge would help to substantially improve the current databases of climate change impact at a local level, contributing to the development of local mitigation and adaptation measures (García-del-Amo 2021). Integrating local communities of Sierra Nevada in the monitoring of environmental changes happening in the region would contribute not only to improve the monitoring system, but also to design more realistic management plans in the context of climate change. Global change is transforming the socio-ecological systems of Sierra Nevada in many different ways, and the creation of interdisciplinary working groups including decision-makers, researchers, technicians, members of the irrigation community, shepherds, ranchers, and beekeepers might be the best way to obtain a correct assessment of the biophysical and sociocultural changes happening in Sierra Nevada (Garcia-del-Amo et al. 2021). These interdisciplinary working groups, in their participatory process, must be focused and designed so that they can have a real impact on the policies and norms that regulate the management of the territory.

6 Conclusions

In this chapter, we have analyzed the importance and contributions of LEK to maintain the proper functioning of Sierra Nevada's social-ecological system. Throughout the twentieth and twenty-first centuries, the different drivers of global environmental change have greatly eroded the proper functioning of this social-ecological system and endangered the transmission of LEK to the new generations.

The numerous challenges derived from global changes require considering all possible sources of knowledge in addressing them. A way to better assess LEK would be to engage local communities in the co-governance of the territory through the co-management and co-production of knowledge. Promotion of local varieties and breeds and favoring the continuity of small local producers and cooperatives will be necessary to ensure the future of local communities and the continuity of these traditional activities. Interdisciplinary and inclusive methodologies can help to avoid power imbalances and to ensure mutual understanding between both sources of knowledge to achieve true participation of the local population, empowering them in the management and conservation of the territory.

If economic and legislative restrictions block local communities to maintain their traditional activities; if the pressure upon their economies and ways of managing environmental resources becomes excessive; if there is not a legitimation of their ways of life; if new formulas for agropastoralism activities are not provided, it will be hard for LEK to survive and become an effective tool for dealing with the new challenges. More than protecting LEK, it is important to protect the needs of those who hold it.

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