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Published version:

DOI:10.1016/j.jchb.2018.06.006

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Spatial diffusion of surnames by long transhumance routes between highland and lowland: A study in Sardinia

A. Orrù[a], , S. De Iasio[b], P. Frederic[c], M. Girotti[a], R. Boano[a], E. Sanna[d]

[a] Department of Life Sciences and Systems Biology, University of Turin, Italy
[b] Department of Biosciences, University of Parma, Italy
[c] Department of Economics “Marco Biagi”, RECent (Center for Economic Research), University of Modena, Italy
[d] Department of Environmental and Life Sciences, University of Cagliari, Italy

A B S T R A C T

We explored the relationships among Sardinian populations by means of a spatial analysis of surnames in five villages in the historical–geographical zone of Barbagia di Belvì, a mountainous area traditionally devoted to sheep-herding and the point of departure of transhumance toward lowland areas. We collected the surnames of 19th century Sardinian populations through the Status Animarum (parish censuses). The structures of past populations were compared with current structures based on surnames reported in telephone directories. The lowland villages studied have been the final destination of transhumance and have a different historical, cultural and economic background. The spread of surnames in Sardinia may have occurred also by means of transhumance which took place every year along precise routes from the pastoral mountain zones to the agricultural plains.

The standardized index of Chen and Cavalli-Sforza was used to calculate relationships among the five villages of Barbagia di Belvì (Aritzo, Belvì, Desulo, Gadoni and Tonara). An application of non-metric multidimensional scaling to the isonymy matrices showed that the villages of Barbagia di Belvì form a group that have changed very little over time. Transhumance routes were studied by spatial autocorrelation (Moran’s I) applied to surnames. The results suggest that there has been an appreciable admixture between the Sardinian populations of the mountain villages of the central areas and the populations of southern lowland villages.

Riassunto:

Nel presente lavoro sono state esaminate le relazioni tra le popolazioni sarde attraverso l’analisi dei cognomi in cinque comuni della zona storico-geografica della Barbagia di Belvì (Aritzo, Belvì, Desulo, Gadoni e Tonara), area montuosa tradizionalmente dedita all'allevamento delle pecore e punto di partenza della transumanza verso zone di pianura. I cognomi della popolazione sono stati rilevati dai registri parrocchiali (Status Animarum) del XIX secolo. La struttura cognominale di questo periodo è stata confrontata con quella attuale, ricavata dallo studio dei cognomi riportati negli elenchi telefonici, dei comuni di pianura, transito e destinazione finale della transumanza, che hanno un differente fondo storico, culturale ed economico. La diffusione dei cognomi in Sardegna, infatti, potrebbe essere avvenuta anche attraverso la transumanza, che si verifica ogni anno lungo percorsi precisi dalle zone montane pastorali alle pianure dedite all’agricoltura.

È stato utilizzato l'indice standardizzato di Chen e Cavalli-Sforza per calcolare le relazioni tra i cinque comuni della Barbagia di Belvì. L'applicazione del non-metric multidimensional scaling alle matrici di isonimia ha mostrato che questi comuni formano un gruppo che è cambiato molto poco nel tempo. Le direttrici di transumanza sono state studiate mediante la spatial autocorrelation (Moran's I) applicata ai cognomi. I risultati suggeriscono che vi è stata un'apprezzabile commistione tra le popolazioni sarde dei comuni di montagna delle aree centrali e quelle dei comuni della pianura meridionale.

Introduction

Surnames have a cultural origin and reflect the ethno-historical, socioeconomic and linguisticbackground of a given population, especially relevant in the context of population mobility(Colantonio et al., 2003, Cheshire, 2014). In “Western” countries, surnames are transmitted from father to children and are similar to a genetic marker, comparable to neutral and highly polymorphic alleles of a Y-chromosome locus (Boattini et al., 2012, Colantonio et al., 2003, Crow, 1983, Darlu et al., 2012, Graf et al., 2010, Jobling, 2001, Jobling and Tyler-Smith, 2003, King and Jobling, 2009a, King and Jobling, 2009b, King et al., 2006, Lacerenza et al., 2017, Lasker, 1985, Lucchetti et al., 1987, Martínez-Gonzalez et al., 2012, Robledo et al., 2015, Sykes and Irven, 2000, Winney et al., 2012). It is usual to select autochthonous DNA donors based on the original surnames of the place of residence (Manni et al., 2005, Winney et al., 2012). Using this specific surname-based approach, several genetic studies observed historical population genetic structure or past admixture events that were otherwise invisible (Bowden et al., 2008, Hill et al., 2000, Larmuseau et al., 2012, McEvoy and Bradley, 2006). Surname analysis can be also used to study migrations (Degioanni and Darlu, 2001, Bloothooft and Darlu, 2013).

The generalized origin of surnames in Italy was decreed by ecclesiastical regulations (*Rituale Romanum*) of the Council of Trent (1545–1563). These rules also prescribed that individuals should be indicated by their first name and surname in the census of the Catholic population (*Status Animarum*).

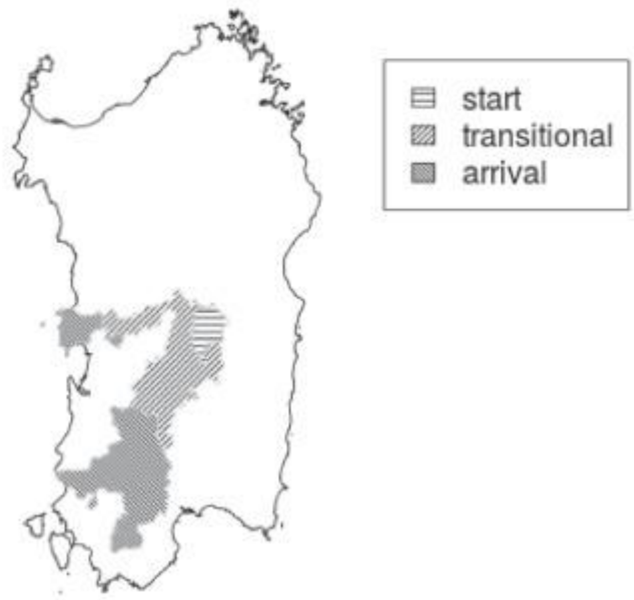
In many populations, civil sources can also be used: lists of surnames for the entire population (family heads, telephone subscribers, users of other utilities, etc.) are readily available. The relatively easy sampling, similarity with genetically inherited traits and high polymorphism make surnames particularly suitable for the study of microevolutionary processes in populations from the 17th century onward (Lucchetti et al., 2008). Evolutionary processes in populations, isolation, and migrations based on the surname analysis can be considered complementary to other methods (Boattini and Pettener, 2013, Henneberg, 1979, Zei et al., 1993).

In this paper we analyze the spread of the typical surnames from the central area of Sardinia.

Earlier studies on the distribution of surnames in Sardinia have demonstrated that: they act like neutral alleles (Zei et al., 1983a, Zei et al., 1983b, Zei et al., 1986); the migration matrices determined from the temporal differences in surname distributions agree with what is known about the history of the population and its mobility (Wijsman et al., 1984); the temporal variation of the frequency of surnames is 10 times lower than the spatial variation (Zei et al., 1986); the similarities among village populations based on the relative distribution of erythrocyte markers agree with the similarities among villages based on surname distributions (Lucchetti et al., 1987); isonymic relationships among various

Sardinian villages follow the isolation by distance model and the isonymy among nearby villages increases in time (Sanna et al., 2001, Sanna et al., 2006). Moreover, the genetic homogeneity of Sardinians, shown by the distribution of some Y-chromosome genetic markers, is not confirmed when samples are formed based on the zone of origin of the surnames of sampled individuals rather than their zone of residence (Zei et al., 2003).
It is also noteworthy that the isonymic difference/similarity among various municipalities of Sardinia is conditioned by their geographical location and historical background (Sanna et al., 2006, Orrù et al., 2008). The Sardinian municipalities form a particular and well defined cluster when compared with other Mediterranean communities (Lucchetti et al., 2008).
The island has presented two different but complementary socioeconomic and cultural realities through the centuries. One, typical of mountainous areas, is characterized by mainly pastoral activities, while the other, typical of lowland areas, is characterized mainly by agricultural activities (Sanna and Danubio, 2008). This economic system remained the same until the second half of the 20th century (Sanna, 2006).
There were two basic types of transhumance in Sardinia: short-range, involving movements within the same municipal territory or toward nearby villages, and long-distance, from the western slopes of the Gennargentu Massif in central Sardinia to the south-western plains (Le Lannou, 1941, Ortu, 1988, Sanna and Danubio, 2008).
Sardinian shepherds who practiced long-distance transhumance remained for about six months in the plains, where the flocks wintered: transhumance began in December and was finished at the end of April (Meloni, 1982, Sanna and Danubio, 2008). The transhumance covering the longest distances started in the villages forming Barbagia di Belvì and Barbagia di Ollolai, with migrations to the wintering areas of up to 150 km. To reach the wintering areas, the flocks of Barbagia had to cover many kilometers of highlands and plains densely populated by farmers. Sometimes, en route, this created conflicts with the owners of the lands bordering the winter pastures (Le Lannou, 1941).
The spread of surnames in Sardinia may also have occurred by means of long-distance transhumance, occurring every year along precise routes from the pastoral mountain zones to the agricultural plains.

Historically, the territory of the island is divided into 34 zones (Ghiani Moi, 1964). This categorization provides important information about the territorial distribution of people in Sardinia: people living in the same zone have likely shared the same habits, living conditions, food, meteorological features, etc. We considered a subset of these zones, i.e. only the ones involved in transhumance (Fig. 1). The point of departure of transhumance toward lowland areas was the zone of Barbagia di Belvì, a mountainous area traditionally devoted to sheep rearing. From the genetic point of view, the population of this zone is considered one of the most conservative of the island (Calò et al., 1998, Cappello et al., 1996, Vona and Calò, 2006).



STARTING ZONE	ARRIVAL ZONE	TRANSITIONAL ZONE
Barbagia di Belvì	Campidano di Cagliari	Barbagia di Ollolai
	Campidano di Oristano	Barbagia di Seulo
	Iglesiente	Sarcidano
	Sulcis	Trexenta
		Marmilla
		Zona Tirso
		Arborea
		Mandrolisai

Fig. 1. Historical-geographical zones of Sardinia involved in transhumance. Highlighted areas are starting, transitional and arrival points.

We obtained the frequencies of surnames of these mountain populations in the 19th century and in recent times and compared them with the current distribution of surnames in the lowland villages. These lowland populations live in a cultural and economic environment very different from that of the populations of Barbagia di Belvì.
The aims of this paper are: 1) to highlight the relationships among the Sardinian populations in relation to transhumance, and 2) to determine if transhumance resulted in appreciable admixture between the pastoral populations of the mountains and the agricultural populations of the plains.

Methods

The populations considered were those of the villages of Aritzo, Belvì, Desulo, Gadoni and Tonara, which form the historical-geographical zone of Barbagia di Belvì (Ghiani Moi, 1964), and the populations of the lowland areas, which were the traditional destination of transhumance.

In order to describe the structure of surnames in the ancient population of Barbagia di Belvì, we used the books of the *Status Animarum*, the ecclesiastic books of censuses in which the priest recorded the name and surname of the head of the household and the other family members.

The registers of all the villages of Barbagia are available only since 1840; before that, there are no years for which the parish books of all five villages are present contemporaneously. Nevertheless, we extended the analysis by considering the *Status Animarum* books of 1815 for Aritzo, Belvì and Gadoni, of 1816 for Desulo, and of 1811 for Tonara; in addition, we consulted the *Status Animarum* of 1844 for Desulo. We compared these data with the recent distribution of surnames in the transit and destination villages of transhumance obtained from telephone subscribers in 1993. The telephone directory lists the people who reflect the family groups living in a given area, so much so that this device has been frequently used in various demo-ecological and genetic analyses of Italian populations (Boattini et al., 2012, Risso et al., 2015).

Fig. 2 shows the geographical distribution of the villages of Barbagia di Belvì and their long-distance transhumance routes.

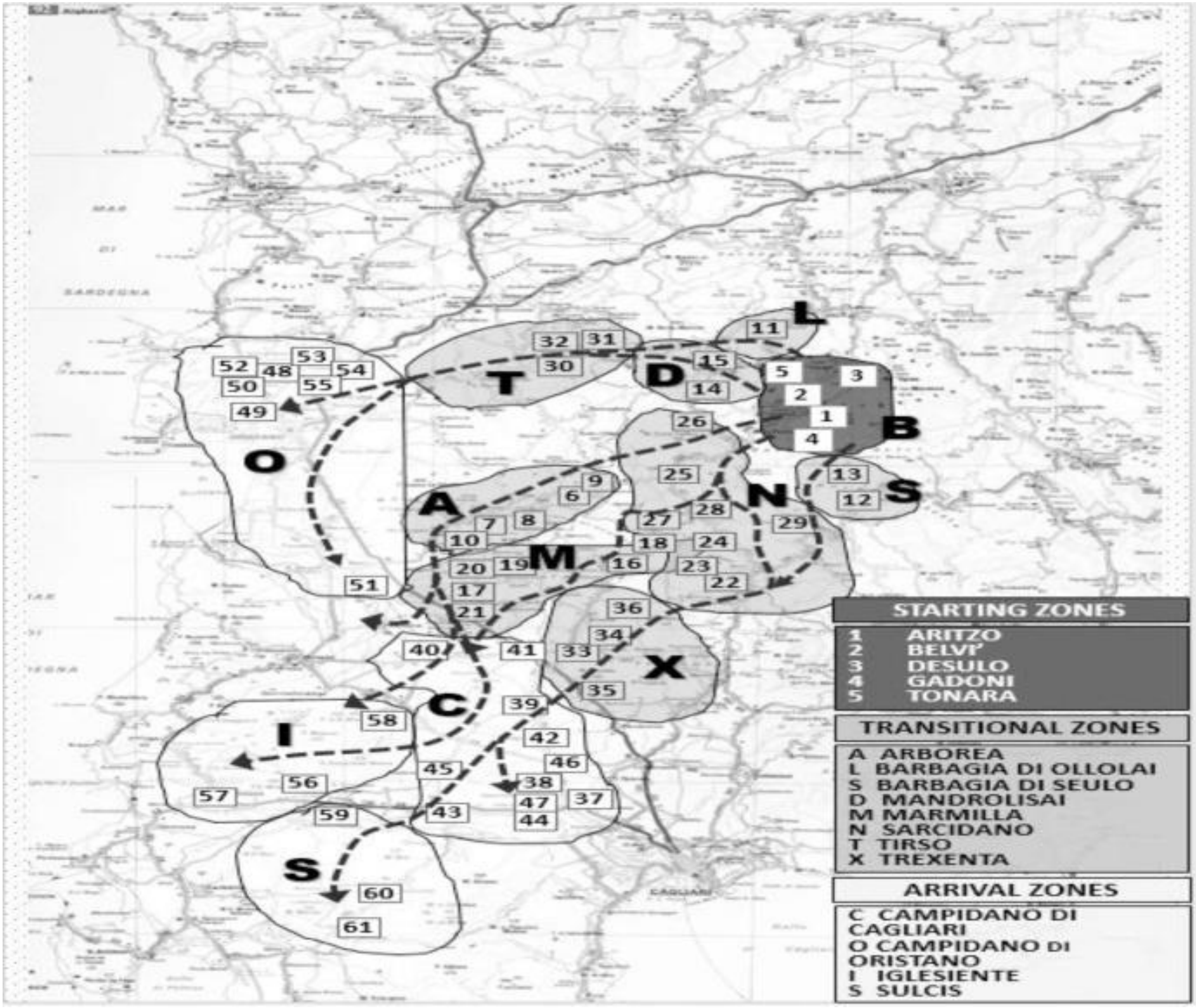


Fig. 2. Map of the geographical distribution of the villages of Barbagia di Belvì and long-distance transhumance routes.

Table 1 reports the number of records of the *Status Animarum* registered in the years considered; from each act, we extracted the surname of the householders to identify the original surnames in Barbagia di Belvì. This table also reports the number of surnames present in the telephone directories of 1993.

Table 1. Villages of Barbagia di Belvì. Years examined, number of householders (*Status Animarum*), number of individuals present in the telephone directories (Telephone directories). In brackets, the percentage obtained by dividing the number of different surnames present in the municipality by the total number of individuals listed in the telephone directories or in the *Status Animarum*.

Status Animarum											***Telephone directories***	
Years											**Year**	
	1811		**1815**		**1816**		**1840**		**1844**		**1993**	
Villages												
Aritzo	–		580	(18.45)	–		479	(19.83)	–		483	(25.26)
Belvì	–		225	(30.66)	–		205)	(29.76	–		215	(40.00)
Desulo	–		–		473	(18.60)	463	(17.49)	455	(17.58)	755	(25.16)
Gadoni	–		83	(51.81)	–		206	(27.18)	–		314	(29.94)
Tonara	651	(15.36)	–		–		655	(16.18)	–		729	(24.55)
Total	651	(15.36)	888	(24.66)	473	(18.60)	2008	(19.87)	455	(17.58)	2496	(20.31)

Table 2 reports the records of the surnames present in the telephone directories of 1993 in the villages involved in transhumance, from each historical-geographical area.

Table 2. Historical-geographical zones involved in transhumance, number of villages, number of different surnames, number of individuals present in telephone directories, percentage of different surnames with respect to the total number of individuals considered concerns the telephone directories of 1993.

Telephone directories				
	No. of villages	**No. of surnames (S)**	**No. of householders (N)**	**S/N %**
Zones				
Barbagia di Belvì	5	507	2496	20.31
Arborea	5	237	774	30.62
Barbagia of Ollolai	1	63	175	36.00
Barbagia of Seulo	2	154	637	24.18
Campidano di Cagliari	14	2707	16499	16.41
Campidano di Oristano	8	1266	5984	21.16
Iglesiente	3	2761	13445	20.54
Mandrolisai	2	281	996	28.21
Marmilla	5	540	2563	21.07
Sarcidano	8	690	3699	18.65
Sulcis	2	543	1787	30.39
Tirso	3	243	916	26.53
Trexenta	3	538	2689	20.01
Total	61	7105	52,660	13.49

The isonymic relationship between populations was calculated with the index of “standardized isonymy” proposed by Chen and Cavalli-Sforza (1983):

$$R_{ij} = \frac{\sum_x (x_i x_j)}{\sqrt{\sum_x x_i^2 \sum_k x_j^2}}$$

where R_{ij} is the coefficient of similarity between two populations *i* and *j*, x_i and x_j are the frequencies in them of the *x*-th surname, and the total is extended to all the surnames. The value of R_{ij} is zero when the two populations do not have any surname in common; it is 1 when the two populations share the same surnames with equal frequencies, independently of their numbers.

The isonymy index was used to produce a similarity matrix between the populations of the five villages of Barbagia di Belvì, the starting area of transhumance. Non-metric multidimensional scaling (nmMDS) was used to produce a synthetic plot of the isonymic relationships among the five Sardinian villages and their variation in time. The results showed that the five villages have a peculiar surname structure, very diversified and self-preserved over time. This allowed us to proceed with a subsequent spatial investigation. When sampling locations are known, the association between genetic and geographical distances can be tested by spatial autocorrelation or geographically weighted regression methods.

Spatial autocorrelation analysis was applied to the quantitative data summarizing the genetic similarity between populations in relation to their proximity in space. In this specific case, spatial autocorrelation allows us to determine the similarity of values of the frequency of a surname between pairs of localities within arbitrary distance classes. This method allowed estimation of the spatial distribution of the selected surnames in the starting, transitional and arrival areas of transhumance in order to emphasize the specific diffusion processes of the individuals independently of the migration rates of the various localities. Spatial autocorrelation was developed by Moran (1950) and refined by Ripley (1981) and by Cliff and Ord (1981). It was first applied to biological problems by Sokal and Oden, 1978a, Sokal and Oden, 1978b. The computation of spatial autocorrelation requires a set of localities represented as points on the plane (Caravello and Tasso, 1999). We used Sardinian municipalities located along transhumance routes and compared the results with the remaining municipalities of the island not involved in transhumance. The coefficient of autocorrelation (Moran's *I*) is calculated as:

$$I_x = \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - x)(x_j - x)}{\sum_{i=1}^{n}(x_i - x)^2},$$

where *x* represents the surname, w_{ij} is a proximity weight representing the degree of relatedness between location *i* and *j* (greater relatedness implies a higher weight); *n* is the number of locations; x_i and x_j are the frequency of name *x* at location *i* and *j* respectively. Moran's index has been widely used in surname analyses (Caravello and Tasso, 1999, Caravello and Tasso, 2007, Román-Busto et al., 2013, Tasso and Caravello, 2010). The *I* coefficient generally varies between −1 (negative autocorrelation) and +1 (positive autocorrelation). In the absence of spatial autocorrelation, the expected value is −1/(n − 1), where n is the size of the sample. A significant negative autocorrelation indicates that at a determined distance the frequencies of a variable are dissimilar, while a significant positive autocorrelation indicates a similarity between populations; a non-significant value shows no relationship between pairs of frequencies of a surname at a certain distance (Sokal and Oden, 1978a).

In this study we have selected the 18 most common surnames extracted from the ancient registers of parish censuses of the considered villages. We think that these surnames have a low level of polyphyletism, since they are absent or present at very low frequencies in the other parishes for which it was possible to obtain data from the 19th century.

We explored two different proximity matrices $W = \{w_{ij}\}$, one based on transhumance regions $W_T = \{w_{ij}^{(T)}\}$ and one based on non-transhumance regions $W_{\overline{T}} = \{w_{ij}^{(\overline{T})}\}$.

In the transhumance matrix W_T, weights $w_{ij}^{(T)}$ were chosen such that

$$w_{ij}^{(T)} = \begin{cases} 1, & \text{if region } i \text{ and } j \text{ are both transhumance regions} \\ 0, & \text{if not,} \end{cases}$$

Instead, matrix $W_{\overline{T}}$ is such that

$$w_{ij}^{(\overline{T})} = \begin{cases} 1, & \text{if region } i \text{ and } j \text{ are both non} - \text{transhumance regions} \\ 0, & \text{if not,} \end{cases}$$

Both W_T, and $W_{\overline{T}}$ have zeros in diagonal.

Our goal was to check whether some surnames are clustered in transhumance regions. Thus we tested H0 for independence of name *x* in transitional regions.

Results

Table 3 shows the most common surnames originating in Barbagia di Belvì, derived from data of the 19th century *Status Animarum*, and the relative current frequencies in the historical-geographical areas involved in transhumance. These surnames were selected as they were the most frequent in the nineteenth-century *Status Animarum* relating to the five villages of Barbagia di Belvì. Following the current frequency of these surnames in the transit and arrival areas of the transhumance allows us to hypothesize that they have moved along its lines, indicating the migration of surnames.

Table 3. Surnames originating in Barbagia di Belvì and their current relative frequencies in the historical-geographical zones involved in transhumance.

	AGUS	ARANGINO	CABRAS	CASTANGIA	CASULA	FRAU	ONANO	PEDDIO	POLLA
Barbagia Belvì	0.481	1.002	0.601	0.280	2.324	2.043	1.923	2.003	0.521
Arborea	0.000	0.000	1.421	0.000	0.388	0.904	0.000	0.000	0.000
Barb. Ollolai	0.000	0.000	1.143	0.000	0.000	0.000	0.000	0.000	0.000
Barbagia Seulo	2.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Camp. Cagliari	0.006	0.000	0.206	0.006	0.467	0.309	0.000	0.067	0.000
Camp. Oristano	0.050	0.000	0.033	0.518	0.552	0.334	0.000	0.000	0.017
Iglesiente	0.104	0.000	0.208	0.067	0.431	0.238	0.007	0.037	0.000
Mandrolisai	0.000	0.000	0.402	0.000	0.904	0.100	0.100	0.000	0.000
Marmilla	0.000	0.000	0.273	0.039	0.585	0.702	0.000	0.000	0.000
Sarcidano	0.135	0.054	0.027	0.108	0.541	0.108	0.054	0.000	0.000
Sulcis	0.000	0.000	0.000	0.000	0.392	0.560	0.000	0.112	0.000
Tirso	0.328	0.000	0.000	0.000	0.328	1.092	0.000	0.000	0.000
Trexenta	0.037	0.000	0.223	0.112	0.112	2.231	0.000	0.000	0.000

	PORRU	SAU	SECCI	TODDE	TORE	URRU	VACCA	ZANDA	ZUCCA
Barbagia Belvì	1.362	2.564	1.322	1.122	0.761	0.681	1.042	1.683	0.441
Arborea	0.129	0.000	0.000	0.000	0.000	0.129	0.129	0.000	0.258
Barb. Ollolai	0.571	0.571	0.000	2.857	1.143	0.000	0.571	0.000	3.429
Barbagia Seulo	0.471	0.000	0.314	1.413	0.000	0.000	0.000	0.000	0.000
Camp. Cagliari	0.133	0.018	0.582	0.097	0.006	0.036	0.430	0.115	0.424
Camp.Oristano	0.033	0.000	0.033	0.000	0.000	0.017	1.203	0.033	0.368
Iglesiente	0.074	0.007	0.446	0.149	0.015	0.045	0.625	0.186	0.260
Mandrolisai	0.000	0.301	0.201	0.703	0.301	1.807	0.100	0.100	0.000
Marmilla	0.039	0.000	0.078	0.039	0.000	0.000	0.585	0.000	0.273
Sarcidano	0.433	0.027	0.487	0.027	0.000	0.541	0.514	0.027	0.270
Sulcis	0.168	0.000	0.783	0.056	0.112	0.000	0.839	0.056	0.112
Tirso	0.000	0.000	0.000	0.000	0.437	0.437	0.000	0.000	1.201
Trexenta	1.376	0.000	0.000	0.000	0.000	0.112	0.818	0.112	0.223

Fig. 3 shows where these frequencies are higher (dark areas) or lower (white areas). The geographical units represented in Fig. 3 do not exactly cover the historical-geographical areas involved in transhumance. In fact, not all the villages that are part of these historical geographical areas are crossed by transhumance routes, therefore we have taken into account only those directly involved in the transhumance.

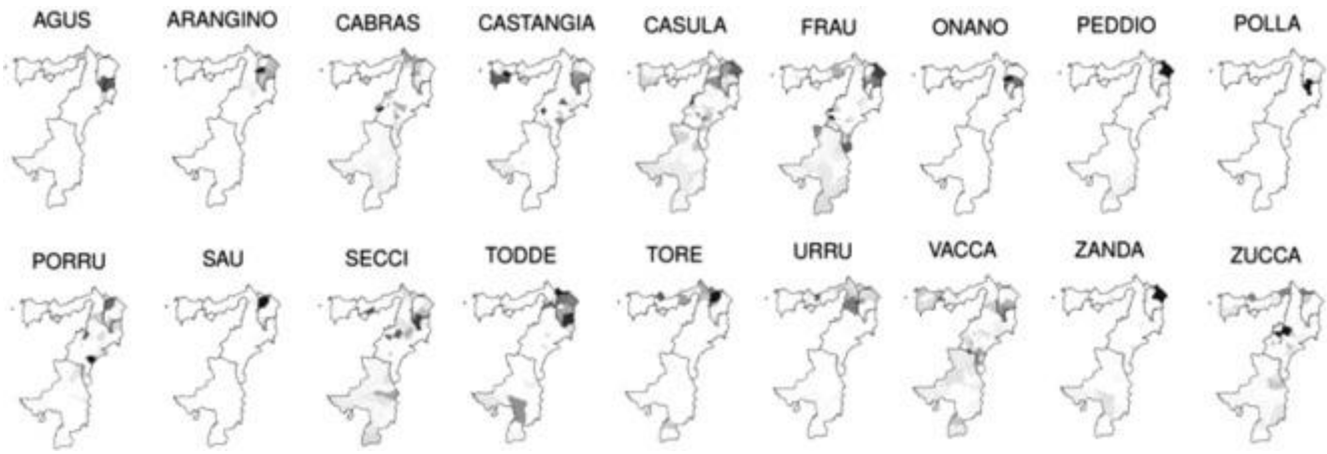
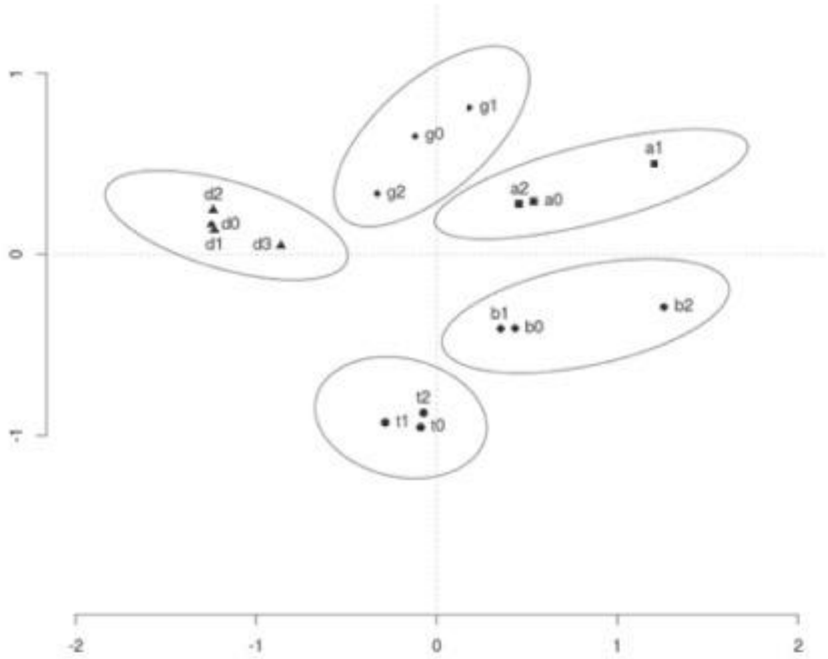


Fig. 3. Current distribution of 18 surnames selected in the historical-geographical zones involved in transhumance; darker regions correspond to higher frequencies.

Fig. 4 illustrates the relationships among the villages of Barbagia di Belvì and their variations in time. The populations are clearly differentiated on the scatter plot and each of them maintains its specific identity in time. The first two dimensions group together the samples of each municipality, keeping the different communities separate from one another. Desulo and Tonara form a closed cluster without differentiation in time; they are the villages with the most homogeneous structure of surnames. Population growth in the first half of the 20th century seems not to have changed the surname structure of the two villages. This was probably because of their greater geographical isolation due to their higher altitude (*ca.* 900 m a.s.L.). The clusters of Gadoni, Belvì and Aritzo are more dispersed. Belvì exhibits two small distinct clusters, one including the 19th century populations and the other the 20th century populations. This indicates that changes have occurred in the interval between the surveys in the structure of the Belvì surnames, becoming even more peculiar: the position of the village is on the edge of the chart. The Aritzo cluster is characterized by the isolation of a1 with respect to a0 and a2. The decrease in the number of inhabitants from 1815 to 1840 may have justified the change of the surname structures and the shift of a1 on the scatterplot.



Villages	*code*	*Villages*	*code*	*Villages*	*code*	*Villages*	*code*
Aritzo 1815	a0	Belvì 1840	b1	Desulo 1844	d2	Gadoni 1993	g2
Aritzo 1840	a1	Belvì 1993	b2	Desulo 1993	d3	Tonara 1811	t0
Aritzo 1993	a2	Desulo 1816	d0	Gadoni 1815	g0	Tonara 1840	t1
Belvi 1815	b0	Desulo 1840	d1	Gadoni 1840	g1	Tonara 1993	t2

Fig. 4. Scatter plot of non-metric multidimensional scaling of the five villages of Barbagia di Belvì in time.

It is interesting to note that, if one tries to invert the y axis, the dispersion of the villages is closely related to their geographical position.

Fig. 5 shows the isonymic relations that exist between the historical geographical areas involved in the transhumance and the five municipalities of Barbagia di Belvì. The first dimension separates the Barbagie (Belvì, Ollolai and Seulo) from the rest of the areas involved, underlining the geographical difference (the Barbagie are the most inaccessible and isolated areas of the island). The remaining areas include two clusters, one comprising the Mandrolisai and Tirso areas, which are geographically closer to the Barbagie, and the other comprising the plain areas.

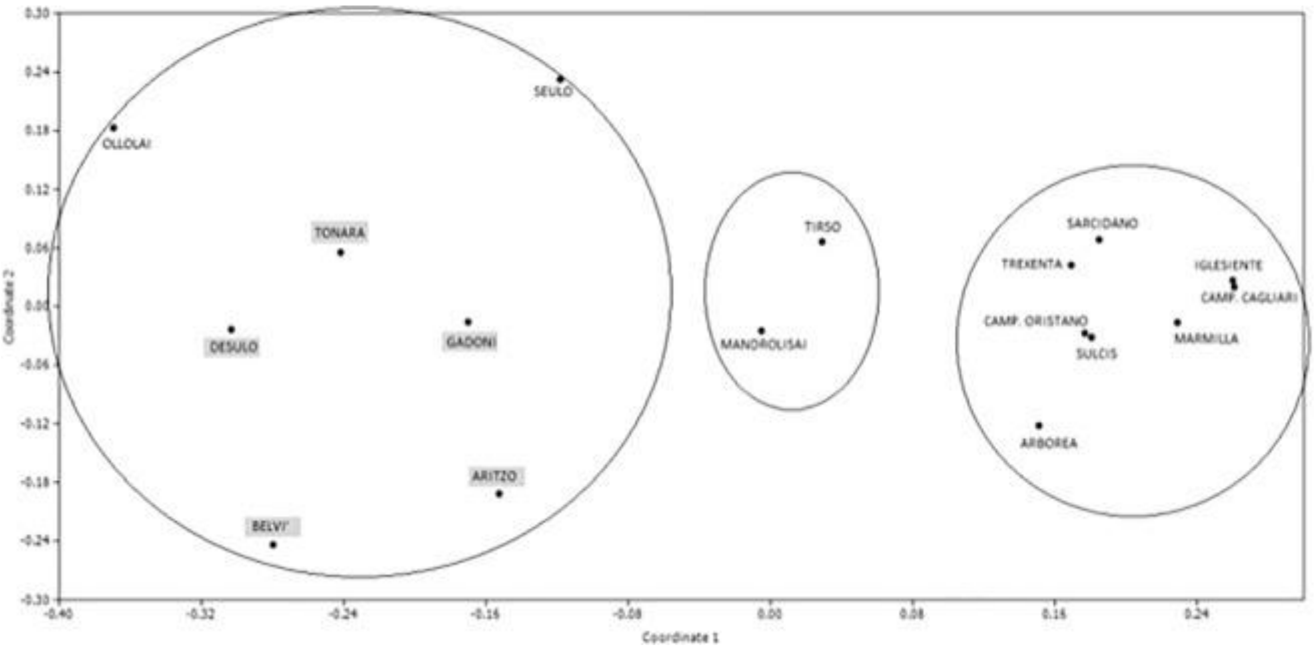


Fig. 5. Scatter plot of non-metric multidimensional scaling of the five villages of Barbagia di Belvì and the historical–geographical zones involved in transhumance in 1993.

Table 4 shows the values of Moran's index with WT. Note that target surnames such as "Arangino", "Castangia", "Casula", "Onano", "Peddio", "Polla", "Sau", "Todde" and "Zucca" have significant Moran's *I* positive autocorrelation. These results indicate that those surnames are clustered in the transhumance regions. In particular, "Arangino" and "Onano" have high values of the index, clearly clustered in the transhumance path, which is consistent with Fig. 3.

Table 4. Moran's *I* evaluated with W_T.

	AGUS	**ARANGINO**	**CABRAS**	**CASTANGIA**	**CASULA**	**FRAU**	**ONANO**	**PEDDIO**
Ix	−0.0158	0.3620	0.0066	0.0578	0.0525	0.0344	0.2239	0.0480
E(Ix)	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027
St. Err.	0.0254	0.0166	0.0264	0.0264	0.0270	0.0271	0.0184	0.0113
***p*-value**	0.6046	**0.0000**	0.7247	**0.0221**	**0.0411**	0.1709	**0.0000**	**0.0000**

	POLLA	**PORRU**	**SAU**	**SECCI**	**TODDE**	**TORE**	**URRU**	**VACCA**	**ZANDA**	**ZUCCA**
Ix	0.0212	0.0285	0.0263	0.0093	0.1040	0.0388	0.0266	0.0350	−0.0170	0.0418
E(Ix)	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027
St. Err.	0.0103	0.0254	0.0127	0.0268	0.0265	0.0242	0.0256	0.0263	0.0235	0.0264
***p*-value**	**0.0209**	0.2199	**0.0220**	0.6549	**0.0001**	0.0872	0.2539	0.1524	0.5424	0.0930

Numbers in bold represent statistically significant values.

Table 5 shows the values of Moran's *I* with W_T. It is noteworthy that each surname has a very low negative Moran's *I*, even the ones with a significant index. This indicates that all the examined surnames are spatially uncorrelated or very slightly negatively correlated in the regions outside of the transhumance routes.

Table 5. Moran's *I* evaluated with W_T

	AGUS	ARANGINO	CABRAS	CASTANGIA	CASULA	FRAU	ONANO	PEDDIO
Ix	−0.0023	−0.0067	−0.0027	−0.0034	−0.0027	−0.0030	−0.0052	−0.0033
E(Ix)	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027
St. Err.	0.0006	0.0003	0.0006	0.0006	0.0006	0.0006	0.0004	0.0002
***p*-value**	0.5779	**0.0000**	0.9325	0.2084	0.9147	0.5288	**0.0000**	**0.0025**

	POLLA	PORRU	SAU	SECCI	TODDE	TORE	URRU	VACCA	ZANDA	ZUCCA
Ix	−0.0030	−0.0051	−0.0030	−0.0023	−0.0031	−0.0041	−0.0038	−0.0045	−0.0030	−0.0087
E(Ix)	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027	−0.0027
St. Err.	0.0002	0.0006	0.0002	0.0006	0.0006	0.0005	0.0006	0.0006	0.0005	0.0006
***p*-value**	0.0610	**0.0000**	0.1182	0.5681	0.4130	**0.0069**	**0.0418**	**0.0013**	0.5591	**0.0000**

Numbers in bold represent statistically significant values.

Table 6 summarized all the villages used in our study, the number of surnames (S) and the number of individuals (N) per municipality, the S/N ratio and the historical-geographical zones of belonging, from the telephone directories of 1993.

Table 6. Villages, number of surnames, number of individuals, S/N ratio and historical-geographical zones of belonging, from telephone directories of 1993.

Code	Villages	Surnames (S)	Individuals (N)	S/N	Zones
Starting Villages					
1	ARITZO	122	483	0,2526	BARBAGIA DI BELVI'
2	BELVI'	86	215	0,4000	BARBAGIA DI BELVI'
3	DESULO	190	755	0,2517	BARBAGIA DI BELVI'
4	GADONI	94	314	0,2994	BARBAGIA DI BELVI'
5	TONARA	179	729	0,2455	BARBAGIA DI BELVI'
Transit Villages					
6	ASSOLO	49	146	0,3356	ARBOREA
7	CURCURIS	33	78	0,4231	ARBOREA
8	GONNOSNO'	104	257	0,4047	ARBOREA
9	SENIS	83	164	0,5061	ARBOREA
10	SIMALA	53	129	0,4109	ARBOREA
11	TIANA	63	175	0,3600	BARBAGIA DI OLLOLAI
12	SADALI	88	311	0,2830	BARBAGIA DI SEULO
13	SEULO	66	326	0,2025	BARBAGIA DI SEULO
14	ATZARA	98	382	0,2565	MANDROLISAI

Code	Villages	Surnames (S)	Individuals (N)	S/N	Zones
15	SORGONO	221	614	0,3599	MANDROLISAI
16	BARUMINI	133	386	0,3446	MARMILLA
17	COLLINAS	84	272	0,3088	MARMILLA
18	GESTURI	125	378	0,3307	MARMILLA
19	GONNOSCODINA	68	169	0,4024	MARMILLA
20	GONNOSTRAMATZA	102	246	0,4146	MARMILLA
21	SARDARA	279	1112	0,2509	MARMILLA
22	ESCOLCA	66	202	0,3267	SARCIDANO
23	GERGEI	130	447	0,2908	SARCIDANO
24	ISILI	305	855	0,3567	SARCIDANO
25	LACONI	193	688	0,2805	SARCIDANO
26	MEANA SARDO	147	566	0,2597	SARCIDANO
27	NURAGUS	91	317	0,2871	SARCIDANO
28	NURALLAO	87	334	0,2605	SARCIDANO
29	VILLANOVA TULO	86	290	0,2966	SARCIDANO
30	BUSACHI	158	492	0,3211	TIRSO
31	NEONELI	84	239	0,3515	TIRSO
32	ULA' TIRSO	59	185	0,3189	TIRSO
33	FURTEI	157	444	0,3536	TREXENTA
34	SEGARIU	125	361	0,3463	TREXENTA
35	SERRENTI	329	1433	0,2296	TREXENTA
36	VILLANOVAFRANCA	110	451	0,2439	TREXENTA
					Arrival Villages
37	DECIMOMANNU	632	1582	0,3995	CAMPIDANO DI CAGLIARI
38	DECIMOPUTZU	261	990	0,2636	CAMPIDANO DI CAGLIARI
39	SAMASSI	364	1360	0,2676	CAMPIDANO DI CAGLIARI
40	SAN GAVINO MONREALE	645	2516	0,2564	CAMPIDANO DI CAGLIARI
41	SANLURI	595	2226	0,2673	CAMPIDANO DI CAGLIARI
42	SERRAMANNA	604	2529	0,2388	CAMPIDANO DI CAGLIARI
43	SILIQUA	360	1098	0,3279	CAMPIDANO DI CAGLIARI
44	UTA	409	1545	0,2647	CAMPIDANO DI CAGLIARI
45	VALLERMOSA	168	451	0,3725	CAMPIDANO DI CAGLIARI
46	VILLASOR	428	1778	0,2407	CAMPIDANO DI CAGLIARI
47	VILLASPECIOSA	180	424	0,4245	CAMPIDANO DI CAGLIARI
48	BARATILI SAN PIETRO	137	341	0,4018	CAMPIDANO DI ORISTANO
49	CABRAS	577	2403	0,2401	CAMPIDANO DI ORISTANO

Code	Villages	Surnames (S)	Individuals (N)	S/N	Zones
50	NURACHI	178	444	0,4009	CAMPIDANO DI ORISTANO
51	PABILLONIS	204	697	0,2927	CAMPIDANO DI ORISTANO
52	RIOLA SARDO	218	613	0,3556	CAMPIDANO DI ORISTANO
53	SAN VERO MILIS	358	903	0,3965	CAMPIDANO DI ORISTANO
54	TRAMATZA	113	263	0,4297	CAMPIDANO DI ORISTANO
55	ZEDDIANI	129	320	0,4031	CAMPIDANO DI ORISTANO
56	DOMUSNOVAS	565	1738	0,3251	IGLESIENTE
57	IGLESIAS	2080	8047	0,2585	IGLESIENTE
58	VILLACIDRO	741	3660	0,2025	IGLESIENTE
59	MUSEI	181	360	0,5028	SULCIS
60	NUXIS	188	463	0,4060	SULCIS
61	SANTADI	313	964	0,3247	SULCIS

Discussion

Data on classical genetic markers (Cavalli-Sforza et al., 1994, Vona, 1997), the HLA system(Contu et al., 1992, Lampis et al., 2000, Grimaldi et al., 2001), autosomal markers (Moral et al., 1994, Calò et al., 1998, Battaggia et al., 2003), mtDNA (Barbujani et al., 1995, Morelli et al., 2000, Malaspina et al., 2000, Richards et al., 2000, Fraumene et al., 2003, Falchi et al., 2006) and Y-chromosome polymorphisms (Semino et al., 2000, Scozzari et al., 2001, Ghiani and Vona, 2002, Francalacci et al., 2003, Quintana-Murci et al., 2003, Rootsi et al., 2004, Capelli et al., 2006) show that the Sardinian population (or its subpopulations) has a peculiar genetic structure that clearly differentiates it from the continental European and circum-Mediterranean populations, as well as from the other populations that currently constitute Italy. Moreover, Sardinia is characterized by specific autochthonous surnames (Lucchetti et al., 1996).

The genetic differences between Sardinians and the other Mediterranean and European populations are very likely due to the upper Paleolithic/Mesolithic settlements of the island (Chikhi et al., 2002, Vona and Calò, 2006, D'Amore et al., 2010), its geographical isolationand, despite the many colonizations, the marginal position of the island with respect to mainstream economic development (Le Lannou, 1941, Sanna, 2006). Therefore, the Sardinian people, considered as a whole or as sub-populations, are very distinct among European populations. Nevertheless, the Sardinian population exhibits microgeographical heterogeneity (Vona and Calò, 2006). In fact, various authors have found marked variabilitywithin Sardinia (Piazza et al., 1985, Porcella and Vona, 1987, Ulizzi et al., 1988, Cavalli-Sforza et al., 1994, Vona, 1997, Cappello et al., 1996, Calò et al., 1998, Vona and Calò, 2006), leading to a mosaic genetic structure of the Sardinian population, often with different patterns according to the considered genetic markers. Regarding the debate about the heterogeneity of Sardinian populations, it is interesting that the Y-chromosome haplogroup that particularly characterizes the Sardinians with respect to other European and circum-Mediterranean populations (I2a2, M26) is distributed almost uniformly throughout the island (Zei et al., 2003). However, Zei et al. (2003) reported that this genetic marker showed high heterogeneity among the three zones that they considered (northern, central-eastern and south-western) when the samples were formed on the basis of the origin of the surnames rather than the zone of residence. Hence, surname analysis is an excellent tool to validate the genetic relationships among populations.

Therefore, Sardinians are heterogeneous in relation to the specific history of the communities living in the island's different historical-geographical zones and also to the isolation of the mountain zones from those of the plains. In particular, Barbagia di Belvì exhibits isonymic variability in relation to the geographical position of its villages.

Comparison of single villages indicates that they are different from each other and the differentiation persists over time, so that the same village maintains its identity over the centuries: evidently, the geographical dimension and the local peculiarities are predominant. This is especially true for the two most isolated villages (Desulo and Tonara) but it also holds for the other villages, perhaps more open to migratory exchanges (Aritzo, Belvì, Gadoni), although they became differentiated over time while maintaining their diversified characterization.

Therefore, our results indicate that transhumance from the mountainous center to the southern lowlands and the recent internal migrations (Sanna, 2006) resulted in an appreciable flow of surnames toward the villages of the southern plains. Likewise, there has been a substantial gene flow between the mountain villages and those of the plains. In addition, the historical and geographical areas of the mountains have retained their specific surname identities, which strongly differentiate them from each other.

Nevertheless, we must consider the possible effect on the results of so-called virilocal marriages, i.e. the custom of celebrating the marriage in the village of the bride and then living in the village of the bridegroom (Sanna et al., 2004, Sanna et al., 2006). Hence the children of parents who have followed the practice of virilocal marriage will bear the surname of the father, who remains to live in his native village. The maiden surnames of brides who migrate from the villages of Barbagia leave no traces in their native villages. It is also true, however, that marriages are not only exchanges of surnames and therefore of genes, but also occasions of cultural exchanges.

The genetic structure simulated by surnames indicates continuity between the populations of the villages of the southern lowlands and the populations of the mountain villages of the central area of Sardinia. Moreover, the latter differ according to the historical-geographical zones to which they belong; in view of their positions on the nmMDS plot, the villages of Barbagia di Belvì are differentiated from each other.

The results suggest that there has been appreciable admixture between the Sardinian populations of the central mountains and those of the southern lowlands.
In view of the similarities found between the surnames of the populations of the central area of the island and those of the lowlands, future research should address the genetic relationships among these Sardinian individuals. For this purpose, studies should include individuals whose origin is known and for whom a genealogical reconstruction is possible.

Acknowledgements

The authors thank the ecclesiastical authorities and the staff of the Archivio della Curia Arcivescovile di Oristano for their assistance with the data collection.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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