Detecting temporal changes in the extent of High Nature Value farmlands: the case-study of Entre-Douro-e-Minho Region, Portugal

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Abstract

In the European Union, the socio-ecological systems underlying the maintenance of low-intensity farming systems supporting the occurrence of several species and habitats are known as High Nature Value farmlands (HNVf).

Detecting trends of change in the extent and location of HNVf is essential to monitor the impact of policies on biodiversity. However, assessing changes in HNVf extent is challenging, due to the lack of tested approaches and lack of data with adequate spatial and temporal resolutions. We address such a challenge by evaluating the usefulness of an existing methodological framework to analyse changes in the extent of HNVf in the agrarian region of Entre-Douro-e-Minho, Northwestern Portugal between 1989 and 2009. Changes in the extent of HNVf between 1989 and 2009 were analysed for whole study area, and within and outside areas designated for conservation.

Results depicted a trend of decreasing extent of HNVf between 1989 and 2009, irrespective of being inside or outside a nature conservation designation. This provides an early warning that nature conservation designation does not ensure HNVf persistence. We consider that this research represents an advance in the field of HNVf assessment and monitoring. In particular, by providing an approach to analyze the location and changes over time of HNVf types in relation to areas under distinct legal protection (such as the Natura 2000 network), it can help assess the role that such nature conservation designations have in protecting HNVf and indicate where additional agricultural or nature conservation policy and support mechanism may need to be targeted.

1. Introduction

Agriculture is a dominant use of the land and a major driver of environmental change in the Anthropocene (DeClerck et al., 2016; Rockström et al., 2017). Increasing population growth and demand for food production places an unprecedented demand on agricultural land, with intensification and climate change resulting in degradation of the world's natural capital through erosion of biodiversity and ecosystem services (Foley et al., 2011; Tscharntke et al., 2012). Representing ~40% of global terrestrial area, agricultural landscapes and underlying farming systems are essential to meet key sustainable development goals such as those related to food security and environmental sustainability (DeClerck et al., 2016). The potential of low-intensity farming systems to support biodiversity while contributing to the delivery of multiple ecosystem services to society has been increasingly highlighted (Power, 2010; Rockström et al., 2017; Swinton et al., 2007).

Within the European Union (EU), the recognition of High Nature Value farmlands (HNVf) from a nature conservation viewpoint goes back to the 90s´ (Andersen et al., 2004; Bignal et al., 1996; Lomba et al., 2014). HNVf are landscapes dominated by agriculture where high nature value, often reflected by the occurrence of species and habitats with conservation interest, depend on the maintenance of specific low-intensity High Nature Value (HNV) farming systems (Andersen et al., 2004; Halada et al., 2011; Lomba et al., 2014). HNV farming systems are adapted to local climatic, geographic and environmental conditions. They are characterized by low levels of agro-chemical inputs, mechanization, and livestock stocking levels and frequent rotational uses of the land, thereby maximizing the appropriation of local natural resources for food security while assuring ecosystem stewardship (Oppermann et al., 2012; Plieninger and Bieling, 2013). The cultural and natural value of HNVf results from the intertwined relationship between farmers and nature over centuries, and therefore represent complex socio-ecological systems (SES) (Lomba et al., 2014; Plieninger and Bieling, 2013). The intrinsic nature value of HNVf relates primarily to: (i) the prevalence of a high proportion of semi-natural habitats (referred as HNVf type 1; hereafter HNVf1); and (ii) the presence of landscape mosaics where crop fields are intermingled with small-scale elements, such as field margins, hedgerows and tree lines (HNVf type 2, hereafter HNVf2). An additional HNVf type 3 is used to indicate the presence of species of conservation interest (e.g. farmland birds, reptiles), in often more intensively managed farmlands, but it was not assessed in the landscape-level case study under consideration here (Andersen et al., 2004; Lomba et al., 2014; Mäkeläinen et al., 2019).

Estimates highlight that about 30% of all EU farmland correspond to HNVf (Paracchini et al., 2008). Currently, such farmlands are mainly found on marginal landscapes under natural constraints to agriculture (e.g. poor soils, steep slopes, often in remote areas), often within Less Favoured Areas and Natura 2000 sites (Brunbjerg et al., 2016). Essential to meet the EU 2020 Biodiversity Strategy Target 3, the extent and condition of HNVf are among the agro-environmental indicators that Member States (MSs) are required to monitor within the EU Common Monitoring and Evaluation Framework (CMEF) of the Common Agricultural Policy (CAP) (Keenleyside et al., 2014; Lomba et al., 2017). Whilst recent analysis reports a sharp decline of areas under HNV farming systems due to socio-economic drivers (market pressures and agricultural policies, lowering farm income and rural population decline) (Keenleyside et al., 2014; Pe'er et al., 2017), dynamics of HNVf in space and time have seldom been scrutinized (Benedetti, 2017; Lomba et al., 2014; Morelli et al., 2014; 2017). Conceptual and methodological challenges have limited the ability of MSs to assess the extent and monitor HNVf trends (Lomba et al., 2014; Strohbach et al., 2015). Assessing the extent of HNVf implies understanding and integrating information on both the socio-economic (i.e. the farming system) and the ecological (i.e. nature value) dimensions of the

SES underlying the nature value of farmlands. It also entails the ability to map areas being managed under HNV farming systems, which in itself requires the ability to define spatially-explicit indicators and associated ranges/thresholds able to discriminate between HNVf and non-HNVf at different scales (Lomba et al., 2014; Strohbach et al., 2015). Operational limitations revolve around the lack of common guidelines and methodological approaches and informative datasets with suitable temporal and spatial resolutions (Lomba et al., 2015). Such challenges have been addressed over recent years, with several research projects developing the use of specific indicators e.g., the application of distinct datasets or methodological approaches for assessing HNVf types, from local (e.g. Pinto-Correia et al., 2018) and regional (e.g. Lomba et al., 2017), to national (e.g. Brunbjerg et al., 2016; Kikas et al., 2018) and EU scales (e.g. Paracchini et al., 2008). Overall, advances rely on the use of distinct sets of indicators defined according to available data at several scales, most of them surrogate indicators of the relevant social-ecological dimensions underlying HNVf (Benedetti et al., 2017). As a result, the methodological approaches used differ, compromising the ability to compare assessments across the full extent of the EU and thereby develop a common assessment of HNVf extent and trends (for a review of methods see also Lomba et al., 2014; for an overview of research see also Benedetti, 2017; Strohbach et al., 2015). In addition, most approaches described to-date have not been applied to other social-ecological contexts and scales using distinct sources of data. Lomba et al. (2014, 2015) proposed a spatially-explicit approach which considers three sets of indicators (landscape elements, reflecting landscape structure and composition; extensive practices and crop diversity, informing on farming systems' characteristics, and indicator species, reflecting the occurrence of species and habitats). This approach was first illustrated at the local scale in northern Portugal (Lomba et al., 2015), and has subsequently been applied in a contrasting social-ecological context at the regional context (the more intensive farmlands of Lower Saxony), using the high spatial (and temporal) resolution data from the parcel-level Integrated Administration and Control System (IACS) dataset (Lomba et al., 2017).

The aim of this current contribution is to evaluate the usefulness of the methodological framework described by Lomba et al. (2015) for assessing High Nature Value farmlands in space and time. To do that, we assessed HNVf extent in both 1989 and 2009, in the agrarian region of Entre-Douro-e-Minho region (EDM), Northwest Portugal. We analyse : (i) changes occurring between these two years, reflected as gains, losses or maintenance of HNVf and the main land use transitions underlying such changes; and, (ii) trends inside and outside areas designated for nature conservation. Finally, we discuss the implications of our results and future perspectives for effective monitoring of HNVf dynamics across the EU.

2. Methods

2.1. Study area

The agrarian region of Entre-Douro-e-Minho area (hereafter EDM), NorthWest Portugal (Figure 1) occupies ~900 729 ha, comprises 6 NUTS III regions, 53 municipalities and 1341 civil parishes, each of the latter coinciding with a local administrative unit (LAU 2, Eurostat, http://epp.eurostat.ec.europa.eu/). Overall, 66.66% of the EDM region is designated as mountain/hill Less Favoured Area (LFA; article 3.3 of the Directive 75/268/EEC). With roughly 23% of the area (204.78 ha) within the EU Natura 2000 Network, EDM encompasses 12 Sites of Community Importance (SCIs), 2 Special Protection Areas (SPAs), the Transboundary Biosphere Reserve Gerês-Xurés (RBTGX), and part of the Peneda-Gerês National Park (for detailed information see Supplementary Material S1). The EDM region includes a mixture of lowland areas, large valleys and mountain massifs, with altitudes ranging from sea level to over 1500 m. EDM topography closely relates to the basins of the main rivers - Minho, Lima, Cávado, Ave and Douro - all exhibiting an ENE-WSW orientation. Dominant bedrock types are granite and schist, with sandy soils occurring along the coast and alluvial soils in narrow strips along the main rivers. Dominated by temperate oceanic and hyperoceanic climates, the EDM has high annual precipitation (> 3,000 mm on mountain tops), short dry periods in summer (1-2 months), and mild temperature regimes.

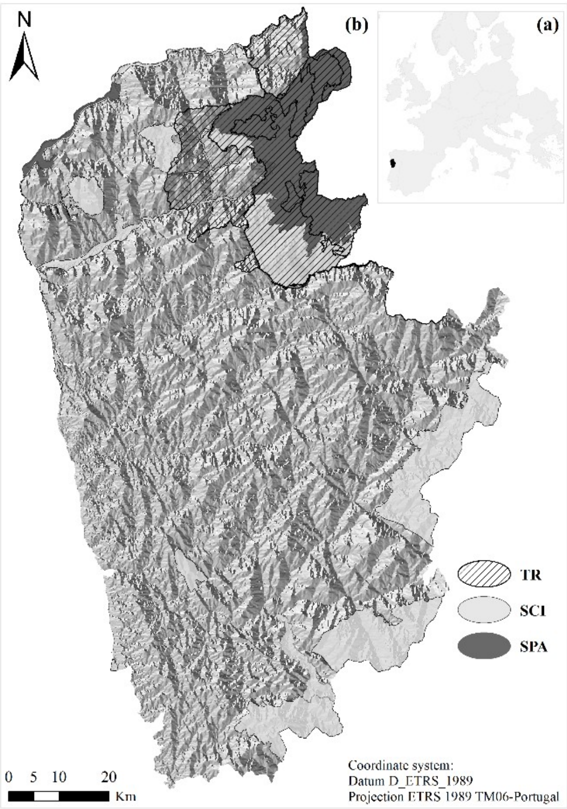

Figure 1. The Entre-Douro-e-Minho agrarian region (b) and its location in the Iberian Peninsula (a). SCI - Sites of Community Importance; SPA - Special Protection Areas; TR - Transboundary Biosphere Reserve Gerês-Xurés (RBTGX).

The EDM region is characterized by heterogeneous landscapes, with larger farms under intensive agricultural practices on the most fertile lowlands, where dairy farming and livestock production are dominant, contrasting with small and scattered low-intensity farms prevailing in the mountains. The dominant HNVf1 (Oppermann et al., 2012) includes the high-altitude irrigated pastures (also known as '*lameiros'*); small terraces, used for the production of a wide range of crops (e.g. potatoes, cereals); and, the common lands (a mix of herbaceous species and shrubs often used for extensive grazing known as '*baldios'*). The occurrence of HNVf2 is reflected via complex, often small-scale, farmland mosaics of arable and horticultural crops, intermingled with vineyards, orchards and small woodlands and permanent pastures for livestock grazing (Lomba et al., 2015; Oppermann et al., 2012). Due to inherent biophysical constraints and resulting low socio-economic viability, mountain HNV farming systems across the EDM region are facing collapse due to agricultural abandonment i.e. the cessation of agricultural management (Beilin et al., 2014; Honrado et al., 2017).

2.2. Spatially explicit assessment of HNVf extent and changes between 1989 and 2009

The extent of HNVf for 1989 and 2009 was assessed by implementing the three-step spatially-explicit approach defined by Lomba et al. (2015). The selection of the period of analysis (1989-2009) reflects the lack of more recent data on farming practices (from Agricultural Census; cf. Table 1). Table 1 presents the sets of indicators used, data sources, and types of HNVf targeted by each indicator.

First, the dominance of farmlands at the parish level (LAU2, the unit of analysis) was determined. To do that, the utilized agricultural area (UAA) per parish was ascertained from fine-scale land cover maps for 1989 and 2009, by considering classes reflecting farmed areas and off-farm areas e.g. grazed heathlands and other grazing areas in common usage, corresponding to other semi-natural areas used as forage or fodder resources (Lomba et al., 2015; see Table S2.1, Supplementary Material S2 for a detailed description of the classes considered). Then, the cover of agricultural ($P.UAA._p$), forest ($P.FOR._p$) and urban ($P.URB._p$) area was determined. Data reflecting natural constraints for agriculture (as defined by Van Orshoven et al., 2012) were applied, so that only heathlands under no or moderate limitations to agriculture were included. The dominance of farmlands was considered when two conditions were met (Lomba et al., 2017): i) a threshold value of 40% for the share of agricultural cover per parish ($P.UAA_p$); and, ii) higher values for the share of agricultural cover ($P.UAA_p$) in relation to the shares of urban ($P.URB_p$) and forest areas ($P.FOR_p$), respectively, per parish. (cf. Supplementary Material S2, Table S2.2). The parishes meeting these criteria were considered eligible for further analyses. Afterwards, for the eligible parishes, land cover classes associated with agriculture (i.e. UAA) were classified according to their potential to exhibit high nature value. The minimum–maximum approach, as defined by Andersen *et al.* (2004) was implemented, resulting in the discrimination between areas with very high likelihood (i.e. classes consisting primarily of HNVf; minimum HNVf areas; $pHNVf_m$) and moderate likelihood (i.e. other classes with potential HNVf depending on the intensity of farming practices; maximum HNVf areas; $pHNVf_M$) of being HNVf1 and HNVf2 farmlands, respectively (see Supplementary Material 2 and Table S2.1 for the classification of land cover classes included in each HNVf type).

Step 2 consisted of a spatially-explicit cluster analysis of the indicators used (except HNVf likelihood) for the parishes dominated by farmlands (Lomba et al., 2017). The cluster analysis allowed the discrimination of parishes under contrasting farming practices, thus more likely to support HNVf in the EDM. Finally, in Step 3, the refinement of HNVf assessment was performed, resulting in the identification of HNVf1 and HNVf2 in the EDM. Overall, such refinement was performed by spatially matching areas under contrasting farming practices with farmlands considered more likely ($pHNVf_m$) to be HNVf1 e.g.

grasslands, pastures, or heathlands in areas suitable for agriculture, and those with moderate likelihood ($pHNVf_M$) as HNVf2 farmland e.g. heterogeneous landscapes (Step 2; Lomba et al., 2015; Lomba et al., 2017).

After determining the area of HNVf1 and HNVf2 for each year (1989 and 2009), changes across years were investigated for: i) gains and losses of the area covered by each HNVf type and areas maintained between years; and, ii) for the qualitative changes in land use in areas where HNVf was lost or gained. After using spatially explicit overlay functions to identify areas where HNVf was lost or gained, a transition matrix was computed, containing changes from *x*, corresponding to the baseline land-cover type (1989), to *y*, the respective 2009 land cover type.

All spatially-explicit analyses were performed using the Spatial Statistics Toolbox for ArcGIS 10.3 (ESRI, 1999-2015). Landscape metrics were computed using Patch Analyst 5.1 extension for ArcGIS (Rempel et al. 2012), considering each civil parish as the unit of analysis (i.e. a landscape; (Lomba *et al.*, 2015). All indicators were tested for their correlation using Spearman correlation coefficient in Excel (Excel, 2013), and a threshold value of 0.7 was established as a maximum for their inclusion in the analysis (Dormann *et al.*, 2013).

A spatial autocorrelation analysis (Global Moran's I; ESRI, 1999-2015) was applied to evaluate patterns (clustered, disperse or random) exhibited by used indicators at the parish level (Table 1). As identifying continuous landscapes under HNV farming systems was the goal of this research, only indicators exhibiting clustered patterns (reflected as positive Moran's I index values) were considered for subsequent analysis. Cluster analysis was performed using the ArcGIS©ESRI Mapping Clusters toolset (ESRI, 1999-2015). To ensure a landscape-level approach to the cluster analysis, the Grouping Analysis tool was implemented with K-Nearest Neighbours as spatial constraints parameters. Statistical outcomes reflected overall and within group statistics, the discrimination ability of each indicator used in the analysis (with better discrimination reflected as higher R^2 values), and an evaluation of the optimal number of groups (reflected as higher values for the Calinski-Harabasz pseudo F-statistic; hereafter F-statistic). F-statistic assesses grouping effectiveness and reflects within-group similarity and between-groups differences. All values are presented as mean ± standard deviation (SD).

2.3. Spatially-explicit assessment of HNVf and areas designated for nature conservation

The assessment of changes in the extent of HNVf in areas designated for nature conservation in the EDM region focused on Natura 2000 sites, including two Special Protection Areas (SPAs) and twelve Sites of Community Importance (SCIs), the most focused legal conservation designation in the EDM (see Supplementary Material S1, Table S1 and Figure S1). The two SPAs designated in the EDM overlap in ca. 90.60% of the area with SICs, with only ca. 9.40% of SCIs located outside the matching area. Nevertheless, as SCIs and SPAs reflect distinct conservation regimes (i.e. SCIs conservation is reflected as more strict limitations to human activities), we first analyzed changes individually for SCIs and SPAs. Afterwards, due to the relevant match between SCIs and SPAs areas and the prevalence of the former in the study-area, we performed the same analysis considering Natura 2000 as the area of both SCIs and SPAs. To perform such analysis, we merged SICs and SPAs, and the resulting area was used to assess changes. As results from both assessments depicted similar trends, the results and discussion presented here focus on the combined analyses, i.e. changes observed in Natura 2000 (but see Supplementary Material S5, Table S5.1 for detailed results). The Peneda-Gerês National Park, was not assessed individually as it is entirely contained within the Natura 2000 SCI and SPA Peneda-Gerês and the Gerês-Xurés Biosphere Reserve. The Gerês-Xurés Biosphere Reserve and its formal zoning, a core, a buffer and a transition zone, reflecting decreasing levels of nature value and increasing levels of human disturbance compatible with the sustainable use of natural resources, respectively. Though many Natura 2000 areas in the EDM region and the Gerês-Xurés Biosphere Reserve were designated between 2004 and 2009, the process for their classification in Portugal started in the late 90s (see Supplementary Material S1, Table S1).

The coincidence between HNVf and areas designated for nature conservation was analysed for the years of 1989 and 2009, assuming that 1989 reflects the 'baseline' area of HNVf before the designation of Natura 2000 areas in the territory. Such coincidence was evaluated by spatially overlapping the 1989 and 2009 HNVf maps with the areas designated for nature conservation (Figure 1). By doing this, the area of HNVf inside the areas designated for nature conservation was determined. Changes in the extent of HNVf outside Natura 2000 network in the EDM were also analyzed. In the case of the Gerês-Xurés Biosphere Reserve, changes were assessed considering also the management-related zoning (for detailed information regarding the zonation of the Biosphere Reserve see Supplementary Material S1).

Table 1. Sets of indicators used to assess the extent of High Nature Value farmlands (HNVf) in the Entre-Douro-e-Minho (EDM).

Indicator	Code(s) and unit(s)	Description	Source	HNVf type	
				HNVf1	HNVf2
Landscape Elements					
Farmland dominance at the landscape level	$P.UAA_p$ (%) $P.FOR_p$ (%) $P.URB_p$ (%)	Areas where the percentage (%) cover of farmlands ($P.UAA_p$) is dominant in relation to forests ($P.FOR_p$; broadleaved, coniferous and mixed forests mapped in the land cover map) and urban areas ($P.URB_p$; urban fabric and other artificial surfaces identified in the land cover map), at the parish level.	Land cover/use Maps (Direção-Geral do Território, 1990, 2007)	x	x
High Nature Value farmlands likelihood	$pHNVf_m$ (%)	Farmlands more likely to support HNVf (minimum; $pHNVf_m$) in the EDM agrarian region and per civil parish.		x	
	$pHNVf_M$ (%)	Farmlands less likely to support HNVf (Maximum; $pHNVf_M$) in the EDM agrarian region and per civil parish.			x
Landscape evenness index	SEI_p (n.a.)	Landscape patterns at the parish level expressed as the Shannon Evenness Index.			x
Patch Number	NP_p (n.a.)	Number of patches at the parish level.			x
Mean shape index	MSI_p (n.a.)	Mean shape index, measures the complexity of patches.			x
Edge Density	ED_p (m/ha)	Density of edges calculated in relation to the parish area.			x
Extensive Practices					
Livestock density index	LSI_p (LSU per ha/UAA)	Livestock units (LSU) per hectare of the UAA at the parish level.	Agricultural Census (INE, 1989, 2009)	x	x
Share of irrigated area	$Irrig_p$ (%)	Share or irrigated area per total of UAA in each parish.		x	x
Crop Diversity					
Crop evenness index	SEI_c (n.a.)	Crop diversity expressed as the Shannon Evenness Index	Agricultural Census (INE, 1989, 2009)		x
Crop richness	$SCrop_p$ (n.a.)	Number of crop types cultivated per parish.			x

Note: % - percentage; n.a. - not applicable; m - meters; ha - hectares; LSU - livestock units; UAA - Utilized Agricultural Area. HNVf1 and HNVf2 - High Nature Value farmlands types 1 and 2, respectively.

3. Results

Overall, changes in the dominant land use were found when analysing dynamics between 1989 and 2009 in the EDM. In 1989, agriculture was the dominant use of the land (401,705 ha; 44.60% of EDM), followed by forest (356,276 ha; 39.56% of EDM) and urban areas (71,916 ha; 7.99% of EDM). Conversely, in 2009 forests were the dominant use of the land (387,679 ha; 43.05% of EDM), followed by agriculture (338,180 ha; 37.55% of EDM) and urban areas (119,492 ha; 13.27% of EDM). Similar patterns were found when analysing changes in the agricultural area at the parish level (see Supplementary Material 3, Table S3.1 for detailed results). The number of parishes where agriculture was the dominant use of the land decreased from 812 (61.10 %) to 621 parishes (46.73 %) between 1989 and 2009.

3.1. Assessment of changes in the extent of HNVf between 1989 and 2009

Considering the values of the F-statistic, ‘2’ was the optimum number of groups discriminating variation among indicators across the EDM region for both years (F-statistic: 87.73 and 115.96 for 1989 and 2009, respectively). An analysis based on the R^2 values (see full results in Supplementary Material S3, Table S3.2) depicted Livestock Density Index (LSI_p) as the highest contributor to within-cluster discrimination. In 1989, LSI_p values were followed by Cropping Patterns (SEI_c) and Share of Irrigated Area ($Irrig_p$), whereas in 2009 they were followed by $Irrig_p$ and SEI_c. (Table 2). Overall, variation of the aforementioned indicators depicted diverging patterns between the two resulting clusters (for both 1989 and 2009).

Table 2. Results of the grouping analysis implemented to assess High Nature Value farmlands in the Entre-Douro-e-Minho (EDM) region.

Year		n	Indicator	Mean±SD	R^2
1989	EDM		LSI$_p$	1.12±1.01	0.52
			SEI$_c$	0.73±0.14	0.13
			IRRIG$_p$	67.24±32.23	0.09
2009			LSI$_p$	1.10±1.69	0.51
			IRRIG$_p$	35.46±25.42	0.36
			SEI$_c$	0.24±0.12	0.28
Year	**Cluster**	**n**	**Indicator**	**Mean±SD**	**Share**
1989	A	106	LSI$_p$	2.99±1.44	1.00
			SEI$_c$	0.60±0.14	0.94
			IRRIG$_p$	92.74±27.59	0.93
	B	706	LSI$_p$	0.84±0.50	0.53
			SEI$_c$	0.75±0.13	1.00
			IRRIG$_p$	63.42±31.12	1.00
2009	A	123	LSI$_p$	3.52±2.40	1.00
			IRRIG$_p$	66.21±25.41	0.92
			SEI$_c$	0.11±0.09	0.67
	B	498	LSI$_p$	0.50±0.57	0.33
			IRRIG$_p$	27.87±18.84	0.66
			SEI$_c$	0.27±0.10	1.00

Note: n - number of civil parishes; SD - standard deviation; R^2 - reflects the discriminating ability of each individual indicator (with higher values depicting a better discriminating ability). Share values depict the ratio between the range of values observed within clusters (A or B) and the full range of values observed for each indicator. Indicators are ordered according to decreasing values of discriminating ability (R^2).

For both years considered, Cluster (A) exhibited higher values of Livestock density index, a higher percentage of irrigation and lower crop diversity (cf. Table 2). Conversely, Cluster (B) showed lower values of LSIp, a lower percentage of irrigation and higher values for crop diversity (Table 2). Analysis of R^2 results and internal variation of indicators within clusters showed that Cluster (B) had potential to support farmlands with High Nature Value (Cluster 'HNVf1+2'; Figure 2), whereas Cluster (A) corresponded to more intensively managed farmlands (Cluster 'non HNVf'; Figure 2). See detailed results for all indicators used in Supplementary Material S3, Table S3.2.

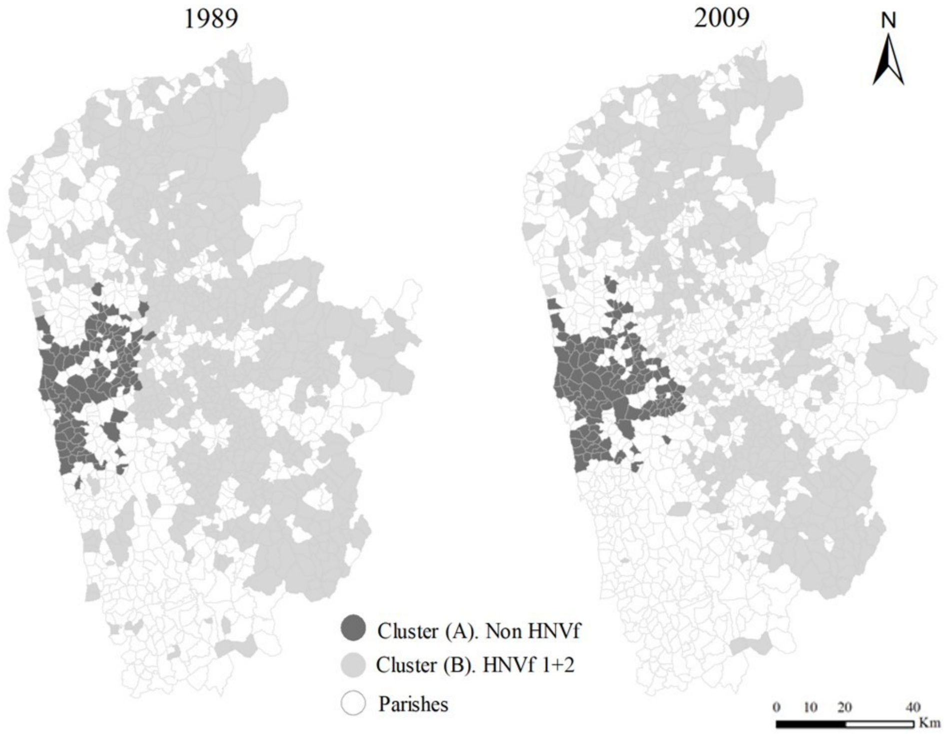

Figure 2. Outcomes from the grouping analysis implemented on the spatially-explicit sets of indicators informing on farming practices, landscape elements and crop diversity in the Entre-Douro-e-Minho (EDM) agrarian region.

A thorough analysis within Cluster (B) helped determined the extent of HNVf1 and HNVf2 (cf. Figure 2). Results from this analysis, which consisted in summing all areas corresponding to each HNVf type are presented embedded in Figure 3. Overall, HNVf1 was found to be the prevailing type in 1989 and 2009.

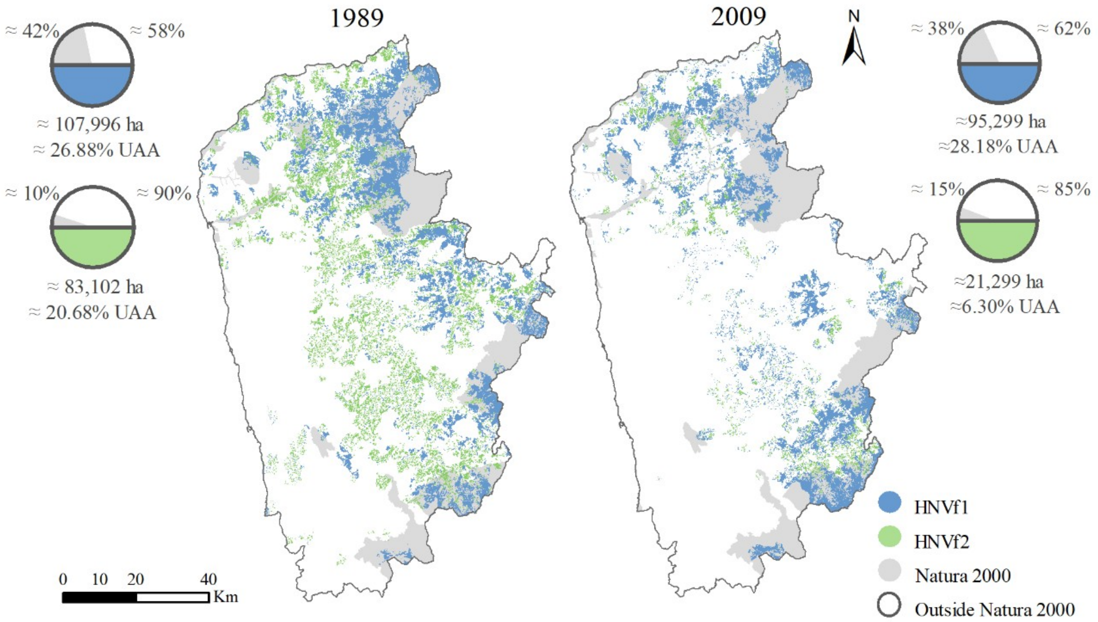

Figure 3. High Nature Value farmlands (HNVf) in the Entre-Douro-e-Minho region for the years of 1989 and 2009. HNVf1 and HNVf2, High Nature Value farmlands types 1 and 2, respectively. Circles represent the extent of HNVf1 and HNVf2. In the lower semi-circle, values of hectares of HNVf (ha) and percentage of HNVf in total UAA (%UAA) are presented, whereas in the upper semi-circle, the percentage is expressed in relation to the total HNVf inside and outside Natura 2000.

Between 1989 and 2009, a net decrease of 12,697 ha of HNVf1 and 61,804 ha of HNVf2 was observed (Figure 4). This happened in the context of a general decrease of total UAA, but the proportion of HNVf1 relative to total UAA increased slightly (1.30%, from 26.88% to 28.18%) which means that HNVf1 declined at a slightly lower rate than total UAA. Conversely, HNVf2 declined at a higher rate than total UAA, as it decreased from 20.68% to 6.3% of total UAA in the same period.

Despite the net decrease, 47,776 ha of HNVf1 remained stable between 1989 and 2009, while 47,522 ha were gained and 60,219 ha were lost (Figure 4). Areas where HNVf1 was maintained generally matched areas designated for conservation (51.33% of

HNVf1), areas where HNVf1 expanded were spread across the region (but mostly located in the surroundings of areas designated for nature conservation in the SE of EDM; Figure 4), while areas where HNVf1 was lost were located mainly in the eastern regions of EDM, both inside and outside conservation areas (Figure 4). As for HNVf2, about 9,257 ha were maintained, 12,042 ha were gained, and 73,846 ha were lost. Most of the HNVf2 areas lost corresponded to landscapes located in the surroundings of the 'Non HNVf' area (cluster A; Figure 2), i.e. in the central area of EDM region. HNVf2 areas gained and maintained coincide with landscapes in the surroundings designated for conservation (Figure 4).

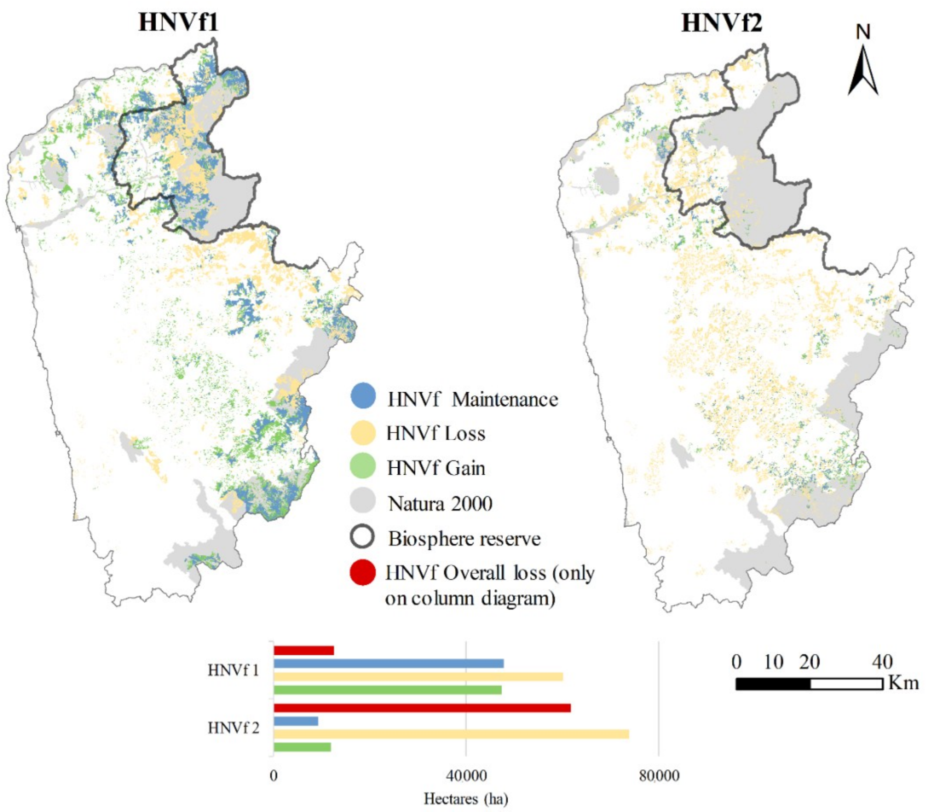

Figure 4. Changes in the extent of High Nature Value farmlands (HNVf), expressed as gain, loss or maintenance between 1989 and 2009 in the Entre-Douro-e-Minho region. Bars represent the Loss, Maintenance, Gain, and Overall loss of HNVf1 and HNVf2 in

hectares (ha). HNVf1 and HNVf2, High Nature Value farmlands types 1 and 2, respectively.

An analysis of the land cover transitions between 1989 and 2009 indicated that the loss of HNVf1 was mainly due to changes from HNV heathlands under contrasting farming practices to degraded forests, sparse vegetation, or patches of forest, which were mainly assemblages of maritime pine and the exotic bluegum (*Eucalyptus globulus* Labill.; see detailed information in Supplementary Material S4, Table S4.1). Regarding the loss of HNVf2, transitions were found from HNV heterogeneous agricultural areas mainly to arable land, other heterogeneous agricultural areas under contrasting (more intensively managed) farming practices, followed by forest assemblages of maritime pine and broadleaved trees and urban areas (Supplementary Material S4, Table S4.1). HNVf1 gain was mainly due to conversion from forests, heathlands and sparse vegetation conversation to heathlands under low intensity farming practices. HNVf2 gain was mainly due to conversion from arable lands, forests, and heterogeneous agricultural areas to complex crop mosaics under low intensity farming practices.

3.2. Changes in the extent of HNVf within areas designated for nature conservation

Our results show that HNVf1 was the predominant type inside the part of EDM that was later designated as Natura 2000 network, both in 1989 (45,806ha) and in 2009 (36,602 ha; Table 3). HNVf2, on the other hand, slightly prevailed outside Natura 2000 areas in 1989 but followed a steeper decline than HNVf1 until 2009 and occupied much less area by then as a consequence (Table 3). Overall, the area of both HNVf types declined between 1989 and 2009, but showed contrasting patterns: HNVf1 decrease was more important inside Natura 2000 areas, while HNVf2 decline was concentrated outside Natura 2000 (Table 3; see Supplementary Material S5, Table S5.1 for detailed results).

Table 3. Trends observed between 1989 and 2009 in High Nature Value farmlands (HNVf) extent in Entre-Douro-e-Minho region inside and outside areas designated for nature conservation.

		Hectares			% area		
		1989	**2009**	**Δ**	**1989**	**2009**	**Δ**
HNVf1	**Inside N2000**	45,806	36,602	**-9,204**	28.59	22.84	**-5.74**
	Outside N2000	62,190	58,696	**-3,493**	8.40	7.93	**-0.47**
HNVf2	**Inside N2000**	8,335	3,139	**-5,195**	5.20	1.96	**-3.24**
	Outside N2000	74,768	18,160	**-56,608**	10.10	2.45	**-7.65**

Note: % area - percentage of HNVf in relation to areas designated versus not designated for nature conservation; Δ - difference between 1989 and 2009. HNVf1 and HNVf2 - High nature Value farmlands types 1 and 2.

Figure 5 shows changes in the extent of HNVf between 1989 and 2009 in the Gerês-Xurés Biosphere Reserve (for detailed results see Supplementary Material S5, Table S5.1). HNVf1 was found to be the more abundant type in 1989 (38,869 ha, 33.42%) and 2009 (26,401 ha, 22.70%). Overall, for both 1989 and 2009, HNVf1 was observed to be mainly located in the buffer zone, followed by the transition and core zones, whereas HNVf2 was found mainly in the transition zone, followed by buffer zone and absent from the core zone. HNVf1 was the dominant type in the core (1989: 6,007 ha; 2009: 2,932 ha) and buffer zones (1989: 20,180; 2009: 12,712 ha), whilst HNVf2 was found to be most abundant in the Transition zone in 1989 (1989: 9,164 ha, 78.80%; 2009: 1,739, 77.91%). Analysis of changes between 1989 and 2009 depict a trend for a strong decline of HNVf in the Biosphere reserve, mostly due to the decrease of HNVf1 cover within the core and buffer zones and decrease of HNVf2 cover within the buffer and transition zones. (Figure 5; Supplementary Material S5).

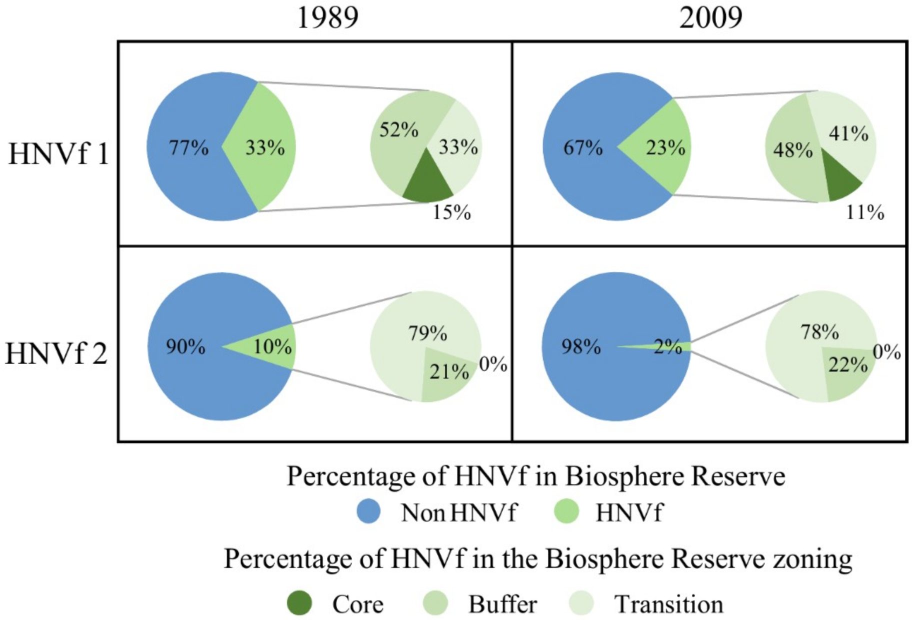

Figure 5. Changes in the proportion of High Nature Value farmlands (HNVf) and Non HNVf between 1989 and 2009 in the Transboundary Biosphere Reserve Gerês-Xurés, including variation observed in the three zones of the reserve (Core, Buffer and Transition). HNVf1and HNVf2, High Nature Value farmlands types 1 and 2, respectively. Values in the left part of the pie diagram depict the percentage (%) of HNVf in relation to the total area of the Biosphere Reserve, whereas values presented in the right part of the pie diagram are expressed in relation to the percentage of total HNVf across zones of the Biosphere Reserve.

4. Discussion

Understanding the dynamics of High Nature Value farmlands in space and time and the drivers underlying such change is key to halting ongoing social-ecological changes threatening their future persistence (Lomba et al., 2015). However, limitations to HNVf assessment and monitoring stem from the lack of tested methodological approaches, applicable to the diversity of EU High Nature Value farmlands across scales of decision, as well as to the lack of suitable data, at adequate spatial and temporal resolutions (Benedetti, 2017; Lomba et al., 2014; Oppermann et al., 2012). The research reported here used a spatially-explicit approach previously described by Lomba et al. (2015) to assess the extent of HNVf in an agrarian region of NW Portugal, and analyse changes between the years 1989 and 2009.

4.1. Assessment of changes in the extent of HNVf between 1989 and 2009

A spatially-explicit cluster analysis of indicators expressing relevant social-ecological drivers underlying the nature value of farmlands, allowed the discrimination of landscapes under contrasting agricultural management for each of the years targeted. Two major clusters were identified, with one including parishes under more intensive agricultural management, and which was roughly coincident with the ‘Bacia Leiteira Primária de Entre-Douro-e-Minho’, an important area of dairy production, characterized by large-scale production of forage crops (Fangueiro et al., 2008; Lomba et al., 2010). A second cluster was considered as potentially supporting farmlands with high nature value and classified as HNVf1+2 (cluster B, Figure 2). While other indicators were analysed, those expressing the intensity of farming practices (such as LSI_p or SEI_c), exhibited higher discriminating ability (expressed as higher R^2 values), even though some variation among years was observed. Overall, our results are in agreement with other studies that identified livestock density (Boyle et al., 2015; Lomba et al., 2017) and the percentage of intensive crops (Lomba et al., 2017) as most relevant to discriminate between HNVf and non-HNVf areas.

An analysis performed to agricultural parcels located within the HNVf1+2 cluster (Figure 2) allowed the identification of HNVf types. Overall, HNVf represented 21% and 13% of the total EDM area in 1989 and 2009, respectively (cf. Figure 3), with HNVf1 found to be the most dominant type for both years. Such results highlight that HNVf in the EDM correspond mostly to natural and/or semi-natural habitats (Halada et al., 2011; Oppermann et al., 2012).

A shift in the prevailing use of the land was observed from agriculture to forest (cf. section 3), reflecting e.g. an increasing forest cover and resulting decreasing number of parishes dominated by agriculture. Changes in the extent of HNVf in time were assessed (cf. Figure 4), and while an increase of 47,552 ha of HNVf1 (1.30%) was observed, a decrease of 60,219 ha (1.41%) of HNVf1 and 73,486 ha (6.86%) of HNVf2 was detected. A qualitative analysis of land use changes underlying HNVf1 loss was associated with farmland being replaced by heathlands, shrublands and forest stands. Such replacement is consistent with the reported trends of farmland abandonment in the mountainous areas of Europe (Beilin et al., 2014; Bielsa et al., 2005). Conversely, transitions towards more intensively managed farming systems (e.g. irrigated temporary crops) were found to be the most relevant changes underlying the loss of HNVf2 areas.

4.2. Changes in the extent of High Nature Value farmlands within areas designated for nature conservation

HNVf1 (i.e. areas with natural and semi-natural agricultural habitats) prevailed inside areas designated for nature conservation. Such results converge with previous publications that reported the prevalence of Habitats of Annex I within Natura 2000 network and the importance of the maintaining low-intensity farming systems for their conservation (e.g. see Halada et al., 2011; Pe'er et al., 2017). Contrastingly, HNVf2 (i.e. agricultural landscapes where crop fields are intermingled with other farmland features such as mature trees, shrubs, scrub, or linear features such as field margins and hedges), were found to prevail outside the EDM Natura 2000 network.

Areas designated for nature conservation seemed to play a modest role in the conservation of HNVf areas: while most of the area gained by HNVf was located near to areas designated for nature conservation, much of the area of HNVf1 lost was inside protected spaces. Despite restrictions to land-use change and financial incentives tailored to support the maintenance of HNV farming systems, our results depict that the magnitude of HNVf1 loss was higher inside Natura 2000 areas. Conversely, the magnitude of HNVf2 was found to be higher outside Natura 2000 areas. This is consistent with the differences in location of HNVf 1 and 2: HNVf1 was observed predominantly in remote mountainous areas, predominantly affected by farmland abandonment, whereas HNVf2 was found in agricultural landscapes near urban areas in soils more suitable to agriculture, often subjected to intensification of farming practices (Honrado et al., 2017; Oppermann et al., 2012).

When analysing the spatial distribution of HNVf in the Gerês-Xurês Biosphere Reserve, HNVf1 was found to be the prevailing type in both years assessed. The highest percentage cover of HNVf1 and HNVf2 was observed in the buffer and transition zones, respectively, even though a sharp decline of both was observed between 1989 and 2009 (Figure 5). The buffer zone corresponds to intermediate levels of human management, reflected in landscapes where traditional uses of the land and eco-tourism are developed as activities compatible with the conservation of areas with high nature value (cf. Supplementary Material S1). On the other hand, the transition zone concentrates most urban areas and thus higher intensity of land use. Altogether, such results highlight that the designation of areas e.g. as Natura 2000 and other instruments, *per se*, may not be enough to halt the loss of HNVf currently ongoing in the region.

4.3. Implication for High Nature Value farmlands assessment and monitoring

This research is, to our knowledge, the first attempt to assess changes of HNVf extent in space and time. Whilst based on a previously described approach to map HNVf extent, it advances the field by testing its applicability to identify areas under distinct farming systems, when data expressing landscape structure and composition, intensity of farming systems, and crop diversity, with adequate spatial and temporal resolutions is available. Overall, our research helped discriminate the extent and location of main HNVf types recognized at the landscape level. In addition, the assessment of changes in the extent and location of HNVf between 1989 and 2009 provided insights into the dynamics occurring in the region, both inside and outside areas designated for nature conservation. The decrease in extent of areas under HNV farmland between 1989 and 2009 provides an early warning that nature conservation designation does not ensure HNVf persistence. While we had no data available with which to investigate potential drivers, changes to biodiversity conservation support payments made during the 2003 CAP reform (Pe'er et al., 2019) may have contributed to this decrease.

Whilst our approach and results are promising, there is still room for improvement. Approaching HNVf monitoring in space and time would definitely benefit from datasets with higher spatial and temporal resolutions, such as those provided by the Integrated Administration and Control System (IACS) and associated Land Parcel Information System (LPIS), as described and used by Lomba et al. (2017). Using IACS and LPIS would also allow analyses of how changes in HNVf in space and time relate to changing policies, such as those that took place during period of reform. However, such data were not available for this research, due to issues of privacy that limit the access to such datasets, e.g. see. Pe'er et al., 2017; Strohbach et al., 2015. Data publicly available to the completion of this case-study restricted the HNVf assessment to only two points in time (1989 and 2009), limiting our ability to assess and analyze potential long-term trends (losses or gains) and respective processes underlying such trends (abandonment or intensification) e.g. linked to periods of changing policies in time and space. Despite that, this case-study provided a baseline, and an analysis of changes occurring between two points in time separated by 20 years. As no regional estimates for HNVf (quantitative or spatially-explicit) were available for the period between 1989 and 2009, it was not possible to validate the accuracy of our assessment. Nevertheless, we consider that this research represents an advance in the field of HNVf assessment and monitoring. In particular, by providing an approach to analyze the location and changes over time of HNVf types in relation to areas under distinct legal protection (such as the Natura 2000 network), it can help assess the role that such nature conservation designations have in protecting HNVf and indicate where additional agricultural or nature conservation policy and support mechanism may need to be targeted.

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Supplementary Material

Supplementary Material S1. Areas designated for nature conservation in the Entre-Douro-e-Minho (EDM) region.

Supplementary Material S1 presents detailed information on the areas currently designated for nature conservation in the Entre-Douro-e-Minho (EDM). Areas designated for nature conservation in the EDM comprise those included within the Natura 2000 network i.e. *Sites of Community Importance* (SCI's) under the Habitats Directive and the *Special Protection Areas* (SPA's), under the Birds Directive; and the Transboundary Gerês-Xurés Biosphere Reserve (Table S1). The Natura 2000 network was evaluated through merging SCI's and SPA's, since much of the SPAs is within the SCI area (90.60% of the SPAs area, with only 9.4% of the SPAs being 'outside' the area designated as both SCI and SPA). The EDM agrarian region also includes the only National Park recognized in Portugal: the Peneda-Gerês National Park, which is entirely contained within the Natura 2000 SCI Peneda / Gerês (PTCON0001) and SPA Serra do Gerês (PTZPE0002) and within Gerês-Xurés Biosphere Reserve (Figure S1).

Table S1. Areas designated for nature conservation in the Entre-Douro-e-Minho region, including Sites of Community Importance (SCI); Special Protection Areas (SPA); the Transboundary Biosphere Reserve Gerês-Xurés (RBTGX); and, the Peneda-Gerês National Park. Site type, Site code, Name and Year of designation is presented. *n.a.* stands for not applicable.

Site type	Site Code	Name	Year of designation
SCI	PTCON0001	Peneda / Gerês	2004
	PTCON0003	Alvão / Marão	2008
	PTCON0017	Litoral Norte	2004
	PTCON0018	Barrinha de Esmoriz	2008
	PTCON0019	Rio Minho	2004
	PTCON0020	Rio Lima	2004
	PTCON0024	Valongo	2004
	PTCON0025	Montemuro	2008

	PTCON0039	Serra D'Arga	2004
	PTCON0040	Corno do Bico	2004
	PTCON0047	Serras da Freita e Arada	2008
	PTCON0059	Rio Paiva	2008
SPA	PTZPE0001	Estuários dos Rios Minho e Coura	1988
	PTZPE0002	Serra do Gerês	1988
Transboundary Biosphere Reserve	RBTGX	Transboundary Biosphere Reserve Gerês-Xurés	2009
National Park	*n.a.*	Peneda-Gerês National Park	1971

The *Transboundary Biosphere Reserve* (RBTGX) was formally recognized by UNESCO in 2009, and includes part of the territory of Galicia (Spain) and North Portugal. This Reserve is under specific planning and management regimes, aiming to target different needs for conservation and different levels of management and use of the natural resources, which resulted on the establishment of distinct zones. The zonation of the Biosphere Reserve includes a core, a buffer and a transition zone (Figure S1). Overall, while the core area aims to maintain traditional patterns of use of natural resources compatible with the maintenance of the structure and functioning of ecosystems, the buffer zone includes areas where traditional land uses and environmental tourism are considered compatible with the conservation of areas with high nature value (currently equivalent to the area designated as SIC Peneda-Gerês, see Figure S1). The transition area corresponds to areas heavily populated where policies for sustainable development benefiting both local people and nature conservation are fostered. The core, buffer and transition zoning correspond to decreasing levels of nature value and increasing levels of human disturbance compatible with sustainable use of natural resources, respectively.

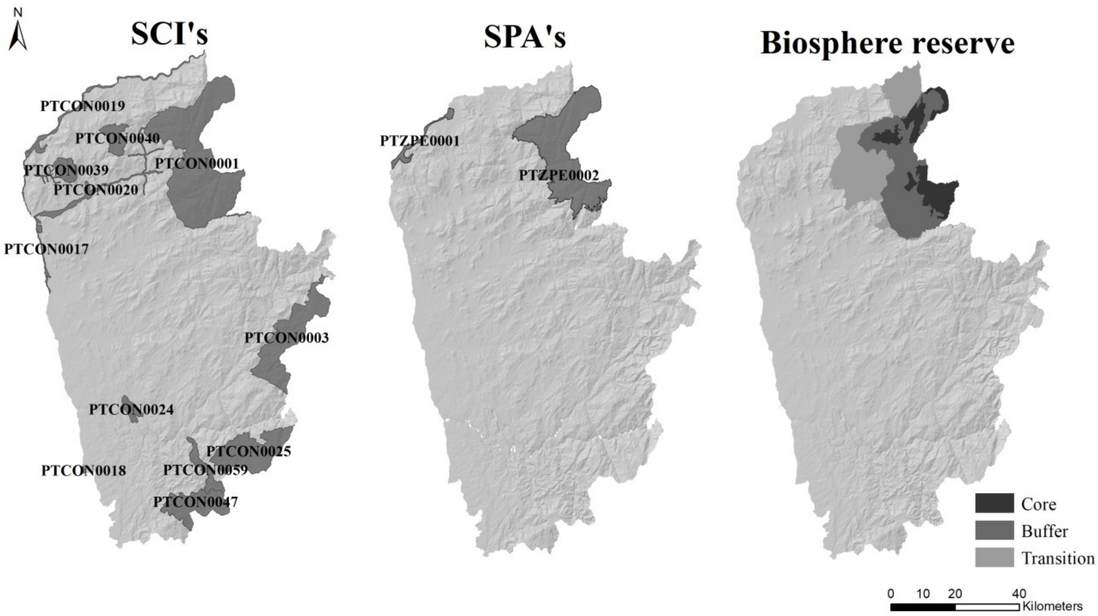

Figure S1. Location of the areas designated for nature conservation in the Entre-Douro-e-Minho region. Sites of Community Importance (SCI), Special Protection Areas (SPA) and the Transboundary Biosphere Reserve Gerês-Xurés (RBTGX). In the case of the Transboundary Biosphere Reserve Gerês-Xurês, the official zones, i.e. Core, Buffer and Transition are also shown.

Supplementary Material S2. Spatially-explicit assessment of High Nature Value farmlands

Supplementary Material S2 provides additional information regarding the spatially-explicit assessment of High Nature Value farmlands (HNVf). More specifically, Table S2.1 shows the land cover classes identified as potentially corresponding to farmlands and used to discriminate between the Utilized Agricultural Area (UAA; i.e. areas used for farming, including arable land, permanent grassland, permanent crops and other agricultural land such as kitchen gardens) from other areas (i.e. land cover classes not eligible as farmed areas e.g. artificial surfaces and forests). Other classes expressing farmed areas and land cover classes covering areas off the farm (e.g., grazed heathlands and other grazing areas in common usage), known to express other semi-natural areas used as forage of fodder resources, were selected, to determine the total UAA (Lomba et al., 2015). Data reflecting natural constraints for agriculture (Van Orshoven et al., 2012) were used to identify heathlands under no or moderate limitations to agriculture, enabling the identification of off-farm grazing areas, known to constitute a large proportion of HNVf in some regions, as UAA (Lomba et al., 2015).

Classes potentially expressing farmlands (UAA in Table S2.1) and other classes of semi-natural vegetation were identified and their potential to reflect HNV and non HNVf disentangled, assuming that some predominant land-cover types are characteristic of each category of HNV farmlands. A Minimum-Maximum selection (as described by Andersen et al. 2004) allowed to analyse putative “extremes” within which HNVf was likely to occur could be defined. Overall, the Minimum selection includes only the classes of land cover which are made up primarily of HNV land, while the Maximum selection included all classes with some farmed HNV land. As so, the Minimum is a more conservative estimate of HNV land (~HNVf1). Such classification was supported by previous research performed in the field of HNVf (e.g. Andersen et al., 2004; Parachnini et al., 2008) and specifically in Northern Portugal (Lomba et al., 2015).

Table S2.2 presents the sets of indicators used to assess the extent of High Nature Value farmlands (HNVf) in the Entre-Douro-e-Minho (EDM), including a short description of the rationale underlying their selection, in relation to HNVF types

Table S2.1. Land Cover classes occurring in the study area, classification within broad land use classes, and their likelihood to correspond to High Nature Value farmlands (HNVf). *Minimum HNVf* areas comprise areas with very high likelihood of being farmlands with high conservation value (thus, comprising land cover classes which are made up primarily of HNVf landscapes), whereas the *Maximum HNVf* coincide with farmed areas where some may be associated with HNVf (i.e. comprise classes in which farmed areas are not the predominant land use). Classes of land cover that can be grazeable (this is, fodder areas) are also highlighted as even if they are only partially coincident with the Utilised Agricultural Area (UAA), they are relevant for the estimation of HNVf. *n.f.* stands for *not farmlands* and includes all other classes that are not eligible as they do not include potentially farmed areas (Lomba et al., 2015).

Land Cover classes		**Description of land-cover classes in relation to land-use**	***n.f.***	**UAA**	**Grazeable**	***non* HNVf**	**HNV farmlands**	
							***Minimum* HNVf**	***Maximum* HNVf**
Artificial surfaces		Urban fabric	x					
		Infrastructures and equipments	x					
		Mine, dump, construction sites and other degraded areas	x					
Agricultural Areas	Arable land	Non-irrigated arable land, permanently irrigated land, rice fields and others		x	x	x		
		Mosaics of arable land and grasslands		x	x		x	x
	Permanent crops	Vineyards		x		x		
		Vineyards and arable land		x	x	x		
		Vineyards and orchards		x	x	x		
		Orchards		x	x			x
		Fruit trees + Olive groves		x	x			x
	Pasture	Grasslands		x	x		x	x
	Heterogeneous agricultural areas	Annual crops + Vineyards		x				x
		Annual crops + Fruit trees		x				x
		Complex crop mosaics		x				x
		Agro-forestry areas with broadleaved trees		x	x			x
		Other agro-forestry areas with planted trees		x	x			x
Forest and	Forests	Broad-leaved forests	x					

semi-natural areas		Coniferous forests	x					
		Mixed forests	x					
	Scrub and/or herbaceous vegetation associations	Heathlands located in areas under low or no natural constraints for agriculture	x	x	x		x	x
		Other heathlands and transitional woodland-shrub	x					
		Degraded forests	x		x			
	Open spaces with little or no vegetation	Sparsely vegetated	x		x			
Water bodies		Water courses	x					

Table S2.2. Sets of indicators used to assess the extent of High Nature Value farmlands (HNVf) in the Entre-Douro-e-Minho (EDM).

Designation	Code(s) and unit(s)	Description and rationale	Source	HNVf type	
				HNVf1	HNVf2
Landscape Elements					
Farmland dominance at the landscape level	$P.UAA_p$ (%) $P.FOR_p$ (%) $P.URB_p$ (%)	Areas where the percentage (%) cover of farmlands ($P.UAA_p$) is dominant in relation to forests ($P.FOR_p$; broadleaved, coniferous and mixed forests mapped in the land cover map) and urban areas ($P.URB_p$; urban fabric and other artificial surfaces identified in the land cover map), at the parish level. Values were calculated from the land cover maps considering the area covered by each class (farmland, forest and urban) in relation to the total area of the civil parish (LAU2), and are expressed as percentage (%). Dominance of farmlands at the parish level was considered whenever two conditions were met: i) 40% of P.UAA per parish Lomba et al (2015); and, ii) higher values for the share of agricultural cover (P.UAAp) in relation to the shares of urban (P.URBp) and forest areas (P.FORp), respectively.	Land cover/use Maps (Direção-Geral do Território, 1990, 2007)	x	x
High Nature Value farmlands likelihood	$pHNVf_m$ (%)	Farmlands more likely to represent HNVf (minimum; $pHNVf_m$) in EDM agrarian region and per civil parish.		x	
	$pHNVf_M$ (%)	Farmlands less likely to represent HNVf (Maximum; $pHNVf_M$) in EDM agrarian region and per civil parish.			x
Landscape evenness index	SEI_p (n.a.)	Landscape patterns at the parish level expressed as the Shannon Evenness Index. The index accounts for the diversity of land use types and the evenness of their distribution. Varies between 0 and 1.			x
Patch Number	NP_p (n.a.)	Number of patches at the parish level is considered an indicator for landscape fragmentation, potentially positive for agro-biodiversity (Lomba et al., 2015).			x
Mean shape index	MSI_p (n.a.)	Higher MSI values occur in natural and semi-natural landscapes, here analysed at the parish level (Lomba et al., 2015).			x
Edge Density	ED_p (m/ha)	Density of edges in relation to the parish area is relevant to wildlife maintenance, as they constitute semi-natural areas (Lomba et al., 2015).			x
Extensive Practices					
Livestock density index	LSI_p (LSU per	Livestock units (LSU) per hectare of the UAA (LSU/ha) at the parish	Agricultural	x	x

	ha/UAA)	level, used as a proxy for agricultural intensification (i.e. pressure of livestock on the environment).	Census (INE, 1989, 2009)		
Share of irrigated area	$Irrig_p$ (%)	Share or irrigated area per total of UAA in each parish. Proxy for agricultural intensification (Lomba et al., 2015).		x	x
Crop Diversity					
Crop evenness index	SEI_c (n.a.)	Crop diversity expressed as the Shannon Evenness Index. The index accounts for the diversity of crops and the evenness of their distribution and was calculated at the parish level. Varies between 0 and 1.	Agricultural Census (INE, 1989, 2009)		x
Crop richness	$SCrop_p$ (n.a.)	Number of crop types cultivated per parish. Lower specialization contributes to higher heterogeneity at the landscape level and thus is related to higher levels of biodiversity.			x

Note: % - percentage; n.a. - not applicable; m - meters; ha - hectares; LSU - livestock units; UAA - Utilized Agricultural Area. HNVf1 and HNVf2 - High Nature Value farmlands types 1 and 2, respectively.

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Supplementary Material S3. Grouping analysis targeting High Nature Value farmlands in the Entre-Douro-e-Minho (EDM) region, Portugal.

Supplementary Material S3 complements results described in what concerns the grouping analysis performed to assess the extent of High Nature Value farmlands (HNVf) in EDM for each of the years of 1989 and 2009. Table S3.1 shows all results regarding the changes in the dominant uses of the land (agriculture, forest and urban) observed in the study-area for both 1989 and 2009. Overall, it provides an overview of how indicators used to assess the *Farmland dominance at the landscape level* (Landscape elements set of indicators used to assess HNVf extent, see also Table S2.2, Supplementary Material 2) changed between the years targeted.

Table S3.1. Changes observed in the main uses of the land in the Entre-Douro-e-Minho (EDM) between 1989 and 2009.

Year	$P.UAA_{EDM}$ (%)	$P.UAA_p$ (mean $_{\%}$ ± SD)	$P.FOR_{EDM}$ (%)	$P.FOR_p$ (mean $_{\%}$ ± SD)	$P.URB_{EDM}$ (%)	$P.URB_p$ (mean $_{\%}$ ± SD)
1989	44.60	45.77 ± 14.46	39.56	37.29 ± 15.45	7.99	11.50 ± 14.46
2009	37.55	38.99 ± 15.73	43.05	39.02 ± 17.21	13.27	18.86 ± 17.54

Note: $P.UAA_{EDM}$ - percentage of Utilized Agricultural Area (UAA) in the EDM; $P.UAA_p$ - percentage of UAA per parish; $P.FOR_{EDM}$ - percentage of forest area in the EDM; $P.FOR_p$ - percentage of forest area per parish; $P.URB_{EDM}$ - percentage of urban areas in the EDM; $P.URB_p$ - percentage of urban areas per parish; mean $_{\%}$ - average values of each use of the land considered across all civil parishes; SD - standard deviation.

Table S3.2 presents results (for all indicators used) of the grouping analyses performed to assess the extent of High Nature Value farmlands (HNVf) in the Entre-Douro-e-Minho (EDM) region for the years of 1989 and 2009. For the full name, description and rationale underlying the use of indicators, see Table S2.2, Supplementary Material S2.

Table S3.2. Grouping analysis targeting High Nature Value farmlands in the Entre-Douro-e-Minho (EDM) region.

Year		n	Code and units	Mean	SD	Min	Max	R^2
1989	Full area (EDM)		LSI_p (LSU per ha/UAA)	1.12	1.01	0.00	7.10	0.52
			SEI_c (n.a.)	0.73	0.14	0.00	0.95	0.13

			$IRRIG_p$ (%)	67.24	32.23	0.00	200.53	0.09
			ED_p (m/ha)	217.34	44.96	54.10	372.40	0.01
			NP_p	23.09	10.43	6.00	148.00	0.01
			SEI_c (n.a.)	0.75	0.09	0.24	0.90	0.01
			$SCROP_p$ (number crops/parish)	8.29	1.84	0.00	14.00	0.00
			MSI_p	2.74	0.49	1.70	4.77	0.00
2009	Full area (EDM)		LSI_p (LSU per ha/UAA)	1.10	1.69	0.00	14.79	0.51
			$IRRIG_p$ (%)	35.46	25.42	0.00	165.28	0.36
			SEI_c (n.a.)	0.24	0.12	0.00	0.69	0.28
			$SCROP_p$ (number crops/parish)	6.82	2.04	2.00	15.00	0.09
			SEI_c (n.a.)	0.73	0.09	0.23	0.92	0.01
			NP_p	81.41	58.58	4.00	602.00	0.00
			ED_p (m/ha)	226.08	49.72	79.31	384.49	0.00
			MSI_p	1.89	0.19	1.41	4.71	0.00
Year	**Grouping**	**n**	**Code and units**	**Mean**	**SD**	**Min**	**Max**	**Share**
1989	A	106	LSI_p (LSU per ha/UAA)	2.99	1.44	0.00	7.10	1.00
			SEI_c (n.a.)	0.60	0.14	0.00	0.89	0.94
			$IRRIG_p$ (%)	92.74	27.59	0.00	185.49	0.93
			ED_p (m/ha)	228.68	37.18	152.34	372.40	0.69
			NP_p	92.74	27.59	0.00	185.49	0.93
			SEI (n.a.)	228.68	37.18	152.34	372.40	0.69
			$SCROP_p$ (number crops/parish)	8.05	1.69	0.00	11.00	0.79
			MSI	2.79	0.53	1.81	4.75	0.96
	B	706	LSI_p (LSU per ha/UAA)	0.84	0.50	0.00	3.77	0.53
			SEI_c (n.a.)	0.75	0.13	0.00	0.95	1.00
			$IRRIG_p$ (%)	63.42	31.12	0.00	200.53	1.00
			ED_p (m/ha)	215.65	45.78	54.10	371.14	1.00
			NP_p	23.49	10.87	6.00	148.00	1.00
			SEI (n.a.)	0.75	0.09	0.24	0.90	1.00
			$SCROP_p$ (number crops/parish)	8.33	1.86	0.00	14.00	1.00
			MSI	2.74	0.49	1.70	4.77	1.00
2009	A	123	LSI_p (LSU per ha/UAA)	3.52	2.40	0.02	14.79	1.00
			$IRRIG_p$ (%)	66.21	25.41	13.82	165.28	0.92
			SEI_c (n.a.)	0.11	0.09	0.00	0.47	0.67
			$SCROP_p$ (number crops/parish)	5.62	1.70	2.00	10.00	0.62
			SEI (n.a.)	0.72	0.10	0.23	0.89	0.96
			NP_p	73.54	44.06	4.00	290.00	0.48
			ED_p (m/ha)	231.46	49.21	94.16	332.25	0.78
			MSI	1.89	0.15	1.41	2.56	0.35
	B	498	LSI_p (LSU per ha/UAA)	0.50	0.57	0.00	4.94	0.33
			$IRRIG_p$ (%)	27.87	18.84	0.00	109.84	0.66
			SEI_c (n.a.)	0.27	0.10	0.00	0.69	1.00
			$SCROP_p$ (number crops/parish)	7.12	2.01	3.00	15.00	0.92
			SEI (n.a.)	0.73	0.08	0.42	0.92	0.72
			NP_p	83.36	61.49	7.00	602.00	1.00
			ED_p (m/ha)	224.74	49.75	79.31	384.49	1.00

	MSI	1.89	0.20	1.52	4.71	0.97

Note: Statistics for indicators for both the EDM (Full area) and clusters (A and B) are presented for the years of 1989 and 2009. n, stands for the number of parishes; n.a., not applicable. Mean, standard deviation (SD), minimum (Min) and maximum (Max) values for each indicator are presented. R^2, reflects the discriminating ability of each individual indicator (with higher values depicting a better discriminating ability). Share values depict the ratio between the range of values observed within clusters (A or B) and the full range of values observed for each indicator. Indicators are ordered according to decreasing values of discriminating ability (R^2).

Supplementary Material S4. Qualitative analysis of major land use changes behind High Nature Value farmlands loss and gain between 1989 and 2009)

Assessment of High Nature Value farmlands between the period of 1989 and 2009 showed changes in the extent and distribution of HNVf. To uncover land use changes underlying the loss and gain of types HNVf1 and 2, maps from 1989 and 2009 were used and analysed. Overall, an intersection was performed between the HNVf assessment for 1989 and 2009 and the land use map for 1989 and 2009, respectively. By comparing land use classes between 1989 and 2009, we analysed the transitions between years in areas where HNVf1 and 2 were lost and gained (Table S4.1). Such changes are complementary to changes in the extent of HNVf, as such changes reflect changing farming practices, namely the intensity of agricultural management (reflected e.g. as increasing livestock density index) and respective impacts at the landscape level. As a result, land use classes, *a priori*, supporting HNVf may not be considered as High Nature Value farmlands in 2009 due to the fact that civil parishes are not within the thresholds of management intensity considered to be extensive farming.

Table S4.1. Land use changes between 1989 and 2009 underlying the loss and gain of HNVf 1 and 2 area in hectares (ha). For each land use class, the classes presenting the 4 highest conversion values are shown, depicting more than 75% of total area converted. In brackets is listed the major land cover under each category.

Land cover in 1989	Land cover in 2009	Area converted (ha)
Loss HNVf1 –60,219.37 ha in total		
Scrub and/or herbaceous vegetation associations (heathlands)	Scrub and/or herbaceous vegetation associations (heathlands and degraded forests)	28,021.66
Scrub and/or herbaceous vegetation associations (heathlands)	Open spaces with little or no vegetation	14,031.28
Scrub and/or herbaceous vegetation associations (heathlands)	Forests (mostly assemblages of maritime pine and exotic bluegum)	12,021.55
Scrub and/or herbaceous vegetation associations (heathlands)	Urban fabric	1,140.17
Gain HNVf1 – 47,519.94 ha in total		
Forests (mainly assemblages of maritime pine)	Scrub and/or herbaceous vegetation associations (heathlands)	22,473.72
Scrub and/or herbaceous vegetation associations (heathlands and degraded forests)	Scrub and/or herbaceous vegetation associations (heathlands)	7,263.44

Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations (heathlands)	3,356.45
Arable land	Scrub and/or herbaceous vegetation associations (heathlands)	3,338.54
Loss HNVf2 –73,845.66 ha in total		
Heterogeneous agricultural areas (mainly complex crop mosaics and mix of annual crops and Vineyards and agro-forestry areas with broadleaved trees)	Arable land	21,243.97
Heterogeneous agricultural areas (mainly complex crop mosaics and mix of annual crops and Vineyards and agro-forestry areas with broadleaved trees)	Heterogeneous agricultural areas (mainly complex crop mosaics and mix of annual crops and Vineyards)	14,901.37
Heterogeneous agricultural areas (mainly complex crop mosaics and mix of annual crops and Vineyards and agro-forestry areas with broadleaved trees)	Forests **(**assemblages of maritime pine and broadleaved trees**)**	13,185.33
Heterogeneous agricultural areas (mainly complex crop mosaics and mix of annual crops and Vineyards and agro-forestry areas with broadleaved trees)	Urban fabric	11,696.52
Gain HNVf2 – 12,042.13 ha in total		
Arable land	Heterogeneous agricultural areas (complex crop mosaics)	5,852.19
Forests **(**assemblages of maritime pine and broadleaved trees**)**	Heterogeneous agricultural areas (complex crop mosaics)	2,444.37
Heterogeneous agricultural areas (mix of arable crops and other crops)	Heterogeneous agricultural areas (complex crop mosaics)	1,411.18
Urban fabric	Heterogeneous agricultural areas (complex crop mosaics)	845.38

Supplementary Material S5. High Nature Value farmlands dynamics in areas designated for conservation (Natura 2000 and Transboundary Biosphere Reserve Gerês-Xurés) in the EDM

The EDM agrarian region comprises several areas designated for nature conservation under the Natura 2000 framework, including Sites of Community Interest (SCIs) and Special Protection Areas (SPAs) (see also Supplementary Material S1). Interestingly, the two SPAs designated in the study-area are located mainly within SCIs located in the same area, and a coincidence of 90.6% was observed between both instruments of the Natura 2000 network. Nevertheless, as SCIs and SPAs differ in the restrictions imposed to human activities, which in turn can impact High Nature Value farmlands assessment in space and time, we analysed changes both jointly, i.e., considering both SCIs and SPAs areas (referred as Natura 2000 network, an area resulting from a merge between the SCIs and SPAs), and individually, i.e., by considering individually the areas only designated as SCIs and only designated as SPAs. Results from such analysis are presented in Table S5.1. Given the results obtained, only results from the assessment based on the merged area between SCIs and SPAs are presented in the main manuscript.

Table S5.1. Trends observed between 1989 and 2009 in High Nature Value farmlands (HNVf) extent in the EDM region in Special Protection Areas (SPAs) and Sites of Community Interest (SCIs).

	HNVf1		**HNVf2**		**Area (ha)**
Designation	Ha change	% change	Ha change	% change	
Results (individual and joint assessment) for areas designated both as SCIs and SPAs (overlaying areas)					
SPA PTZPE0002 only	-206.80	-12.78	-164.41	-10.16	1,618.27
SCI PTCON0001 only	-1,878.00	-8.75	-1,079.27	-5.03	21,451.87
SPA PTZPE0002 and SCI PTCON0001	-8,454.80	-18.33	-748.07	-1.62	46,115.08
SCI PTCON0020 only	95.47	1.78	-1,132.04	-21.13	5,358.08
SPA PTZPE0002 and SCI PTCON0020	0.00	0.00	0.11	13.99	0.77
SPA PTZPE0001 only	-5.98	-1.56	-26.58	-6.93	383.78
SCI PTCON0017 only	-26.15	-1.60	-49.11	-3.01	1,634.22
SPA PTZPE0001 and SCI PTCON0017	0.00	0.00	0.00	0.00	225.75
SCI PTCON0019 only	33.42	1.73	-239.38	-12.39	1,931.41
SPA PTZPE0001 and SCI PTCON0019	-5.84	0.05	-261.19	-10.57	2,470.85
Results for the other areas designated as SCIs in the EDM					

SCI PTCON0003	-3,160.23	-11.98	-337.94	-1.28	26,373.02
SCI PTCON0018	-67.28	-28.99	-5.11	-2.20	232.12
SCI PTCON0024	41.84	1.64	-7.52	-0.29	2,552.30
SCI PTCON0025	3583.43	16.81	-1,161.96	-5.45	21,311.43
SCI PTCON0039	168.67	3.75	-52.48	-1.17	4,492.94
SCI PTCON0040	-199.04	-3.87	114.52	2.23	5,138.97
SCI PTCON0047	875.76	6.21	-4.77	-0.03	14,107.62
SCI PTCON0059	1.45	0.03	-39.76	-0.84	4,747.17

Note: HNVf1 and HNVf2 - High nature Value farmlands types 1 and 2; % - percentage; Ha - hectares. Area depicts the area, in hectares, correspondent to each instrument i.e. where a given area is only SCI, only SPA or SCI and SPA.

In Table S5.2 the overall results observed when analysing trends in HNVf extent within Natura 2000 area of the EDM are presented. To analyse the potential of Natura 2000 areas to contribute to HNVf persistence, changes outside such areas were also assessed and are shown in Table S5.2.

Table S5.2. Trends observed for High Nature Value farmlands (HNVf) in the Entre-Douro-e-Minho region between 1989 and 2009, inside and outside areas designated for nature conservation.

		Hectares			**% UAA**			**% area**			**% of EDM HNVf**		
		89	**09**	**Δ**	**89**	**09**	**Δ**	**89**	**09**	**Δ**	**89**	**09**	**Δ**
HNVf1	**Inside N2000**	45,806	36,602	**-9,204**	59.97	60.00	**0.03**	28.59	22.84	**-5.74**	5.10	4.06	**-1.02**
	Outside N2000	62,190	58,696	**-3,493**	19.12	21.18	**2.06**	8.40	7.93	**-0.47**	6.91	6.52	**-0.39**
HNVf2	**Inside N2000**	8,335	3,139	**-5,195**	10.91	5.15	**-5.77**	5.20	1.96	**-3.24**	0.93	0.35	**-0.58**
	Outside N2000	74,768	18,160	**-56,608**	22.98	6.55	**-16.43**	10.10	2.45	**-7.65**	8.30	2.02	**-6.29**

Note: % UAA - percentage of HNVf in the Utilized Agricultural Area (UAA); % area - percentage of HNVf in relation to areas designated versus not designated for nature conservation; % of EDM HNVf - percentage of HNVf in relation to the total area of EDM. % - percentage; Δ - difference between 1989 and 2009. HNVf1 and HNVf2 - High nature Value farmlands types 1 and 2.

Table S5.3. presents the results obtained when analysing changes in the Transboundary Biosphere Reserve Gerês-Xurés, when assessing changes for all area, and when analysing each of the areas defined within the zonation (core, buffer and transition).

Table S5.3. Extent of High Nature Value farmlands (HNVf) for the years of 1989 and 2009 in the Transboundary Biosphere Reserve Gerês-Xurés. Values are presented for each of the zones, core, buffer and transition, of the Biosphere Reserve.

Year	Zone	HNVf1 (ha)	HNVf2 (ha)	HNVf1 (%UAA)	HNVf2 (%UAA)	HNVf1 (%FullA)	HNVf2 (%FullA)
1989	**Core**	6,007	4	87.87	0.06	26.50	0.02
	Buffer	20,180	2,460	74.57	9.09	43.30	5.28
	Transition	12,681	9,164	46.49	33.60	26.97	19.49
	All	38,869	11,629	63.54	19.01	33.42	10.00
2009	**Core**	2,932	0	77.30	0.00	12.93	0.00
	Buffer	12,712	493	69.13	2.68	27.28	1.06
	Transition	10,757	1,739	46.49	7.52	22.88	3.70
	All	26,401	2,232	58.26	4.93	22.70	1.92

Note: HNVf areas inside designated areas are expressed as: i) hectares (ha); ii) percentage of UAA (%UAA); and, iii) as percentage of the total area of the Transboundary Biosphere Reserve Gerês-Xurés (%FullA). %, percentage; HNVf1 and HNVf2 - High nature Value farmlands types 1 and 2.