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Working Papers - Economics

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Working Paper N. 10/2018

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www.disei.unifi.it

Agricultural landscape change and land footprint from 1970 to 2010: the case study of Sardinia, Italy

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Declarations of interest: none

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Abstract

Urban population growth has triggered a process of change in rural areas and landscape patterns. This transformation has a twofold consequence. On one hand, land conversion causes loss of biodiversity and habitat destruction (Deng et al., 2017). On the other hand, higher levels of food demand, together with the reduction of available land, endanger the capability of supplying food at local level. The local food systems and food security is increasingly dependent by trade and transport costs. Local food system conservation is increasingly recognized as a key factor in the pursuit of sustainable and bio based economy perspective. Land food footprint is a significant tool in assessing food self-sufficiency, land displacement and thus food system sustainability. In this paper we adopt a landscape approach to analyse the evolution of land food footprint and landscape diversity in Sardinia over the period 1970-2010 to assess the impact of land use change and food systems evolution. Time series show a decrease in landscape diversity and greater degrees of few landscape elements dominance, agricultural specialization and land food footprint unbalance. In summary, these results show that diversified and traditional landscape have been replaced by specialised, less diverse landscape where labour-intensive crops and intensive agriculture results in environment impact and in integration of local food systems by food imports, resulting in land unbalance (land displacement), in landscape features simplification and in rural settlements abandon.

Highlights

We quantify regional land food print associated with food local consumption over the period 1970-2010
We assess landscape simplification and we find out it is linked with the food system evolution

Landscape approach is useful to assess production systems externalities

Keywords: Land food footprint; Landscape diversity; Food planning; Landscape quantitative analysis; Land use.

JEL code: Q56

1. Introduction

World's concerns about run-away population growth have raised the debate about natural resource carrying capacity for human life. Scarcity of life-sustain natural resource have raised interests on the concepts of resource constraints and sustainability. Ecological Footprints (EF) are wide spread instruments applied in quantifying the impacts of human activities on natural resources (Ferng, 2011). The ecological footprint 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 resource impact indicators such as 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, as a metric to asses actual land needed to meet specific good demand, is only recently widely implemented using biophysical, economic or hybrid accounting methods. In particular, the biophysical approach assesses the land food footprint (LFF) on the base of land productivity expressed by yield (tonnes per hectare) or by a conversion rate, providing the amount of a given crop yield needed to obtain one unit (kg) of the consumed food (meat, milk etc.). The economic approach accounts the land footprint as different monetary values of the products obtained by the harvest of each considered hectare. The hybrid methods combine the biophysical and the economic approach. The land footprint approach is used to assess differences in land availability and land demands at different scale. LFF is accounted to investigate the change of land footprint over time (Bosire et al., 2015; de Ruiter et al., 2017; Kastner et al., 2012) and the differences in countries land availability and demand (land flows) to assess land use sustainability and inequality between regions. So far, however, no research has been found that analyses the impact of the land food footprint changes on the rural landscape feature. Underpinning the link between land footprint and rural landscape evolution can promote integration of food planning into agricultural policy and urban planning towards more sustainable land use choices. Sustainable land use concept may provide comprehensive view of the social, economic and environmental sustainability of human settlements. People migrations, from the country to the cities, drives urban expansion into agricultural area with loss of cultivated land. The main consequences of such phenomena, at local level, are: increasing urban food demand and population and reduction in bio productive land. These consequences set in motion a vicious cycle in which abandon of rural areas and reduction of agricultural cultivated land are tied with growing urban demand of food at declining prices up to levels to which local agricultural cannot compete, resulting in farms exit. This process endangers both the capability of supplying food at regional level and the environmental sustainability of food production systems increasing regional dependency by global food market and by fossil fuel. The aim of this study is to analyse the LFF evolution and its implication in terms of landscape changes in Sardinia case study over the last 50 years (1970 to 2010) to provide insights of food production and consumption systems externalities. In this aim the paper analyses the regional food production capacity in the time series and explores how this capacity is influencing rural landscape and rural societies values. To this respect, we apply biophysical LFF accounting methods and Shannon, Dominance and Sharpe landscape indexes for two considered scenarios: i) actual time series from 1970 to 2010, ìi) hypothetical time series from updating 2010 consumption and yield with the land use of the previous years (1970, 1982, 1990 and 2000). Results show a change in time series LFF with a great declining in local food self-sufficiency and a decrease in landscape diversity with greater degrees of dominance. In summary, these results show that, in response to global market cost efficiency requirements, diversified and traditional crops have been replaced by specialised, less labour-intensive crops and that the local food system is integrated by food imports, resulting in the following externalities: land unbalance (land displacement), landscape feature simplification and rural settlements abandon. This paper is organized as follows: Section 2 illustrates the method and data collection; in Section 3 we discuss the results; conclusions are reported in Section 3.

2. Case study, materials and methods

The Sardinia island (Italy) accounts for 1.639.362 inhabitants, with approximately 68 inhabitants/km^2 (ISTAT, 2013). Regional area covers about 24.090 km^{2,} mainly dominated by grassland and meadows (55%) and arable land (13%). Urban area covers about 3,8% of the regional territory, while Italian mean is of 7,6% of the national territory (ISPRA, 2017). Moreover, Sardinia accounts for approximately 0,7 hectare of Agricultural Utilised Area (AUA) per capita (ISTAT, 2018). This value is much greater than Italian mean of 0,2 hectare of AUA per capita (Roser and Ritchie, 2018). Nevertheless, economic growth and technical progress, especially with respect to transport sector, has led to major changes in food production and consumption system. In this case study, we develop a two-step consumption oriented approach to assess LFF evolution and its implication, if any, in terms of rural landscape change. First, we assess the agricultural land needed to satisfy regional demand for crop in two scenarios, one actual and one hypothetical, covering the period between 1970 and 2010. Data sources are FAO for wheat consumption (FAOSTAT, 2014a), ISTAT for wheat yields, number of livestock units and days of work (ISTAT, various years). Then, we examine the evolution of land uses for agriculture over the period 1970-2010 through landscape diversity indexes, using data derived from the Italian general censuses of agriculture (ISTAT, 2018).

2.1 Land food footprint

Many studies (Alexander et al., 2015; de Ruiter et al., 2017) provide an evaluation of land food footprint with a top-down approach based on the agricultural land use and on its productivity in term of potentially supplied food. According to Qiang et al. (2013) we adopt a bottom-up, biophysical methodology. While Qiang et al. (2013) use trade quantities for each product, we use a consumption oriented methodology that considers the land needed to sustain the per capita annual consumption of food by a given population. We assess land footprint for wheat, since it is one of the main component of the agro-food sector. Moreover, cereals are an important part of Italian diet, providing the 32% of total protein intake (FAOSTAT, 2014b) and the 32% of the total calorie intake (FAOSTAT, 2014a). We use data on regional yield of crops, then we apply a food conversion rate to assess the amount of agricultural land needed to supply one kilo of each consumed food type. The food conversion rate allows to consider for the conversion of raw materials into edible products through the primary (e.g. milling) and secondary processing (e.g. baking) and for the rotation pattern selected. We do not consider food waste since they are included in the consumption values. Specifically, we assign agricultural area necessary to produce one kilo of a cereal product according to the following equation (1):

$$area_i = FCR_i / yield_i \qquad (1)$$

where FCR_i and $yield_i$ are, respectively, the food conversion rate and yield for crop i. Then, we calculate land food footprint for the generic item i (LFF_i) as in (2):

$$LFF_i = area_i * consumption_i \qquad (2)$$

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

$$LFF_{pc} = \sum_{i=1}^{k} LFF_i \qquad (3)$$

To model the rotation pattern we consider three different land uses according to the regional rotation pattern and agricultural practices (Fig. 1). We assume an agricultural management orientation in which wheat is in rotation with feed. The land utilised for feed crops, supplying the meat or milk production systems, should be computed in animal protein production allowing to account the net land needed for wheat production. Since we do not assess LFF for meat, we will report the gross land needed for wheat production, including rotation area. We apply this methodology to two scenarios: i) one actual scenario considering consumption, yields and land use of each year (1970, 1982, 1990, 2000 and 2010); one hypothetic scenario considering a baseline with 1970, 1982, 1990 and 2000 land use and the 2010 population size, yield and consumption levels. For land food footprint assessment, we use different data sources: for the cereal yield, we obtained the required data by Italian statistical yearbooks (ISTAT, various years); for consumption levels we use FAO data (FAOSTAT, 2014a). The actual scenario allows us to calculate the LFF change in function of the consumption patterns and the land uses of the various years. The hypothetical scenario allows us to evaluate the effect of localization of 2010 regional food demand at local level, referring to past landscapes and land uses under current production practises. To assess whether and how land unbalance occurs, the obtained values of time series LFF is compared with the land use of AUA provided by the National Agricultural Census (ISTAT, 2018) for each considered period. This approach enable us to assess land unbalance between regional land availability and regional land demand (LFF) in the different scenarios. We then compare the actual land unbalance evolution with the time series landscape indexes changes.

2.2 Landscape diversity indexes and rates of change

To analyse the landscape change over time, we first calculate three indexes: i) Shannon, ii) Dominance and iii) Sharpe for 1970, 1982, 1990, 2000, 2010 land use. Then, we use two basic indicators expressing relative proportion of land cover types: $AUA/Total$ and $Arable\ land/AUA$.

Shannon index was initially developed to quantify the entropy in strings of text (Shannon, 1948), then it was used by the ecological literature to analyse the apportionment of abundance into animal and plant species (Barabesi et al., 2015). Here, we apply this index to show the variance in the proportion of land used for different crops (Deng et al., 2017) as a proxy of landscape diversity. The Shannon diversity index (5) is computed as:

$$H = -\sum_{i=1}^{k} p_i \ln p_i \qquad (5)$$

where p_i denotes the proportion of the crop i related to the AUA (Agricultural Utilized Area) and k is the total number of land use categories in the study area. We have minimum diversity when $H = 0$ (there is a unique type of land with relative abundance of 1) and maximum diversity when $H = \ln k$ (all the crops have relative abundance of $1/k$). Moreover, this index can be modified to better deal with the patterning of ecosystems in space (O'Neill et al., 1988), resulting in a measure of dominance expressed as in (6):

$$D = \ln k + \sum_{i=1}^{k} p_i \ln p_i \qquad (6)$$

The use of the maximum term of the Shannon index, $\ln k$, is useful to compare landscapes with different numbers of land use types. Landscape diversity decreases with increasing values of D, because a few land cover categories dominate the total AUA. We also consider the Sharpe index, which shows the rate of change of each crop type in each period (Sharpe et al., 1981). It is expressed in ha/year/km^2 and it can be calculated through the formula (7):

$$C = \frac{(n_{i2} - n_{i1})}{(t_2 - t_1)} / S \qquad (7)$$

where $(n_{i2} - n_{i1})$ is the difference in ha of area covered by land category n_i in the period $t_2 - t_1$; S is the total surface in km^2 of the study area; $(t_2 - t_1)$ is the difference in years (Hulshoff, 1995). With regard to the other indicators used in this study, the ratio $AUA/Total$ quantifies the balance, within the total agricultural land, between productive and natural areas. Indeed, agricultural utilized land represents areas subject to human intervention which affects biodiversity, but they contribute to food production. Similarly, the ratio $Arable\ land/AUA$ gives a measure of human disturbance. In the context of farming systems, arable land is the agricultural area more subjected to processing. An increasing amount of arable land on AUA denotes a greater degree of human disturbance for biodiversity. To this respect, Sallustio et al. (2017) assess habitat quality in Italy and find that it decreases when passing from less to more intensively cultivated area.

3. Results and discussion

Results in Table 1 show the cereal LLF for the considered scenarios. As the results reveal in the actual scenario land balance decreases from 1970 to 2010. This means that in 1970 there is a smaller land unbalance, despite the 1970 productivity levels are lower and the consumption are higher than the 2010 ones. This implication is more straightforward in the hypothetical scenario results. 1970 LFF exceeds available land for

57%, while 2010 LFF exceeds available land for 82%. This result shows that past land uses have a positive role in terms of landscape value and in terms of sustainability of land use. These findings may be somewhat limited by reliability of data sources, mainly because FAOSTAT consumption data are higher than data reported from other sources (Coldiretti, 2016; ISMEA, 2014). Nevertheless, we chose to use FAO data due to their homogeneity and comparability in the time series.

Tab. 1 Total Land Footprint and Available Land in the two scenarios considered

Actual Scenario						
Year	**Total Population**	**LFF (ha/per capita)**	**Total LFF (ha)**	**Available Land (ha)**	**Land Balance (ha)**	**Land Balance (%)**
1970	1.476.528	0,2630	388.360	106.143	-282.217	-73%
1982	1.591.703	0,2216	352.747	88.569	-264.178	-75%
1990	1.646.142	0,2307	379.842	84.511	-295.331	-78%
2000	1.632.342	0,2264	369.566	85.400	-284.166	-77%
2010	1.639.764	0,1507	247.032	45.406	-201.626	-82%
Hypothetical Scenario						
Year	**Total Population**	**LFF (ha/per capita)**	**Total LFF (ha)**	**Available Land (ha)**	**Land Balance (ha)**	**Land Balance (%)**
1970	1.639.764	0,1507	247.032	106.143	-140.889	-57%
1982	1.639.764	0,1507	247.032	88.569	-158.463	-64%
1990	1.639.764	0,1507	247.032	84.511	-162.521	-66%
2000	1.639.764	0,1507	247.032	85.400	-161.633	-65%
2010	1.639.764	0,1507	247.032	45.406	-201.626	-82%

With reference to landscape diversity indexes, data derived from the Italian general censuses of agriculture has been partially reclassified according to the level of detail provided in the 1970 census. AUA composition is shown in Tab. 2[1]. Changes in landscape patterns can be highlighted from the numerical (Tab. 2) and graphical (Fig. 1) analysis of relative incidences of different crops accounted in the agricultural area.

Tab. 2 Crops relative incidence on AUA, without permanent grassland

Category	**1970**	**1982**	**1990**	**2000**	**2010**

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[1] We choose to examine AUA composition without considering permanent grassland because this land category represents the greatest part of AUA and it was unaltered in all considered years. On account of this, it would have been difficult to analyse differences in the relative incidence of other land categories.

Cereals	133.219	30,90%	198.558	39,59%	206.007	36,23%	146.009	29,49%	104.986	22,79%
Vegetables	21.322	4,94%	18.441	3,68%	19.023	3,35%	13.461	2,72%	14.784	3,21%
Fodder crops	78.383	18,18%	106.526	21,24%	185.511	32,63%	201.658	40,73%	228.678	49,64%
Other arable crops	82.699	19,18%	51.861	10,34%	47.774	8,40%	50.713	10,24%	45.190	9,81%
Vine	65.320	15,15%	70.128	13,98%	47.900	8,43%	26.301	5,31%	18.935	4,11%
Olive	31.979	7,42%	35.675	7,11%	40.735	7,16%	39.945	8,07%	36.472	7,92%
Citrus fruit	5.474	1,27%	6.995	1,39%	7.418	1,30%	5.798	1,17%	4.105	0,89%
Fruit	11.956	2,77%	12.755	2,54%	12.996	2,29%	8.983	1,81%	4.887	1,06%
Other permanent crops	2.621	0,61%	126	0,03%	257	0,05%	312	0,06%	292	0,06%
Kitchen gardens	0	0,00%	227	0,05%	805	0,14%	1.732	0,35%	1.290	0,28%
Others	842	0,20%	217	0,04%	106	0,02%	174	0,04%	1.086	0,24%
AUA	**431.195**		**501.508**		**568.532**		**495.085**		**460.704**	

As the graphs show, between 1970 and 2010, the agriculture has reduced the production of many food crops, increasing the fodder crops with impact at landscape level. 1970 AUA shows a certain balance between cereals, fodder crops, vine and other arable crops. Total arable crops cover about 75% of total AUA. In 2010 the same category accounts for 85% of total AUA, while fodder crops alone cover about 50%. Sharpe index results are useful to better figure out changes occurred in land use (Fig. 2) detailing which crops are more responsible for landscape transformation. As Fig. 2 shows, the landscape composition in the examined period experienced a generalised reduction of cultivated crops such as fruits, vine, vegetables and cereals; at the same time generalised increase in fodder crops is characterising the landscape feature, as an effect of the regional agriculture specialization in sheep rearing. On the basis of the data presented on Tab. 2, we calculated landscape diversity indexes mentioned above. Results are presented in Tab. 3.

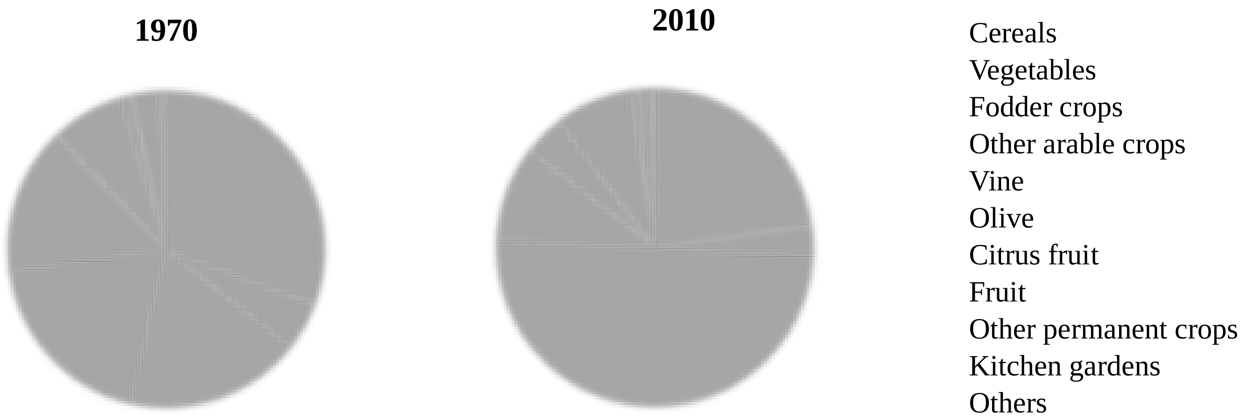

Fig. 1 AUA Composition in 1970 and 2010 in Sardinia (no permanent grassland)

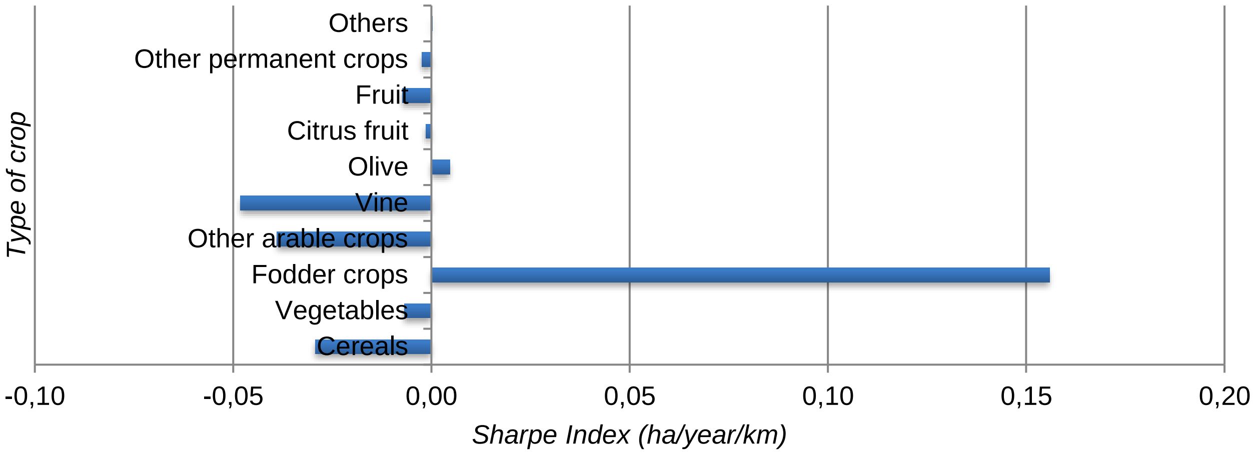

Fig. 2 Sharpe Index over the period 1970-1982

Tab. 3 Indexes of landscape diversity over the period 1970-2010

Index	1970	1982	1990	2000	2010
Normalized Shannon Index	0,826	0,728	0,699	0,681	0,643
Dominance Index	0,382	0,626	0,693	0,734	0,822

The results show Shannon index following a decreasing trend toward a lower landscape complexity and loss of aesthetic value. According to that, Shannon dominance index is on an upward trend, implying an increasing domination of a few land cover types, indicating specialization and abandonment of farmland. The greatest gap can be detected between 1970 and 1982, probably due to the first effects of the CAP (Common Agricultural Policy) bolstering farms specialization through agricultural products price support. Finally, results for land cover indicators are presented in Tab. 4.

Tab. 4 Land cover categories indicators

Indicator	1970	1982	1990	2000	2010
AUAT (AUA/Total)	0,540	0,507	0,502	0,461	0,592
AAUA (Arable land/AUA)	0,732	0,749	0,806	0,832	0,854

AUAT indicator shows a greater proportion of agricultural utilized area, implying a minor component of more natural landscapes, such as woodland and grassland. At the same time, within agricultural utilized area, AAUA indicator reveals arable land has steadily grown, from 73% in 1970 to 85% in 2010. As explained above, this denotes a greater degree of human disturbance, since arable land is subjected to frequent processing. Fig.

3 shows the trend of Shannon Diversity and Dominance Indexes compared with the evolution of days of work per hectare, land unbalance, ovine per farm and AAUA ratio. In the first plot we can highlight that the decreasing diversity is paired with a decrease in days of work per hectare, entailing a transition toward less labour-intensive and more productive crops. At the same time, land unbalance increases because agricultural land available is less and less sufficient to satisfy food demand at local level. In the second plot we can see how the growth of dominance index goes hand in hand with the increase in the portion of arable land and in the number of ovine per farm, implying a greater specialization of the local agricultural system, especially with reference to sheep farming.

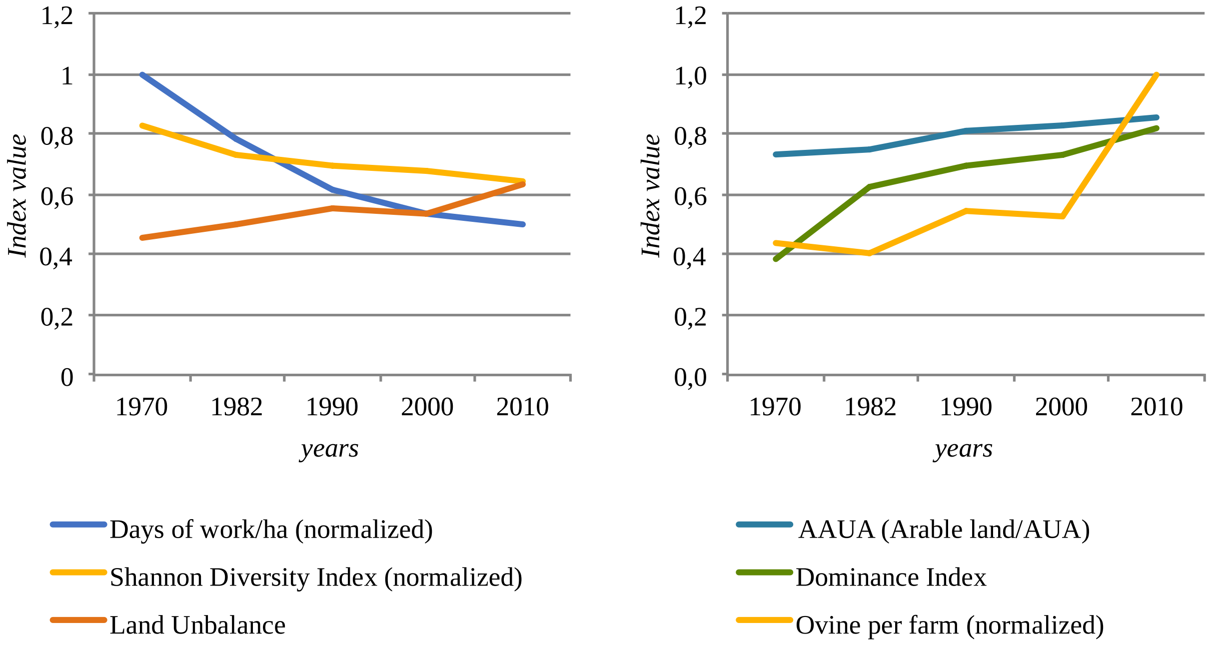

Fig. 3 Agriculture and landscape trends

4. Conclusions

This study underlines the connection between landscape and agri-food systems. The transition from short and local supply chains towards longer and international chains severed the bond between food production and food consumption, changing the features of territory, landscape and society. This confirms the multifunctional role of agriculture and its combined provision of private (food) and public goods (landscape).

The implication of that is that landscape simplification and degradation means delocalization of regional food production systems (land displacement and food import) and rural societies' heritage and tradition loss. In fact landscape simplification (Shannon diversity index) is also paired with decreasing farms labour (days of work index), which may imply rural exodus and abandonment of rural settlement with loss of cultural and social richness. In this respect, one interesting finding is the abandon of less productive areas and the intensification of specialised productive areas with negative externalities in terms of biodiversity, landscape values, traditions and food security. A possible explanation for this might be that between 1970 and 2010 the agricultural sector transformation process is led by Common Agricultural Policy measures and by the market requirements in terms of cost effectiveness. Cost minimization prevails on distance minimization, not without consequences. Even though per capita amount of AUA would be sufficient to satisfy Sardinian levels of food consumption for the selected key foodstuff, we found that wheat balances are negative for every year and scenario considered. The study underlines the productive landscape dimension as a functional space whose simplification endangers the local capability of supplying food. A key role to address land displacement is played by local actors food choices. The consumption of food produced locally promotes local development, revitalizing rural systems and protecting landscape and ecosystem values. Moreover, the enhancement of culinary heritage can contribute to the sustainability of food systems and to the protection of cultural and gastronomic diversity (Serra-Majem et al., 2017). Another possible solution to boost local agricultural competitiveness may involve the use of quality labels and the shortening of the supply chain, in a monopolistic competition perspective. In conclusion, localizing food consumption/production system at regional level may represent a viable tool to address landscape conservation, food security, biodiversity and cultural conservation, sustainability of consumption (reduction in: land displacement, energy consumption, pollution), ensuring sustainable and resilient settlement systems in a bio-economy perspective.

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Captions

Fig. 1 AUA Composition in 1970 and 2010 in Sardinia (no permanent grassland)

Fig. 2 Sharpe Index over the period 1970-1982

Fig. 3 Agriculture and landscape trends

Tab. 1 Total Land Footprint and Available Land in the two scenarios considered

Tab. 2 Crops relative incidence on AUA, without permanent grassland

Tab. 3 Indexes of landscape diversity over the period 1970-2010

Tab. 4 Land cover categories indicators