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ORIGINAL PAPER

The multifunctional role of linear features in traditional silvopastoral systems: the sabana de morro in Dolores (El Salvador) and the pastures with carob trees in Ragusa (Italy)

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Abstract

Traditional agro-silvo-pastoral systems are becoming each day more important, representing multifunctional systems that can contribute to the preservation of agrobiodiversity and of traditional knowledge and associated culture, to the wellbeing of local communities and to sustainable development of rural areas, as testified by the increasing interest regarding the Globally Important Agricultural Heritage Systems (GIAHS) Programme of the Food and Agriculture Organization (FAO). Despite many researches on traditional agro-silvo-pastoral systems tend to focus only on land uses and land use changes, is also important to analyse the different features that characterize cultural landscapes, as well as to produce detailed spatial maps, in order to preserve and valorise these systems as a whole. The paper intends to compare two traditional silvopastoral systems in two different continents and environments: *sabana de morro* (El Salvador) and pastures with carob trees (Italy), considered as good example of biocultural diversity. Both these sites are characterized by extensive cattle breeding in a hot climate under the shade of trees, whose fruits can also integrate the animal diet. The study analyzed the traditional landscape structure, with particular attention to the presence of linear elements, that act as property divisions and as ecological corridors, contributing to biodiversity at landscape scale. Sabana de Morro is characterized by a complex system of hedges that enhances the variety of species, while an extensive network of dry-stone walls divides the Sicilian pastures with carob trees. These two different types of linear elements created thanks to the local farmers' knowledge are made of different materials but can play a similar ecological and social function, acting as a division between one pasture and another, as a delimitation of property boundaries, and are necessary to allow a correct pasture management. Despite the differences, these two traditional linear features deeply characterize the landscape structure and fragmentation, creating important microhabitat for many animal and vegetal species and a network of ecological corridors. For these reasons the conservation of linear features should be promoted at planning level, as well as their restoration. Thanks to the applied methodology, it was possible to identify peculiarities and vulnerabilities of linear features and of the systems as a whole, so that it will be possible to create effective management and conservation tools.

Communicated by Mauro Agnoletti.

Keywords Traditional agricultural heritage · Hedges · Dry-stone walls · Traditional landscape · Linear features

Introduction

Traditional agro-silvo-pastoral systems are becoming each day more important being a valid alternative to agricultural models based on maximizing productivities, as they could actively support climate change mitigation strategies while preserving traditions and cultural values (Agnoletti 2019). Being an invaluable heritage, these realities are spread all over the world creating historic landscapes that are the results of cultural factors important to recognize and protect (Palmieri et al. 2011; Agnoletti 2014). Moreover, they can contribute to the preservation of biocultural diversity (Agnoletti and Rotherham 2015) and of traditional knowledge and associated culture, to the wellbeing of local communities and to sustainable development of rural areas. This is testified by the growing interest at international level regarding the Globally Important Agricultural Heritage Systems (GIAHS) Programme of the Food and Agriculture Organization (FAO) (Koohafkan and Altieri 2011).

Nowadays traditional agro-silvo-pastoral systems have to face new technologies which have modified both the production methods and the landscapes' shapes. The introduction of new agricultural machines and the changes in the production system and markets question and supply has deeply modified traditional agricultural systems. Considering that agriculture is one of the main pressures on world's ecosystems and a major driver of biodiversity loss (IPBES 2019), traditional agro-silvo-pastoral systems constitute an invaluable heritage that has to be protected, being above all a valid alternative in climate change mitigation because of their reduced impact in energy utilization and for the role in carbon sequestration (Pandey 2002; Lasco et al. 2014), as well as for the associated ecosystem services (Torralba et al. 2016; Jose 2009). Despite the multifunctional role of traditional agro-silvo-pastoral systems is today widely recognized at scientific level (Tieskens et al. 2017), it is necessary to deepen the study of the different features that characterize these systems and that play a crucial role, not only for the maintenance of the system itself as a whole, but also for their importance for the environment, for biodiversity, for the cultural role, and for the sense of place for local communities (Bignal and McCracken 1996; Schaich et al. 2010; Tengberg et al. 2012; Waterton 2005). For these reasons, analysing all the features composing a traditional agricultural system is crucial to highlight both their importance and their multifunctional role while understanding their vulnerabilities so that it might be possible to develop a successful management and protection strategy.

The present paper focuses on two different traditional silvopastoral systems: the *sabana de morro* in Dolores municipality (El Salvador) and the pastures with carob trees in Ragusa Municipality in the Hyblean Mountains (Sicily, Italy). These two systems are located in different countries and have different environmental characteristics, but also share common features. Both of them are the result of the farmers' adaptation to the environment during the centuries, leading to traditional landscapes made of pastures, used for cattle grazing mainly for cheese production, with abundant presence of scattered trees: *Crescentia alata* (locally called *morro*) in Dolores (El Salvador) and *Ceratonia siliqua* in Sicily (Italy). These trees provide multiple benefits both to the animal and to the farmers, as fruits to integrate the animal feeding and shade during the day as the two places are characterized by hot temperatures. The landscapes are characterized not only by scattered trees, but also by linear features that divide the pastures. In Dolores the division of the pastures is traditionally made with hedgerows of local species, while in Sicily it is made by dry-stone walls.

The presence of scattered trees and of linear features (hedgerows, dry-stone walls, terraces, channels,…) deeply characterizes many cultural landscapes all over the world (Baudry et al. 2000; Wei et al. 2016; Gascuel-Odoux et al. 2011) representing an identity feature and being also important in terms of biodiversity, as they create microhabitat for small animals and plants (Meurk and Swaffield 2000; Manenti 2014; Avila-Flores et al. 2019). In fact, the presence of these elements contributes to protect native species which, even in intensively managed landscapes, are often largely restricted to linear boundary features (Cherrill and McClean 1997). Furthermore, the biodiversity of the margins may be of particular importance for the maintenance of species at higher trophic levels, notably farmland birds, at the landscape scale. At the same time, margins contribute to the sustainability of production by enhancing beneficial species within crops and reducing pesticide use (Marshall 2002). The study of the landscape structure and of the diverse features that characterize a given landscape are, in fact, important for biodiversity, especially for the gamma diversity (γ-diversity), a concept introduced in the ‘60 s by Whittaker (1960). Despite the fact that there is no consensus regarding the adequate spatial scale in order to quantify gamma diversity, the use of similar scales and of equal area grid cells allows to compare different environments and situations (Whittaker et al. 2001).

The aim of the research is to carry out an assessment of the linear features in two traditional silvopastoral systems, in order to quantify and measure their presence inside these landscapes. Moreover, traditional associated practices and techniques are taken into consideration to evaluate the relationships between the specific landscape structure and the multifunctional role of linear features. The research is based on detailed land use and linear features mapping, that might represent a starting point for future monitoring.

Materials and methods

The study areas

The study areas are two: one in Dolores Municipality (El Salvador) and the other one in Ragusa Municipality (Sicily, Italy) (Fig. 1).

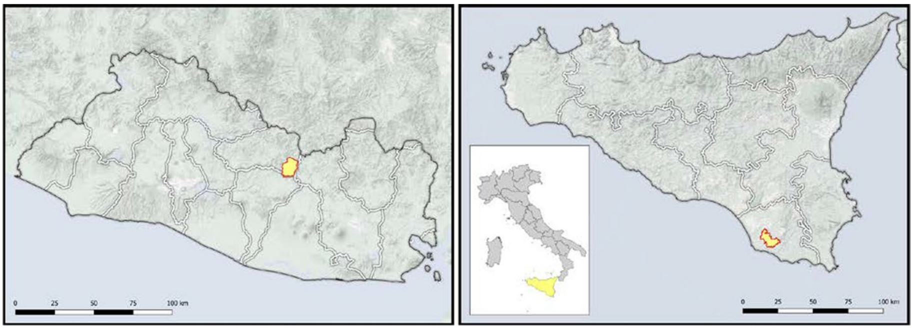

Fig. 1 Location of the two study areas: Dolores, El Salvador (left) and Ragusa, in Sicily Island, Italy (right)

The area of Dolores extends for about 8390 hectares, at altitudes ranging from 44 to 652 m a.s.l. (Fig. 2), in the Department of Cabañas. Most of the area is flat or with gentle slopes and the site is crossed by a rich hydrography. According to the Köppen-Geiger climate classification, the local climate is *Aw—Equatorial savannah with dry winter* (Kottek et al. 2006), with average rain per year of 1823 mm (with well-distinguished dry and wet seasons) and average temperature of 26.6 °C (Centro de Meteorología e Hidrología 1993).

The area of Ragusa extends for about 8208 hectares, at altitudes ranging from 43 to 559 m a.s.l. (Fig. 2) on the Hyblean Mountains in Sicily Island. The morphology is more similar to a plateau than to mountains, and the area is crossed by deep depressions where small and non-perennials streams flow. According to the Köppen-Geiger climate classification, the local climate is *Cs—Warm temperate climate with dry summer* (Kottek et al. 2006), with average rain per year of 646 mm (mostly concentrated during winter months) and significant differences in the climate between summer and winter (average yearly temperature of 14.7 °C, average temperature of the coldest month of 4.8 °C, average temperature of the warmest month of 24.6 °C).

Regarding the temperatures, the two areas are quite different, as the climate in Dolores is more uniform throughout the year while in Ragusa winter temperatures are significantly lower than summer ones. In both areas is instead possible to identify well-distinguished dry and wet seasons.

The methodology

The present study might be divided in two sections: the first part of the methodology focused on the analysis of the land use structure and of the linear features (hedgerows in Dolores, dry-stone walls in Ragusa) while the second part focused on the application of some indexes to quantify the presence of linear elements.

At first, for both areas detailed land use and linear features maps have been created through photointerpretation of Google Satellite images using Quantum GIS 3.10.3 and applying a minimum mapping surface of 250 m^2 for the polygons of the land uses. This allows to study in detail the landscape structure of the two traditional silvopastoral systems and to find possible correlations between land uses and linear features. In the case of Dolores we used Google Satellite images of November 2017 while Ragusa images are referred to June 2019. The land use data for the area of Dolores have been derived by a

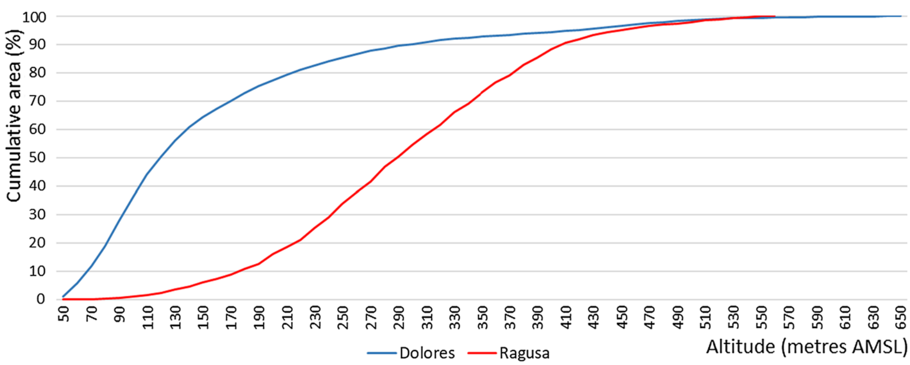

Fig. 2 Hypsometric curves of the two study areas: Dolores (El Salvador) and Ragusa (Sicily Island, Italy)

previous study (Santoro et al. 2020). Digital Terrain Models (DTM) have been used to obtain data about elevation. We used a 30 m resolution DTM provided by the US Geological Service for Dolores, and a 20 m resolution DTM provided by the Italian Institute for Environmental Protection and Research (ISPRA) for Ragusa. Both DTMs have been processed with Quantum GIS 3.10.3 with the support of GRASS (Geographic Resources Analysis Support System) plug-in. Moreover, to better compare the landscape structure of the two study areas, a specific investigation on the density of *Ceratonia siliqua* trees in Ragusa has been carried out, counting the trees with the use of Quantum GIS 3.10.3, based on 10 random sample areas.

The second part of the analysis focused on the application of some indexes to quantify the presence of linear features into the given landscapes. The first index that has been calculated is the linear features density. Since both hedges and dry-stone walls are not found in all the land uses of the two areas (for example forests or urbanized areas) but are related to specific land uses (pastures, arable land…), density has been calculated as meters of linear features per hectare of related land uses.

Furthermore, a density map of linear features has been elaborated in order to highlight their spatial distribution. These maps are based on a hexagonal grid generated with the MMQGIS plug in (a set of Python plugins for manipulating vector map layers in QGIS), each hexagon measuring 10 hectares. Then, using the processing tool "sum line length", the total length of linear features included in each hexagon has been calculated. The results, divided for 10 allows to have for each hexagon the density of linear features expressed as meters/hectare.

Another elaboration has been conducted to investigate the average and the maximum distance of each pixel of the study area from the nearest linear feature. This output has been elaborated starting with the conversion from the vector layer with the linear features in a raster format. Then, through the use of the proximity tool, the minimum distance from the nearest linear feature has been obtained. After that, the use of the zonal statistics tool allows to measure the average and the maximum distance from the nearest linear feature.

Results

The linear features of both study areas examined in this study are different in terms of construction materials, even if both have similar functions and roles within the landscape in which they are (Fig. 3).

In Dolores, hedgerows are used to divide the pastures and sabana de morro patches; they are mainly made of *Bursera simarouba* (Jiote) and *Jatropha curcas* (Tempate) and, to a lesser extent, *Cordia dentata* (Tihuilote) and *Gliricidia sepium* (Madrecacao). Local farmers, first use to place dead posts, made of *Lysiloma auritum* (Quebracho) wood, where they fasten the barbed wire with staples. These dead posts are usually located every 2 or 2.5 m. After that, young trunks of the species adopted as living fences are planted and entangled in the barbed wire, so that with the trunks growing the wire remains stuck in the bark. This is the traditional technique used to create living fences adopted by local farmers. Hedgerows are traditionally pruned every year during the month of March, about one month before the start of the rainy season, to maintain them at a height of approximately 1.50 m, cutting all the branches that grows horizontally. The cut branches are used as vegetative material for establishing new living fences, with the exception of *Gliricidia sepium* (Madrecacao) that can be used as forage for cattle.

Fig. 3 Traditionally managed hedgerow in Dolores, El Salvador (right). In Ragusa, Italy (left), traditional dry-stone walls are not only used to divide pasture but also to protect single Ceratonia siliqua trees

The landscape of the Iblei Mountains is made up of a network of dry-stone walls that identify the territory by forming geometric polygons called *chiuse* (literally "closed"). The walls were built to delimit pastures and arable land, but also with the aim of removing limestones from the ground in order to clear the ground for agro-pastoral activities. Other dry-stone structures characterize the landscape, like *manniruni*, circular walls around single trees with the function of protecting the tree from grazing cattle. Typically, in order to make a wall there are two builders, located on the two sides of the wall, together with two or three labourers who help by collecting the most suitable stones for the construction. The preliminary step is to prepare the soil laying surface, removing the earth to expose the outcropping rock. Starting from the ground, labourers arrange the stones, starting with the largest ones, arranging them in two parallel rows, making sure that the two rows are settled on an ideal plane, slightly inclined towards the center of gravity of the wall. The wall thickness at the base can vary in function to the stones size: higher in the presence of large blocks, or lower in the presence of smaller ones. Then stones are placed in a staggered way until the wall reaches 1–1.20 m (Megna et al. 2013).

Comparing the land use data, is it possible to identify some differences between the two study areas, consequences of the different peculiarities characterizing the two sites in terms of geomorphology and climatic conditions. In both cases pastures with trees are the main land use category even considering the different tree species characterizing the areas. In the case of Dolores, 32% of the surface is composed by pastures with Morro trees while in Ragusa 48% of the territory is characterized by pastures with carobs. In the Italian site, carob trees can also be found scattered on about 990 ha (12.1%) of arable land. In Dolores, forests cover about 25% of the area, while in Ragusa they can be found only on 1.6% of the surface. A similar data can be found for shrublands, as they occupy 6% and 0.9% of the two areas respectively. In both sites pastures cover more or less the same surface: 1575 ha in Dolores and 1616 ha in Ragusa. The main difference is related to agricultural surfaces: the Italian site has a major agricultural character, as the surface of cultivations (with or without carob trees) reaches 1970 ha, while in Dolores cultivations are limited to 626 ha. Fallow lands are around 1% of the whole surface in both territories.

Anthropic areas are more common in Ragusa (4.3%), where they are more spread in the whole territory and where they include streets and railway as well as greenhouses, while in Dolores (2.8%) the road network is not particularly spread and buildings are more concentrated in the main village. Moreover, both the sites are characterized by numerous waterways so that there is a high amount of riparian vegetation along them.

Since the presence of sparse trees in pastures and in cultivations is a common and distinguishing feature, a specific investigation has been carried out in the Italian site to obtain data about tree density. In Ragusa the density ranges from 5 to 62 trees/ha (Fig. 4), highlighting a higher variability compared to Dolores, where the density ranges from 8 to 45 trees/ha (Santoro et al. 2020). In both areas there are surfaces in which the trees canopies are intertwined and others in which are distant one another.

The main common feature and the main objective of the research is the presence of linear elements. Even if they are qualitative different, in both areas they play a fundamental and multifunctional role. In Dolores area there are about 475 km of hedges, while dry-stone walls in Ragusa account for more than 1352 km (Fig. 5).

The first index that has been calculated is the density of linear features. Since linear features are common only in some land uses (pastures, arable land, sabana de morro…) the density refers not to the total surface of the area but to the surface of these land uses. The density of dry-stone walls in Ragusa is much higher than the density of hedges in Dolores, as they are 178.4 and 97.2 m/ha respectively. However, this value must be observed taking into account the different structure of the landscape mosaic. In particular, the fragmentation of the landscape in Ragusa is higher, since the average patch surface of land uses with linear features is equal to 1.58 ha while in Dolores it reaches 2.80 ha (Table 1).

The elaboration of a density map allows to obtain results regarding the spatial distribution of the linear features (Fig. 6). From the maps it is evident that the density of linear features in Ragusa is higher than in Dolores, and that they are more regularly spread on all the surface, while in Dolores they are mainly concentrated in the central and in the south-west

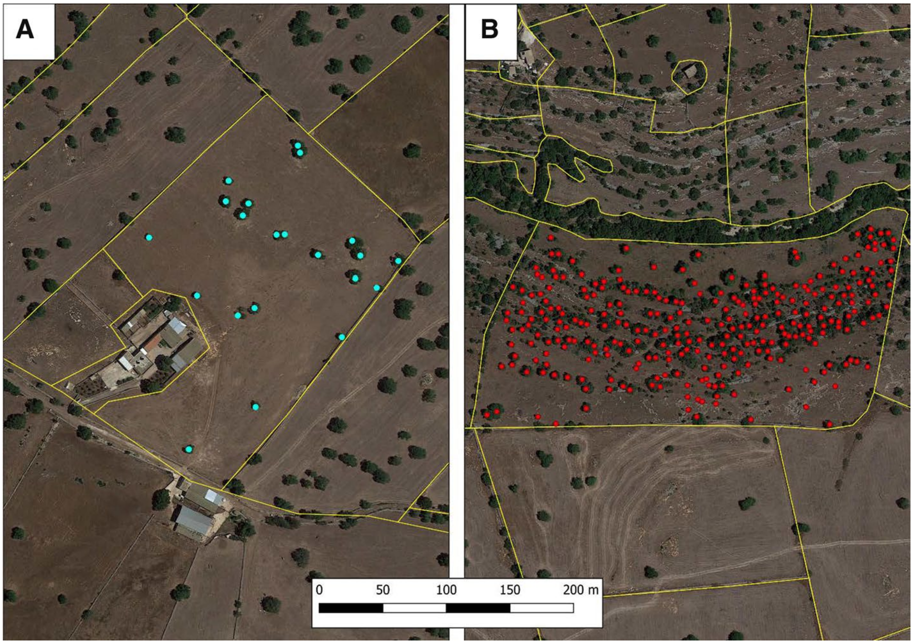

Fig. 4 Density of Ceratonia siliqua in Ragusa area ranges from 5 to 62 trees/ha

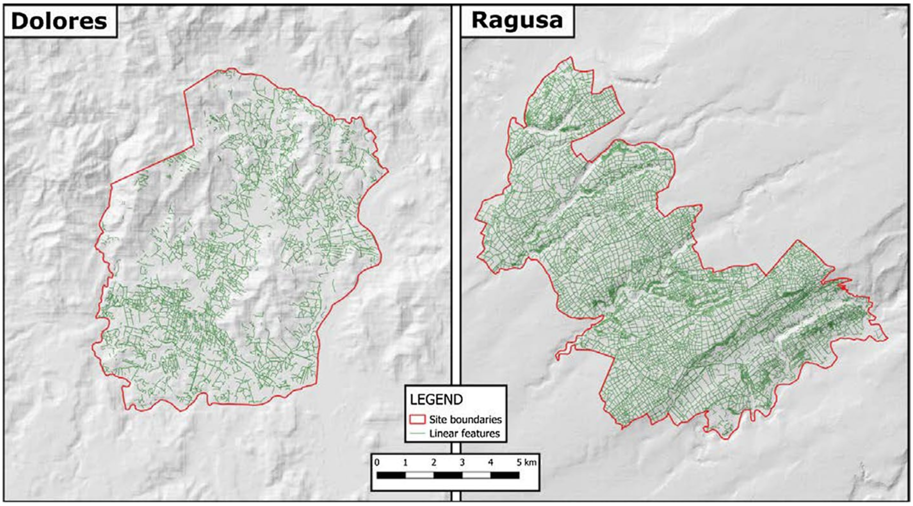

Fig. 5 Map of linear features for Dolores, El Salvador (left) and Ragusa, Italy (right)

Table 1 Main measures and indexes calculated for the two study areas

	Dolores (EL Salvador)	Ragusa (Italy)
Total length of linear features (m)	483,168	1,352,148
Total area surface (ha)	8390	8208
Total surface affected by linear features (ha)	4969	7578
Density of linear features (m/ha)	97.2	178.4
Total average patch surface (ha)	3.28	1.44
Average patch surface of land uses with linear features (ha)	2.80	1.58

part of the area. The maximum density derived from the elaboration of the maps are equal to 262 m/ha for Dolores and to 358 m/ha for Ragusa. The last elaboration that has been done allows to measure the average and the maximum distance from the nearest linear feature. The average distance for Dolores is equal to 105 m, while in Ragusa is equal to only 24 m; the maximum distances are 990 m and 311, respectively.

Discussion

Both study areas still preserve the traditional landscape and the associated linear features, thanks to the fact that traditional animal grazing is still carried out; their presence is still common, as they are one of the distinguishing features of the cultural landscape, even if it is possible to identify some differences. In Dolores linear features are more concentrated in a specific part of the area and their average density is lower. This is due to the different land use structure, as a significant part of the surface is occupied by forests and the fragmentation of the landscape mosaic is lower. Ragusa area, instead, is almost all entirely dedicated to agro-pastoral activities and the fragmentation of the mosaic is higher, since the average

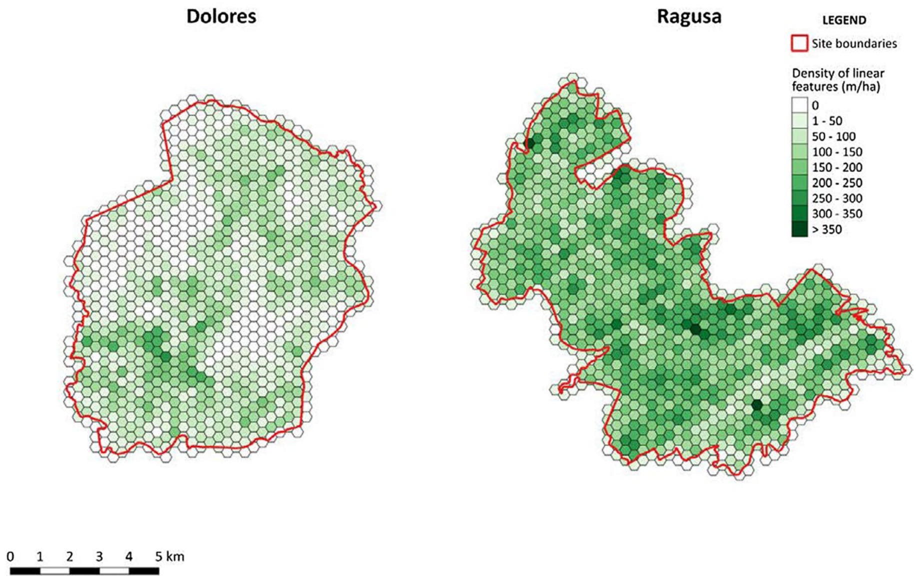

Fig. 6 Density of linear features (m/ha) for Dolores, El Salvador (left) and Ragusa, Italy (right)

patch surface is of 1.58 ha. If we consider the differences in the average patch surface and in the fragmentation of the landscape mosaic, it is possible to state that the density of linear features is really similar. In particular, the two sites share a common visual and aesthetic attitude, as they present landscapes made of open spaces with scattered trees, divided by a regular grid of linear features.

Despite the fact that linear features and traditional landscapes are well preserved, both of the areas deals with some vulnerabilities, mainly due to abandonment of traditional practices. In Dolores in the last decades the surface classified as sabana de morro or as pastures decreased (Santoro et al. 2020) and the abandonment of the traditional practice of regularly pruning the hedgerows can lead to a change in aesthetic characteristic of the local landscape. In Ragusa area the main threats are the abandonment of the regular maintenance works that dry-stone walls require and the fact that some renovations have been done without respecting traditional shapes and materials, such as with the use of concrete blocks or with the use of concrete to fix the stones.

Results have therefore highlighted that the traditional landscapes are well preserved, linear features are well maintained through the regular application of traditional practices and scattered trees deeply characterize the landscape. Land use change is not a major concern, especially in Ragusa area, and this is particularly important as land-use change is considered one of the most relevant drivers of environmental degradation worldwide (IPBES 2019).

Linear features are commonly considered multifunctional elements, especially in relation to four main topics: (a) habitat for certain species, particularly edge species, (b) barrier separating adjacent fields, (c) source of biotic and environmental influences on the adjacent fields, and (d) corridor for movement of certain species (Forman and Baudry 1984). Both of the considered linear features have an important social and cultural role, as they are the product of traditional activities and they contribute in preserving a landscape that is, in the case of Ragusa, also a touristic and therefore an economic resource. Hedges in Dolores have an important role in terms of biodiversity conservation; beside the fact that they are made of different flora species, they could represent a habitat and a corridor for different species, as it is demonstrated for different part of the world and for different species (Van Der Zanden et al 2013; Harvey et al. 2005; Boutin et al. 2002). The ecological role of dry-stone walls is instead less studied than the one of hedgerows (Collier 2013), but some researches based in different European countries highlight their role in creating microhabitat for flora and fauna species (Manenti 2014; Dover et al. 2000; Tanadini et al. 2012; Holland 1972). For these reasons the conservation of linear features should be promoted at planning level, as well as their restoration, also for the positive effects on the surrounding crops or pastures (Benayas et al. 2020; Dainese et al. 2017; Morandin and Kremen 2013).

Conclusions

Thanks to the methodology applied in this research, it was possible to identify both the peculiarities and the vulnerabilities of these systems so that it will be possible to create management and conservation tools in order to preserve these realities and their potentialities. In both sites the traditional landscape elements are well maintained and this plays a fundamental role in terms of cultural, economic and environment conservation. In fact, traditional systems, due to their unique features, are a valid example of sustainable management. Considering this, it might be important to develop an accurate multitemporal analysis for both sites based on land use maps in different periods so that it might be possible to monitor the landscape structure variations during the years. This also might permit to highlight which are the main changes tendencies characterizing both areas and plan a conservation and protection strategy according to the results. Despite the recognized importance of linear features for cultural landscapes, in most cases, researches on traditional agro-silvo-pastoral systems tend to focus only on the analysis of the land uses and on their changes over the years. Instead, it is very important to analyse and to measure the different features that characterize cultural landscapes (Król et al. 2019), as well as to produce detailed spatial maps, in order to preserve and valorise these systems as a whole (Van Der Zanden et al. 2013).

In conclusion, the present research has contributed to identify all the unique features of two traditional silvopastoral systems, geographically very far one another, highlighting both their similarities and differences and emphasizing their crucial multifunctional role in the maintenance of local traditional practices derived from communities' adaptation to the surrounding environment. Moreover, it can represent a starting point to monitor linear features changes and for defining strategies and actions for their preservation. Furthermore, it has been possible to evaluate and stress the relationships between their specific landscape structures and the multifunctional role of linear features.

Authors' contributions Conceptualization, M.V., F.P., F.C., A.S.; methodology, M.V., F.P., F.C., A.S.; software, F.P. and F.C.; writing, M.V., F.P., F.C., E.A.M.A. and A.S.; supervision, A.S.

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Data Availability Data will be provided by the authors upon request.

Declarations

Conflict of interest The authors declare no conflict of interest.

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