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Agricultural landscape modification and land food footprint from 1970 to 2010: A case study of Sardinia, Italy

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A B S T R A C T

Urban population growth has caused significant changes in rural areas, leading to landscape modifications. These modifications affect rural systems via different mechanisms linked to alterations in land use, loss of landscape biodiversity, and habitat destruction. All these mechanism are set in motion by higher levels of global food demand, which requires increasing yields through high-input, specialised agriculture. Consequently, local food systems and food security are increasingly dependent by global food production, trade and transport. The Land Food Footprint is a suitable tool for assessing the evolution of food systems and land displacement, whereas the Shannon, Dominance and Sharpe landscape indexes jointly implemented with indicators of human disturbance and of proportion of natural area allow us to assess landscape modification and its impact on agricultural resources. In this study, we analysed the evolution of land food footprint and landscape changes in Sardinia over the period of 1970–2010 to assess whether land displacement implies landscape modifications. We also evaluated whether landscape modification entails an intensified use of resources and involves enacting changes in regional capability to satisfy the food needs of the local population. In the time series, results of landscape quantitative analysis indicate that the decrease in land food footprint balance is paired with landscape changes with a greater degree of dominance of few land uses due to agricultural specialisation in animal husbandry and abandon of marginal, less suitable and less profitable production areas. The reduced diversity of locally produced food due to the modification of food production and consumption systems is linked to modifications in traditional landscape with implications on local resources conservation. The regional land unbalance and the reduction in agricultural land capacity to support the local population food demand underline the need for food planning in the future.

1. Introduction

Runaway population growth worldwide has raised concerns about the availability of global food supply. The global food system needs to supply a growing amount of food at decreasing prices; this requires an improvement in specialised agriculture and industrialisation in order to maximise food production. In the last 50 years, agricultural productivity has increased more than three times (FAO, 2017). The green revolution enabled agricultural growth and specialisation by introducing new technologies, improved high-yield crop varieties and high-input production methods. Global food security is a crucial issue for humanity, but the pursuit of this goal is associated with extensive transformations of rural areas and landscapes, increased pressure on natural resources, expanding highly productive areas, and abandonment of marginal, less productive regions (FAO, 2017; Shabanzadeh-Khoshrody et al., 2016). Agriculture, as a multifunctional

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production system, is characterised by the joint production of private goods (such as food and fibres) and public goods (such as landscape and biodiversity); these are also known as ecosystem services. Supporting agricultural productivity may affect the quality and quantity of public goods delivered to local communities and increase the production of negative externalities. The consequences are complex and include worldwide negative effects such as land use change, loss of biodiversity and habitat destruction (Deng et al., 2017). Increasing food production using intensive farming and high-input food systems increases human pressure on natural resources, which leads to landscape modification, deforestation, emission of greenhouse gasses, soil degradation, and water depletion and contamination (FAO, 2017; Kaab et al., 2019). In particular, it is estimated that global agriculture produces about 5–13.5% of annual GHG emissions (Nabavi-Pelesaraei et al., 2014; Safa and Samarasinghe, 2012). Natural resources conservation makes it necessary to ensure the sustainability of all farming practices at a societal, economic, and political level (Kouchaki-Penchah et al., 2017). The environmental impact of global food systems has spurred national and international interest because it can undermine the achievement of food security and improved quality of human life (Ingram et al., 2010; Kouchaki-Penchah et al., 2017; Qasemi-Kordkheili and Nabavi-Pelesaraei, 2014). Since the 1960s, the food system has been increasingly industrialised and globalised, and the food chain has grown to be more resource intensive, longer, and more complex. The global, market-based food system has developed at international level, affecting key ecosystem services, landscape diversity and human well-being at different scales (Thompson and Scoones, 2009). Food commodities are transported over long distances and across countries, affecting local consumption habits, traditional farming systems, and availability of locally produced food. This implies an increasing regional dependency on the global food market and fossil fuels (Benis et al., 2017). Analyses conducted at regional and local levels provide a better understanding of the multiple effects exerted by the globalised food market on the carrying capacity of local food systems (Defries et al., 2002; Fischer et al., 2011), on local resources and on traditional landscape. The aim of this paper is to analyse the evolution of the local food system in order to assess the impact of land displacement on landscape changes in the Sardinia Region case study, adopting physical indicators. Sardinia, the second largest island in the Mediterranean (24.100 km^2, of which more than 81% is rural area), is a relevant case study for our analysis. Agriculture has played a very important role in the economic, social and cultural history of Sardinia. The local agricultural production system, traditionally based on subsistence cropping systems, have historically had to face problems such as water scarcity and soils infertility, with negative implications in terms of economic efficiency and competitiveness of local agriculture (EC, 2015). For these reasons the agricultural sector of Sardinia has experienced major structural changes in last decades, which have led to deep transformations in the local food production systems. This allows us to analyse the impact of land displacement on landscape change, in 1970, 1990 and 2010. In this aim the paper used the biophysical Land Food Footprint (LFF) to assess land displacement, the Shannon, Dominance and Sharpe indexes to evaluate landscape changes and further indicators of labour intensity in agriculture, human disturbance, and consistency of natural areas to analyse changes in the regional agricultural system and environment. We adopted a case study approach in order to better investigate the relationship between different drivers operating at the local level (Fischer et al., 2011; Geist and Lambin, 2002).

The scientific literature has focused on identifying the drivers of landscape modifications (Bürgi et al., 2005; Klijn, 2004) and it underlines the importance of landscape diversity as a key element of landscape features and as tool to assess the land “ability to support its population” at different scales (Defries et al., 2002; Wu, 2013). To assess the landscape diversity, two main aspects have to be considered: richness and evenness. These aspects consider the number of different land cover types (richness) and measure the incidence of each land use area on the total. The Shannon index combines in a single number the two aspects of landscape diversity and it is widely used in literature (Nagendra, 2002). The dominance landscape index “measures the extent to which one or a few land use dominate the landscape” (O'Neill et al., 1988). The labour intensity is considered an indicator of agricultural management characteristichs. The Sharpe index shows the rate of change of each crop type in each period, highliting which crop types are subject to greater changes (Sharpe et al., 1981). Ecological Footprints (EF) are widespread instruments used to quantify the impacts of human activities on natural resources (Ferng, 2011). The Land Food Footprint approach is used to assess differences in land availability and land demands (land balance) at different scales enabling to assess whether and to what extent the local food production system is able to support the population's food consumption levels. In addition, LFF allows to investigate the change of land requirements over time (Bosire et al., 2015; de Ruiter et al., 2017; Kastner et al., 2012) and the differences between land availability and land demand (land flows) to assess inequality among regions (land unbalance, land displacement). The novelty of this work lies in analysing the relationship between food systems evolution and landscapes changes assessing land displacement and landscape modification in a time series jointly using the LFF and landscape diversity measures. Previous researches have explored the evolution of land requirements for food (Alexander et al., 2015; de Ruiter et al., 2017) or the relationship between landscape diversity and crop production, comparing the ratio of cultivated land with other landscape indicators (Deng et al., 2017). In contrast, we compared landscape diversity indexes with the land unbalance computed with the LFF. Our LFF assessment is based on a bottom-up approach: starting with the actual food consumption values, the amount of land required to satisfy the local food needs is determined; the difference between actual available land and required land provides a proxy for land displacement over the considered period. In addition, we considered three different years (1970, 1990 and 2010) in order to jointly analyse the landscape changes and those of the food system. This allowed us to investigate the link between the landscape and land balance evolution, highlighting the relationship between local production-consumption pattern and landscape changes, which might provide useful insights for policy makers in order to address action for traditional landscape conservation/restoration.

Results show a change in the LFF time series with a decline in regional food production capacity paired with landscape modification with greater degrees of dominance and human disturbance, aligned with a reduction of labour intensity in agriculture. In summary, these results show that, in response to global food market pressures, land displacement increases and diversified and traditional farming systems have been replaced by specialised, low-labour intensive farming systems and that all these transformations drive to landscape modification.

2. Overview of the state of the art

Food security can be defined as the situation in which “all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (Word Food Summit, 1996). This is a crucial policy issue but its accomplishment is increasingly threatened by climate change as a function of social and environmental processes (Ericksen, 2008) and it might be dependent on food production in foreign lands (O'Brien et al., 2015). In this respect, landscape modifications worldwide jeopardise the provision of food and other ecosystem services essential for human and social well-being (Wu, 2013). Concerns on landscape long-term sustainability have given impulse to the scientific effort for identifying the causes of landscape modification (Bürgi et al., 2005), in search of its main drivers (Klijn, 2004). Given the complexity of factors shaping the landscape feature, the identification of the drivers requires a multidisciplinary research approach and an integrated application of related policies (Jones et al., 2007). Manifold factors influence landscape modification (Plieninger et al., 2016) varying at different scale and under different condition (Pinto-Correia and Kristensen, 2013). In Europe, in the last decades, a growing number of case study researches on the drivers of landscape modification have been carried out (Bieling et al., 2013; Hersperger and Bürgi, 2009; Mottet et al., 2006; Serra et al., 2008). Changes in food demand and supply are among the factors that most shaped and affected landscapes of the entire globe. To analyse this relationship some studies have focused on the relationship between crop production and landscape (Benoît et al., 2012; Deng et al., 2017; Le Féon et al., 2010) underlining that crop production is affected by landscape modification (Mace et al., 2012; Petersen and Nault, 2014; Sayer et al., 2013) and it may affect food security especially at local level. According to Deng et al. (2017) there is a negative correlation between crop productivity and landscape modification. According to Deng et al. (2017) the impact of landscape diversity on crop production occurs both by ecological factors (quality of soils, climate, water etc.) and by economic factors (size of cultivated area). The Mediterranean area is affected both by agriculture abandonment and agriculture intensifications in function of local specific economic and ecological factors (Pinto-Correia and Kristensen, 2013; Sluiter and de Jong, 2007). In our paper we provide information on the relationship between food systems and landscape diversity highlighting the different role played by ecological and economic factors through the time series. Indeed, in the past, ecological factors have played a prominent role in defining cropping and farming systems whereas more recently economic factors have played a major role in agricultural transformations leading to landscape changes. The relationship between the landscape changes and the food systems is poorly explored, although a growing attention is posed by scientific literature to the disconnection between food production and food consumption (Fader et al., 2013). In this respect, many studies have analysed the food production potentiality at country level focusing on the dependency of countries on food imports (Falkenmark and Lannerstad, 2010; Rockström et al., 2009) on the basis of the population's food needs. These researches compute the countries' food consumption on the basis of individual nutritional daily needs (3000 kcal per capita) resulting from indications for a balanced diet. However, the food consumption is not only influenced by nutritional issues but also by cultural, economic, social and physical issues (Charreire et al., 2010; Hesse-Biber et al., 2006; Wang, 2001). According to that, this paper focused on the current diet of the case study population. In particular, we developed a two-step bottom-up approach to assess LFF evolution and its impacts at the landscape level. Our paper relies on a food system approach by analysing the food chain length over the period of analysis by investigating the amount of locally produced food consumed in the region over the time; in this aim we also used actual consumption values, which include food waste, considering both food utilisation (at a nutritional and social level) and food availability (production opportunities at a local level) (Ingram, 2011). First, we assessed the agricultural land needed to satisfy regional demands for selected food items (wheat, milk, and meat) in 1970, 1990, and 2010. Then, we compared this time series with a number of indexes measuring landscape diversity and further indicators describing changes in the regional agricultural system. We adopted a case study approach to address the variability of landscape modification at different scales and conditions (Pinto-Correia and Kristensen, 2013). Indeed, case study research provides insight of place specific condition and characteristics that are crucial in landscape studies (Fischer et al., 2011), enhancing the comprehension of relationships between different forces at local level. Nevertheless case study research poses limitation in upscaling and transferring research output and in findings generalization (Kinzig, 2012). Our paper address this weakness adopting both indicators of driving force at local level (proximate drivers) dealing with human local activities (i.e. agriculture) (Geist and Lambin, 2002) and indicators of driving forces set in motion by large scale processes like national and international policies, demographic trends, economic systems and market pressures (underlying drivers) that have influence at local level and on the proximate drivers (i.e. the global food market).

3. Case study, materials, and methods

3.1. Case study

The island of Sardinia (Italy) accounts for 1.639.362 inhabitants, with approximately 68 inhabitants/km^2 (ISTAT, 2013). Regional area covers approximately 24.100 km^2, mainly dominated by grasslands and meadows (55%) and arable land (13%). Urban area covers approximately 3.8% of the regional territory, whereas the Italian urban area is approximately 7.6% of the national territory (ISPRA, 2017). Moreover, Sardinia accounts for approximately 0.7 ha of Agricultural Utilised Area (AUA) per capita (ISTAT, 2018a). This value is much greater than the Italian mean of 0.2 ha of AUA per capita (Roser and Ritchie, 2018). Sheep breeding has been for thousands of years the most important sector of the farming system (EC, 2015). This specialisation is partly due to a low productivity of soils and to the climate of the island, characterised by fairly rainy winters and hot dry summers (Pungetti, 1995). Nevertheless, Agriculture and the food sector have played a crucial role in rural areas and in the economic and cultural history of Sardinia. Besides sheep and goats farming, the main agricultural products are wheat in the plains - especially in the area of Campidano in South-West Sardinia - vineyards, olives and artichokes (Pungetti, 1995).

In this respect, economic growth and technical progress, especially with respect to trade and transports, generated major changes in local food production and consumption systems. This is particularly important because these transformations may affect the multifunctional role of agriculture in assuring rural livelihood and landscape values. Given these features, there are two main reasons why Sardinia is a suitable case study. First, insularity allows to better analyse changes in the food system. Until last decades Sardinia mainly relied on domestic production due to higher costs of transport in comparison with those incurred by other regions of Italy. Second, urban sprawl have been lower than the Italian mean and mostly concerned coastal areas (ISPRA, 2014). Hence, agriculture in the region has had a major role in landscape changes in comparison to urbanization and industrial transformation.

3.2. Materials

The data sources used in this study were FAO for wheat, milk and bovine meat consumption (FAOSTAT, 2014a) and LAORE for lamb meat consumption (LAORE, 2007). We utilised a different data source for lamb meat consumption because the per capita consumption of lamb meat in Sardinia is significantly higher than that in the rest of Italy. According to the Regional Agency for Agriculture

Development, average consumption of ovine meat in Italy was 1.6 kg/capita/year in 2006, whereas Sardinian consumption in 2006 was 11.5 kg/capita/year (LAORE, 2007).

We used data from the Italian Statistical Yearbook for wheat and feed yields in 1970 and 1990 (ISTAT, 1991, 1971) and online data from the ISTAT data warehouse for 2010 (ISTAT, 2010a). This inconsistency in data sources for yields is due to data availability: national statistical yearbooks provided yields for wheat and feed with a regional detail only until 1997; then, these have been provided via one of the ISTAT data warehouse, namely Agri-Istat (ISTAT, 2018b).

The data source for computing nutrient requirements, nutritional value, and dietary ingredients is the Institut National de la Recherche Agronomique (INRA, 1988), whereas the data on regional livestock statistics were provided by the Italian National Institute of Statistics (ISTAT, 2010b, 1991, 1971).

We then used data derived from the Italian General Censuses of Agriculture (ISTAT, 2018a, 1970) to compute landscape diversity indexes in order to examine land-use changes in agricultural areas and to examine the evolution of number of livestock units and days of work over the same period.

3.3. Land food footprint

The ecological footprint (EF) has been defined by Rees and Wackernagel (1996) as a tool to assess: “how much land/water, wherever it may be located, is required to produce the resource flows (consumption) currently enjoyed by that region's population”. The basic approaches, currently adopted in EF, focus on four different indicators of resource impact including carbon footprint, water footprint, land footprint, and material footprint (O'Brien et al., 2015). According to O'Brien et al. (2015) and Bruckner et al. (2015), land footprint has been widely implemented as a metric for assessing actual land needed to meet specific demand using biophysical, economic, or hybrid accounting methods. In particular, the biophysical approach assesses the land food footprint based on land productivity expressed using yield (tonnes per hectare) or conversion rate; this indicates the amount of a given crop yield needed to obtain one unit (kg) of a consumed foodstuff (such as bread, meat, or milk) (Kastner et al., 2014). Some studies combine the biophysical approach with other methods (e.g. Life Cycle Assessment) in order to capture the impact of highly processed products on natural resource use (Bringezu et al., 2012; Kissinger and Rees, 2010). The economic approach is used to compute the land food footprint using different monetary values of the products obtained via harvesting of each considered hectare, usually applying input-output analysis (Weisz and Duchin, 2006; Wiedmann, 2009). The hybrid methods combine the biophysical and economic approaches (Ewing et al., 2012; Meier et al., 2014; Meier and Christen, 2012; Weinzettel et al., 2014, 2013). This study adopts a biophysical approach and compute the land-foot footprint in order to capture the relationship between the food system and land use change.

Some studies (Alexander et al., 2015; de Ruiter et al., 2017) evaluate the land food footprint using a top-down approach; this technique is based on agricultural land-use values, which are used to assess productivity in terms of land capacity to supply food. In this study, we adopted a bottom-up, biophysical methodology according to Qiang et al. (2013). While Qiang et al. (2013) used trade quantities for each product, we used a consumption-oriented methodology, which considers the land needed to sustain the per capita annual food consumption of a given population. We assessed the individual land food footprint for wheat, milk, and meat (bovine and sheep) consumption because these factors represent the main components of the national diet. Cereals are a staple food in the Italian diet (FAOSTAT, 2014b), providing 32% of total calorie intake and 32% of total protein intake (FAOSTAT, 2014a), with meat providing 72% of protein intake. We collected data on regional crop and feed yields, then applied a food conversion rate to assess the amount of agricultural land needed to supply one kilo of each consumed food type (vegetable or animal). We considered all agricultural production cycles for each key food category; these included crop rotation and the entire chain involved in the production of meat and milk, from breeding of the cows to the birth of calves. For vegetables, the food conversion rate allowed us to consider the conversion of raw materials into edible products via primary (e.g. milling) and secondary (e.g. baking) processing. A Feed Conversion Rate (FCR) was adopted to assess the amount of feed necessary to produce one kilo of animal product (meat and milk). We did not consider food waste because it was included in the consumption values (see Kummu et al. (2012) for a detailed analysis of food losses at global level). The agricultural area necessary to produce one kilo of a cereal product was designated according to the following equation (1):

$$area_i = FCR_i / yield_i \tag{1}$$

where, FCR_i and $yield_i$ are, respectively, the feed conversion rate and yield for crop i. We then calculated the land food footprint for the generic item i (LFF_i), as shown in (2):

$$LFF_i = area_i * consumption_i \tag{2}$$

Land food footprint per capita (LFF_{pc}) is computed as the sum of land food footprint for the k items considered (3):

$$LFF_{pc} = \sum_{i=1}^{k} LFF_i \tag{3}$$

To model the crop rotation pattern, we assumed an agricultural management orientation in which wheat is in rotation with feed, but we did not considered rotation with energy crops or set aside. The land utilised to generate feed crops and produce meat and milk was calculated together with animal protein production in order to determine the net land use for wheat production. To assess LFF for animal products, we considered the specific rearing practises of Sardinian farms. The production efficiencies of crops grown for animal feed are reported in Table 1 (ISTAT, 2010a, 1991, 1971). Data are based on weighted average of the total area and total production of each specific crop in Sardinia. Then, we employed a feed-conversion rate for each type of animal (ruminant or non-ruminant) according to de Ruiter et al. (2017), using a specific conversion rate for the different production levels. While de Ruiter et al. (2017) evaluated the same feed composition for different livestock, we accounted for differences in diet composition depending on species, genotype, type of production (milk or meat), rearing system, and animal performance in terms of fertility and fecundity rate.

For each considered animal species, we adopted a specific feeding system based on cereals and forage. For cattle and sheep, we evaluated grasslands both directly (as pasture) and indirectly

Table 1
Crop yields (q[a]/ha SS) used in domestic animal diets in Sardinia from 1970 to 2010.

	1970	1990	2010
Hordeum vulgare	7.0	14,0	14.9
Zea mays	50.0	65.8	66.8
Forage	43.0	47.8	52.1
Natural pasture	4.8	5.9	5.9

[a] 1 Quintals = 0.1 tonnes.

(as hay). The nutrient requirements, nutritional value, and dietary ingredients were computed according to the Institut National de la Recherche Agronomique (INRA, 1988), and the obtained values are based on milk and meat forage unit.

Based on data on regional livestock statistics provided by the Italian National Institute of Statistics (ISTAT, 2010b, 1991, 1971), we assumed that the dairy husbandry provided 50% of the regional meat supply, whereas cattle husbandry provided the rest. For the meat supplied by cattle husbandry, we took into account autochthonous and French breeds and evaluated feed requirements for young bulls, cows, and heifers. For meat supplied by dairy husbandry, we evaluated feed requirements of, and feed ingested by, young bulls; for cows, these factors were was accounted for when analysing milk production. For cow milk production, we considered the quantity of feed directly ingested by dairy cows, plus a quota of feed ingested by heifers, corresponding to the amount ingested during a 2-year diet.

For sheep's milk production, we considered the amount of feed ingested by “Sarda” dairy sheep, including the period required for maturation from lamb to young ewe (up to 1 year). The feed ingested yearly by sheep were determined for 10 months on milk production and 2 months on lamb-meat production. Lambs are typically fed with milk and slaughtered at approximately 1 month of age at the weight of 10 kg.

FCR is used as a measure of the amount of feed needed to produce 1 kg of animal product. Nevertheless, in our conversion rate, we also considered that the feed, consumed by breeding animals (such as heifers) as part of the production cycle, impacts each kilo of the final animal product. Taking into account all the rearing phases in ruminants, differences in dietary compositions affect FCR, varying as a function of fibre content quality. Table 2 shows the differences in FCR of farming systems evaluated in our study, expressed in kg of dry matter (DM) per kg of animal product. Finally, the total animal production was multiplied by its respective conversion ratio to obtain total crop requirements, to assess the land needed to supply the amount of consumed animal foods and to define the LFF.

We used this methodology to evaluate the years of 1970, 1990, and 2010 with respect to population size, key consumption of foodstuff, crop yield, and land use data per year. This approach allowed us to calculate changes in LFF compared to land availability for each year. To assess whether, and to what extent, land imbalance occurred, we compared the LFF of the local population with regional land availability expressed as agricultural utilised area (AUA); this was determined using data provided by the National Agricultural Census (ISTAT, 2018a) for each considered year. This analysis enabled us to assess the imbalance between regional land availability and regional land demand (LFF) for these years, which can be used as an indicator of food-chain length and regional ability to support food consumption of the local population. We then compared the evolution of land imbalance with landscape modification and agricultural labour data during the examined period.

3.4. Landscape diversity indexes and rates of change

According to Defries et al. (2002), landscape changes are an expression of environmental impact that involves climate change, soil fertility, and genetic diversity. Landscape modification is also associated with reduced net primary production (NPP), which describes organic matter produced via photosynthesis and not used for plant life maintenance and respiration. Reduced NPP indicates a reduction in capacity of the land to sustain human life (Defries et al., 2002). Landscape modification in rural areas mirrors the increased pressure on natural resources (agricultural specialisation), changes in rural economic systems, market-oriented and intensive farming (low labour intensity), reduction in food diversity, and delocalisation of production. We focused on landscape diversity indexes over the time to assess landscape changes. As reported previously, landscape diversity involves two main aspects: richness and evenness. Richness refers to the number of different land cover types, and evenness is used to measure the incidence of each land use area with respect to total area considered. The Shannon index combines these two measures of landscape diversity into a single number and is widely used in different fields (Nagendra, 2002). To analyse the change in landscape over time, we first calculated three indexes: i) Shannon, ii) Dominance and iii) Sharpe for land use in 1970, 1990, and 2010. Then, we used two basic indicators expressing the relative proportion of land cover types: *AUA /Total* and *Arable land /AUA*. We consequently analysed agricultural labour intensity using data on the amount of labour per hectare for the years considered.

The Shannon index was initially developed to quantify entropy in strings of text (Shannon, 1948); then, it was used in ecological applications to analyse the apportionment of abundance into animal and plant species (Barabesi et al., 2015). To assess landscape diversity in this study, we used this index to show variance in the proportion of land cover for different crops (Deng et al., 2017) during the considered period. The Shannon diversity index (4) was computed as:

$$H = -\sum_{i=1}^{k} p_i \ln p_i \tag{4}$$

where, p_i denotes the proportion of the crop i related to AUA (Agricultural Utilised Area) and k is the total number of land use categories in the study area. Minimum diversity is indicated when $H = 0$ (for a unique type of land with a relative abundance of 1) and maximum diversity when $H = \ln k$ (all the crops show a relative abundance of $1/k$). Moreover, this index can be modified to better evaluate the patterning of ecosystems in space (O'Neill et al., 1988), resulting in a measure of dominance expressed as (5):

$$D = \ln k + \sum_{i=1}^{k} p_i \ln p_i \tag{5}$$

$\ln k$, the maximum term of the Shannon index, is useful for comparing landscapes with different numbers of land-use types. Landscape diversity decreases with increasing values of D, because only a few land-cover categories dominate the total AUA. We also used the Sharpe index, which shows the rate of change per crop type for each period (Sharpe et al., 1981). This is expressed in ha/year/km^2 and can be calculated using formula (6):

$$C = \frac{(n_{i2} - n_{i1})}{(t_2 - t_1)} \Big/ S \tag{6}$$

where, $(n_{i2} - n_{i1})$ is the difference in hectares of the area covered by land category n_i during the period $t_2 - t_1$; S is the total surface of the study area in km^2; and $(t_2 - t_1)$ is the difference in years (Hulshoff, 1995). With respect to the other indicators used in this study, the ratio *AUA /Total* quantifies the balance between

Table 2
Feed conversion ratios expressed as kg of feed/kg of weight gain (INRA, 1988).

Animal products	FCR	Percentage of grass in feed (DM basis)
Milk	0.93	52.94
Beef meat	15.47	67.38
Sheep milk	2.74	54.89
Lamb meat	13.65	64.41

productive and natural areas within the total agricultural land. Indeed, agriculturally utilised land represents areas subject to human intervention, which affects biodiversity while concurrently contributing to food production. Similarly, the ratio *Arable land* /*AUA* provides a measure to assess human disturbance. In the context of farming systems, arable land is an agricultural area that is subjected to frequent processing. An increasing amount of arable land on AUA denotes an increased degree of human disturbance, which affects biodiversity (Rundel, 1998). We then analysed labour intensity of the farming systems using data on average labour days per hectare during the examined period. The labour intensity indicator allows the assessment of industrialisation of agriculture. Indeed, a reduction in labour is associated with farming systems characterised by high input, high productivity, advanced management, and market orientation (Alexandratos, 2006).

4. Results

Fig. 1 shows LFF composition for wheat, meat, and milk per capita, indicating 6407 m^2/per capita in 1970, 5755 m^2/per capita in 1990, and 4653 m^2/per capita in 2010. The decrease in the relative incidence of LFF for each food type, except lamb meat, was due to decreased consumption of the food categories evaluated in this study and increased agricultural productivity.

These values are considerably higher than those from Kastner et al. (2012) and O'Brien et al. (2015). According to the latter the cropland footprint of the EU-27 in 2010 was of approximately 2900 m^2/per capita. On the other hand, Kastner et al. (2012) indicate, for Southern Europe, a cropland requirement for food of approximately 3500 m^2/per capita (with minor differences between 1970 and 1990). This difference is even more marked considering that both these studies also include vegetables, sugar crops, oil crops, starchy roots and many others. Nevertheless, this difference is perfectly consistent with the difference in crops yield in Sardinia and in Southern Europe. For example, according to ISTAT data, the yield of wheat in Sardinia in 1990 was of 10.22 q/ha (ISTAT, 1991) whereas it was of 28.73 q/ha in Southern Europe (FAOSTAT, 2014c).

Results in Table 3 show the LFF per capita and total LFF for wheat, meat, and milk. Our results show a positive land balance and a decreasing trend from 1970 to 2010, indicating greater regional food supply in the previous years despite lower productivity levels of agriculture in 1970. In fact, during the 1970s, agricultural specialisation and rural exodus were only beginning, and farming systems were highly diversified. In 1970, available land exceeded regional population LFF by 60%, whereas in 2010, the percentage of available land exceeding the LFF decreased to 27%. These findings indicate that regional ability to support the human population in terms of food availability is decreasing.

Table 4 shows the LFF per capita and total LFF related to the consumption of bread and pasta (wheat). In all the years evaluated in this study, total LFF exceeded available land, showing a regional land imbalance. In addition, the land imbalance increased from 1970 to 2010 due to abandonment of wheat cultivation and/or substituting wheat with more profitable crops.

These results may be somewhat limited by the reliability of data used in this study. This is mainly because FAOSTAT consumption data are higher than those reported in other sources (Coldiretti, 2016; ISMEA, 2014). Nevertheless, the different datasets confirmed the general trend in consumption patterns. Hence, FAO was the preferred data source because of its homogeneity and comparability in time series.

Table 5 shows LFF per capita and total LFF for meat and milk, as well as permanent grassland with respect to total available land; pastures were taken into account during computing of the LFF.

In 1990, the LFF per capita associated with the production of meat and milk is 3813 m^2 per capita, whereas in 2010 it is of 3624 m^2 per capita. The 1990 value is quite close to that from de Ruiter et al. (2017), according to which, in 1986, grassland footprint associated with UK supply of beef, mutton and milk was of 3095 m^2 per capita. In contrast our value is much higher than that of de Ruiter et al. (2017) for 2010, showing a grassland footprint of 2376 m^2 per capita. Our results indicate that the available land was sufficient to satisfy the regional consumption of meat and milk, but the land balance for these products decreased over time mainly due to reduction in permanent grasslands. Despite population growth, individual LLF decreased due to increased agricultural productivity. Land available for meat and milk production included permanent grassland and land supporting fodder crops; as shown in Table 6, permanent grassland was strongly reduced from 1.328.048 ha in 1970 to 692.987 ha in 2010, whereas that supporting fodder crops increased from 78.383 to 228.678 ha. When LFF for meat and milk, and LFF for wheat, were considered jointly, the link between evolution of local food systems and the food market became even

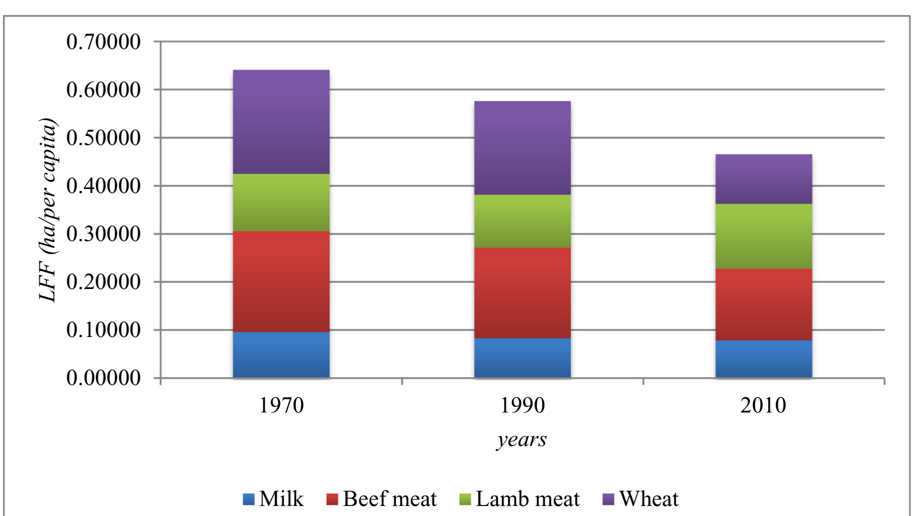

Fig. 1. LFF per capita composition in 1970, 1990 and 2010.

Table 3
Total land footprint and available land with respect to wheat, meat, and milk production (taking into account the role of pasture in the diets of domestic animals).

Year	Total Population	LFF (ha/per capita)	Total LFF (ha)	Available Land (ha)	Land Balance (ha)	Land Balance (%)
1970	1476528	0.6407	946071	1512574	566503	60%
1990	1646142	0.5755	947307	1059508	112201	12%
2010	1639764	0.4653	762914	967071	204157	27%

Table 4
Land food footprint per capita and total land food footprint for wheat.

Year	Total Population	LFF (ha/per capita)	Total LLF (ha)	Available Land (ha)	Land Balance (ha)	Land Balance (%)
1970	1476528	0.2164	319491	106143	−213348	−67%
1990	1646142	0.1942	319607	84511	−235096	−74%
2010	1639764	0.1028	168631	45406	−123225	−73%

Table 5
Land food footprint per capita and total land food footprint for meat and milk.

Year	Total Population	LFF (ha/per capita)	Total LLF (ha)	Available Land (ha)	Land Balance (ha)	Land Balance (%)
1970	1476528	0.4244	626580	1406431	779851	124%
1990	1646142	0.3813	627700	974997	347297	55%
2010	1639764	0.3624	594282	921665	327383	55%

Table 6
Relative incidence of crops on AUA (including permanent grassland) shown in hectares.

Category	1970		1990		2010	
Cereals	133′219	7.56%	206′007	15.17%	104′986	9.10%
Vegetables	21′322	1.21%	19′023	1.40%	14′784	1.28%
Fodder crops	78′383	4.45%	185′511	13.66%	228′678	19.82%
Other arable crops	82′699	4.69%	47′774	3.52%	45′190	3.92%
Vine	65′320	3.71%	47′900	3.53%	18′935	1.64%
Olive	31′979	1.82%	40′735	3.00%	36′472	3.16%
Citrus fruit	5′474	0.31%	7′418	0.55%	4′105	0.36%
Fruit	11′956	0.68%	12′996	0.96%	4′887	0.42%
Other permanent crops	2′621	0.15%	257	0.02%	292	0.03%
Kitchen gardens	0	0.00%	805	0.06%	1′290	0.11%
Permanent grassland and meadows	1′328′048	75.38%	789′486	58.14%	692′987	60.07%
Others	842	0.05%	106	0.01%	1′086	0.09%
AUA	**1′761′864**		**1′358′018**		**1′153′691**	

clearer. On one hand, due to climatic and morphologic conditions, wheat crops are not suitable for cultivation in Sardinia, with the exception of the great plain of Campidano. Consequently, imported wheat, which is sold at lower prices and poses formidable competition, may have been the cause of reduction in land dedicated to wheat.

Conversely, specialised sheep farming ensures a positive land balance for meat and milk. A land surplus appears to endure despite a decrease in land balance over time, enabling the regional food system to redirect meat and milk products to the national market. Our findings show that during the years analysed in this study, evolution of the local food system was interconnected with landscape changes. With respect to landscape diversity indexes, data derived from the Italian general censuses on agriculture were partially reclassified according to the level of detail provided in the 1970 census. AUA composition is shown in Table 6. Changes in landscape patterns were shown by the numerical (Table 6) and graphical (Fig. 2 [1]) analyses of relative incidences of different crops in the agricultural areas.

Between 1970 and 2010, agriculture reduced the production of numerous food crops, increasing fodder crops and leading to landscape changes (Fig. 2). The 1970 AUA shows a balance between cereals, fodder crops, vine vegetables, and other arable crops; total arable crops covered approximately 75% of total AUA. In 2010, fodder crops alone covered approximately 50% of total AUA. The results obtained using the Sharpe index are useful for evaluating changes in land use. Fig. 3 shows which land uses were more responsible for landscape modifications. Landscape composition during the period examined in this study showed a generalised reduction in fruit, vine vegetables, and cereal land covers. Concurrently, a generalised increase in fodder crops affected landscape features. Landscape changes were largely linked to regional agricultural specialisation in sheep rearing, which was driven by evolution of the global food market.

Landscape diversity indexes were calculated based on the data presented in Table 6, and results are shown in Table 7.

Our results reveal that the Shannon index showed a decreasing trend, indicating lower landscape complexity with loss of aesthetic value and biodiversity. Fruits, vine vegetables, and cereals

[1] The AUA graphical composition was examined without taking permanent grassland into consideration because this land category represented the greatest part of AUA. Therefore, it would have been difficult to analyse differences in relative changes for other land categories.

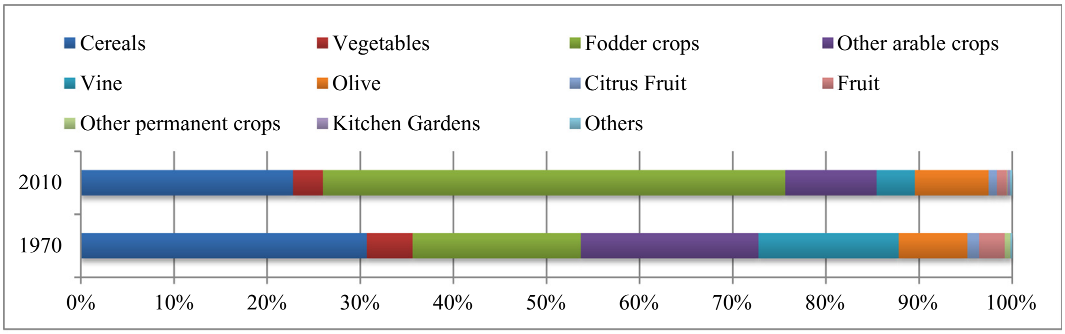

Fig. 2. AUA composition in Sardinia in 1970 and 2010 (without considering permanent grassland).

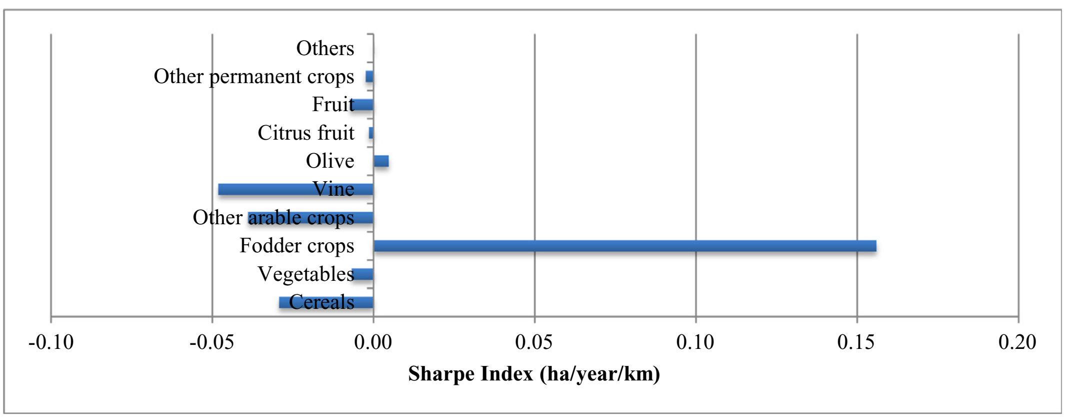

Fig. 3. Sharpe Index over the period 1970–2010.

Table 7
Landscape diversity indexes over the period of 1970–2010 as calculated without taking permanent grassland into consideration.

Index	1970	1990	2010
Normalised Shannon Index	0.826	0.699	0.643
Dominance Index	0.382	0.693	0.822

diminished in favour of fodder crops. Based on these data, the Shannon dominance index showed an upward trend, indicating the growing dominance of land-cover types related to specialisation and abandonment of farmland. The greatest gap was found between 1970 and 1990. According to FAO from 1960 to 1990, global cereal production has more than doubled and meat consumption has increased (FAOSTAT, 2014a). The results for land cover indicators are presented in Table 8. The AUAT indicator shows a greater proportion of agriculturally utilised areas, implying that natural areas, such as woodland and grassland, were minor component of the overall area. The AAUA indicator revealed that within the agriculturally utilised area, arable land steadily grew from 73% in 1970 to 85% in 2010. As explained above, this denotes a greater degree of human disturbance because arable land requires intensive management.

Table 8
Indicators for land-cover categories.

Indicator	1970	1990	2010
AUAT (AUA/Total)	0.540	0.502	0.592
AAUA (Arable land/AUA)	0.732	0.806	0.854

Sallustio et al. (2017) assessed habitat quality in Italy and found that it decreased when progressing from less to more intensively cultivated areas. Fig. 4 shows the trends of Shannon Diversity and Dominance Indexes for land imbalance, evolution of work days per hectare, ovine per farm, and AAUA ratio. In the first plot, decreasing diversity is paired with decreased land balance for meat and milk, and increased land imbalance for wheat. The trends of these indexes show that landscape modification reduced the capacity of agricultural land to support the food needs of the local population. Land imbalance was assessed relative to increases in wheat production because the available agricultural land was less able to satisfy the local demand for bread and pasta; concurrently, land

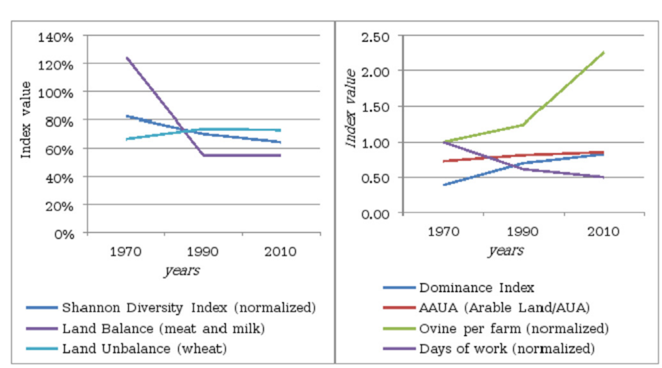

Fig. 4. Agriculture and landscape trends.

balance relative to meat and milk diminished.

The negative relationship between the Shannon Diversity Index and Land Unbalance is consistent with results from Deng et al. (2017) who found that landscape diversity increase with the decrease of cultivated land ratio and that crop production is positively related with the ratio of cultivated land. This also supports the assumption that food production affects landscape diversity.

The second plot shows that increases in the dominance index are paired with increases in the portion of arable land, number of ovines per farm, and labour days per hectare, indicating a transition toward less labour-intensive, and more market-oriented and productive, crops. This finding implies a greater specialisation of the local agricultural system, especially with respect to sheep farming. The second plot confirms that landscape modification is linked with increasing pressure on natural resources, and that specialised and industrialised agriculture affects the environment and ability of the land to support human life.

5. Discussion and conclusions

Between 1970 and 2010, factors, such as Green Revolution and Common Agricultural Policy, have bolstered agricultural specialisation and industrialisation to fulfil the requirements of national and international markets in terms of cost effectiveness and productivity. Competition from global markets leads to abandonment of unsuitable areas and intensified use of more productive areas. In this process, cost minimisation prevails over distance minimisation, but not without consequences. In this study, we evaluated these consequences showing that the delocalisation of regional food production systems (land displacement) causes landscape changes (simplification and degradation) over the time, with several implications in term of policy interventions. In consideration to that the consumption of locally produced foods may ensure landscape conservation, promoting local development and revitalising rural areas. In fact landscape changes (assessed using the Shannon diversity index) are paired with decreasing farm-labour intensity (indicated by the labour days index). This witnesses agricultural exodus and abandonment of rural settlements affecting rural viability and vitality. In consideration to that, shortening the food supply chain as well as promoting quality labels may help landscape preservation and rural development. Promoting consumption of locally produced food could generate different three main benefits. First, recoupling food production and consumption at the local level may help restoring the traditional landscape (Serra-Majem et al., 2017). As a consequence of landscape restoration, the Sardinia tourist offer might be extended, relieving congestion on coastal areas (Gao et al., 2014). Second, it may stimulate the local economy, creating new employment and business opportunities (Van Huylenbroeck et al., 2007). Third, the promotion of local food is positively related to the food system sustainability, gastronomic and cultural heritage conservation and food biodiversity protection. The environment is also more vulnerable to intensive farming systems so that the promotion of sustainable local systems helps protecting biodiversity while at the same time reducing transport costs and carbon dioxide emissions (Serra-Majem et al., 2017). Of course, the viability of a policy preserving domestic cropland is severely limited by economic and weather conditions of Sardinia. Insularity results in additional costs to attract skilled workforce. Moreover, the climate of the region is characterised by fairly rainy winters and quite dry summers which lead to yields lower than the Italian average for most crops. In this respect, a fruitful area for further work could focus on assessing costs and benefits related to the implementation of a policy promoting the enhancement of local production. In this field our results suggest that the monetary value of a traditional rural landscape is likely represented by the difference between the increased cost of producing the formerly locally grown, but currently abandoned, crops and the lower import cost of these abandoned crops. This could represent an innovative contribution to the theoretical framework of landscape economic valuation and it might allow more rational decisions by policy makers (Klijn, 2004) built on public and private goods cost and benefit values.

In conclusion, localizing food consumption/production systems at a regional level is a viable tool in landscape conservation, food security targets, biodiversity, cultural conservation, and sustainability of food systems. This approach can reduce land displacement, energy consumption, and pollution.

This research has also thrown up many questions with respect to disentangling the complexity of food supply chains and how land displacement affects landscape patterns at a wider level of analysis. Although our research approach favour the focus on a specific farming system, it does not allow to track flows of land between regions and/or countries. Nevertheless, our approach is replicable to other study areas (conditional on regional data availability) and easily scalable.

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Declarations of interest

None.

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