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Evaluating population and community structure against climate and land-use determinants to improve the conservation of the rare *Narcissus pseudonarcissus* subsp. *nobilis*

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Abstract

Vaz, A.S., Silva, D., Alves, P., Vicente, J.R., Caldas, F.B., Honrado, J.P. & Lomba, A. 2016. Evaluating population and community structure against climate and land-use determinants to improve the conservation of the rare *Narcissus pseudonarcissus* subsp. *nobilis. Anales Jard. Bot. Madrid* 73(1): e027.

Climate and land-use changes are among the most relevant determinants of future persistence of rare plant species in rural landscapes. We analysed the structure of populations of a rare plant, *Narcissus pseudonarcissus* subsp. *nobilis*, and of their respective plant communities against several environmental variables (climate-, topography-, land-use-, and soil-related) in order to identify the pressures that may directly or indirectly affect the persistence of the rare species. Overall, local land-use was the primary determinant of traits related to population renewal and community composition. Specifically, traditional farmlands supported higher community diversity and population individuals. Though moderate land-use intensification seemed to benefit plant community diversity, land abandonment could allow the persistence of *N. pseudonarcissus* subsp. *nobilis* populations. Also, a relevant influence of regional environment was perceived on species richness as well as on traits related to population condition, highlighting climate change as a potential determinant of the future persistence of the species. This study highlights the importance of considering key population traits as well as of community structure to accomplish conservation goals by accounting with the factors driving changes in the habitats in which rare species occur, from climate change to land-use and landscape management.

Keywords: Endangered species, Iberian Peninsula, land-use, population traits, rural landscapes

Resumen

Vaz, A.S., Silva, D., Alves, P., Vicente, J.R., Caldas, F.B., Honrado, J.P. & Lomba, A. 2016. Evaluando la estructura de la población y de la comunidad frente al clima y el uso del suelo para mejorar la conservación de una especie rara, *Narcissus pseudonarcissus* subsp. *nobilis. Anales Jard. Bot. Madrid* 73(1): e027.

Las alteraciones del clima y del uso del suelo están entre los factores más relevantes para la persistencia de las especies raras de plantas en paisajes rurales. Este trabajo evalúa la estructura de las poblaciones de una especie rara, *Narcissus pseudonarcissus* subsp. *nobilis*, así como de las comunidades de plantas en las cuales se incluyen, frente a variables ambientales (relacionadas con el clima, la topografía, el uso del suelo, y las propiedades del suelo), para identificar las presiones que puedan directa o indirectamente afectar a la especie. En general, el uso local del suelo fue el principal determinante de las características de las poblaciones relacionadas con la capacidad de renovación de esta subespecie, así como de la composición específica de las comunidades. Específicamente, la intensificación media de uso del suelo parece beneficiosa para la diversidad de las comunidades de plantas, pero el abandono agrícola parece permitir la presencia de las poblaciones de *N. pseudonarcissus* subsp. *nobilis*. Adicionalmente, una influencia relevante del ambiente regional fue observada para la riqueza específica, así como sobre las características de las condiciones actuales de las poblaciones, sugiriendo que la alteración del clima es un factor potencial para el futuro de la especie. Este estudio destaca la importancia de considerar características clave de las poblaciones así como de la estructura de las comunidades, lo que permite conseguir objetivos de conservación que incluyen factores de cambio en los hábitats, desde las alteraciones del clima y del uso del suelo hasta la gestión del paisaje.

Palabras clave: Características poblacionales, especies amenazadas, paisajes rurales, Península Ibérica, uso del suelo.

INTRODUCTION

European rural landscapes comprise a diversity of vegetation mosaics of high nature value, with species and habitats of conservation interest (Billeter & al., 2008; Lomba & al., 2014). Still, these landscapes are under several pressures, from climate change to land-use modifications (Deutschewitz & al., 2003; Lomba & al., 2012). Specifically, the abandonment of traditional land-use and the intensification of already intensively managed land are among the main determinants of plant diversity (Vassilev & al., 2011; Plieninger & al., 2014).

Assessing the factors determining the patterns of plant diversity is thus a priority in current research and downstream

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decision making (Schneiders & al., 2012; Smart & al., 2012). However, resources needed for exhaustive surveys are often unavailable, and so indicator-based approaches have been considered due to their cost- and time-efficiency (Smart & al., 2012; González-Oreja & al., 2013). Indicator-based approaches rely on relations between the attributes of distinct levels of ecological organisation (e.g., populations, communities) and their environmental conditions at given spatial and temporal scales (González-Oreja & al., 2013). The rationale is that, in the presence of a significant species-environment relation, when the environmental determinant is intensified or reduced, the attribute or pattern of the focal plant species or community will also change (Smart & al., 2012; Hoare & al., 2013). For several plant taxa, such approaches have focused on traits which exhibit similar responses to environmental conditions or shifts (Gondard & al., 2003; Cousins & Lindborg, 2004; Albert & al., 2010; Lavorel & al., 2011).

Rare taxa constitute one of the key targets of conservation actions as they often exhibit high extinction risks associated to their small population sizes and restricted geographic ranges (Fontaine & al., 2007; Lomba & al., 2010). The persistence of rare plants has been related to population traits that frame their adaptive abilities, renewal capacities and responses to environmental shifts (Shipley & al., 2006; Albert & al., 2010). The assessment of such traits is thus essential for evaluating the condition and dynamics of rare plant populations, and also of the plant communities of which they are part of (Shipley & al., 2006; Violle & al., 2007). The persistence of rare plants has also been related to changes in the habitats in which they occur (Fontaine & al., 2007; Lomba & al., 2010). From a conservation perspective, effective planning and monitoring should consider not only the factors directly affecting the structure of rare plant populations, but also the determinants of their habitats (Broennimann & al., 2005; Regnery & al., 2013). In fact, several initiatives have adopted this approach in important policy instruments such as the EU Habitats Directive (Council Directive 92/43/EEC) and the IUCN European Red Data list (Bilz & al., 2011).

In this study, we aimed at evaluating the determinants of population structure for *Narcissus pseudonarcissus* L. subsp. *nobilis* (Haw.) A. Fernandes, a rare, endangered plant under legal protection, as well as of the plant communities of which the populations are part of. By doing so, we expected to identify the environmental and biotic pressures that may directly or indirectly threaten this plant, thereby addressing common conservation strategies in Portuguese rural landscapes. This taxon, sometimes recognized at the species level as *N. nobilis* (Haw.) Schult. & Schult. fil., is an Iberian endemic plant of European conservation interest, and is considered a rare and threatened species for Portugal (ICNF, 2006). The recent treatment for *Narcissus* in Flora Iberica (Aedo, 2013) assumes this name as a synonym of *N. pseudonarcissus* subsp. *pseudonarcissus*, however, given the synthetic approach adopted in that work, we prefer to preserve the use of subsp. *nobilis* rather than merge it in the typical subspecies. This endemic daffodil has been under several anthropogenic threats (Lozano & al., 1996), which are expected to be aggravated due to future scenarios of land-use change (Bielsa, 2005; Lomba & al., 2012). An analytical framework is proposed that integrates several population traits of the target species as well as several potential determinants operating at distinct scales. The implications of our results and of the novel framework for the conservation and management of subsp. *nobilis* and other rare, threatened plants are also discussed.

METHODS

Study area

The study was conducted in seven sites located in the Northwestern and the Central Portugal (Fig. 1). The Northwestern Portugal is characterised by the biogeographic transition between the Eurosiberian (coinciding with a temperate Atlantic climate) and the Mediterranean regions. This area comprises the only Portuguese National Park, Peneda Gerês, and the Natura 2000 site of Corno do Bico (ICNF, 2012). One site (Videmonte) was located in Central Portugal, specifically in the Natural Park of Serra da Estrela (ICNF, 2012), a mountain area characterised by interchanges between the Atlantic and the Mediterranean climates.

In the ensemble of the seven sites, the altitude ranges from 20 to 1190 m, the mean annual temperature spans from 8.75 to 11.25 °C, and granite is the prevailing bedrock type. Further details on the surveyed sites are presented in Table 1.

Target populations

Narcissus pseudonarcissus subsp. *nobilis* (subsp. *nobilis* hereafter) is an herbaceous and bulbous geophyte, typically occurring in semi-natural grasslands (Honrado, 2003). Populations are usually organised in tuffs i.e., groups of individuals with a maximum distance of 2 cm between them. The aerial structure of each *N. pseudonarcissus* subsp. *nobilis* individual may comprise one, two or at least three leaves, corresponding to juvenile, sub-adult, and adult individuals, respectively (Barkham, 1980a). During the flowering season of the species (April-July) each adult may exhibit a bicolored flower with pale yellow tepals and a golden yellow corona, with or without capsules and seeds (Hanks, 2002). *N. pseudonarcissus* subsp. *nobilis* is an Iberian endemic plant (ICNF, 2006) restricted to the northern half of the Iberia Peninsula (Hanks, 2002; Aedo, 2013), where their populations and habitat have been under several pressures, mostly expressed by the collection of flowers, wildfires and land-use changes (Lozano & al., 1996). The species is a Least Concern for Europe (IUCN criteria; Bilz & al., 2011) and a rare and threatened species for Portugal (ICNF, 2006), being under legal protection (EU Directive 92/43/EEC).

Sampling design and data collection

First, seven sites were selected based on a literature review and previous records on the occurrence of subsp. *nobilis* populations (e.g., Barkham, 1980a, b; Castroviejo & al., 1986-2010; Barkham, 1992; Hank, 2002). These records were confirmed in the field and the population was mapped in each site. Then, based on aerial imagery (http://scrif.igeo.pt/servicos/localiz/), a grid of 25 m^2 cells was considered and overlapped to each site in order to cover the whole extent of each population (see Appendix 1 for the considered images and grids). At each site, five 25 m^2 grid

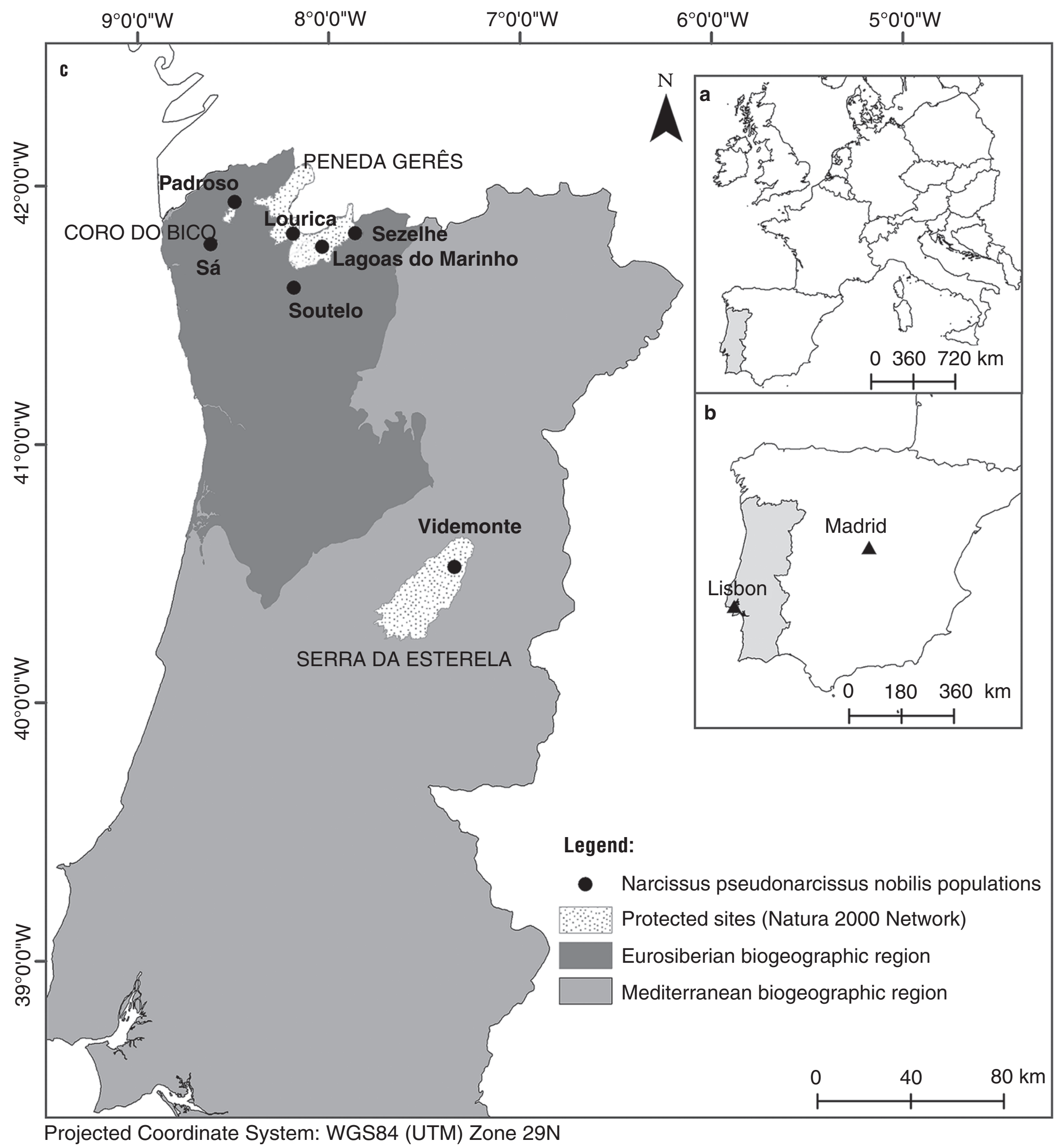

Fig. 1. Location of the study area in Europe, **a**; and in the Iberian Peninsula, **b**. The fig. also shows the location of the sampling sites, the protected areas (Peneda Gerês, Corno do Bico, and Serra da Estrela), and the main biogeographic regions, Eurosiberian and Mediterranean, **c**.

cells were selected for detailed surveys, thus resulting in a total of 35 sampling plots (*n*=35), which was considered representative of each population variability. These procedures were implemented in ArcGIS 10 (ESRI, 2010).

In each plot, nine population traits (sensu "demographic parameter" from Violle & al., 2007) were measured following in-field standardised protocols (e.g., Cornelissen & al., 2003). These traits (Table 2) were selected as they express the condition, renewal capacity, and disturbance on renewal of subsp. *nobilis* populations (Barkham, 1980a, b, 1992; Hanks, 2002; Colling & al. 2010). The surveillance effort for these traits was proportional to the density of the populations surveyed in each site.

A complete list of vascular plant species was also recorded at each plot. The % cover of each species was measured following a simplified Domin scale (Kent & Coker, 1992): (1)<1%, (2) 1-5%, (3) 6-15%, (4) 16-25%, (5) 26-50%, (6) 51-75%, (7) 76-90%, (8) 91-100%. Species nomenclature generally followed Castroviejo et al. (1986-2010).

Habitats surveyed and underlying land-use

Based on in-field observations, each plot was classified according to their dominant habitat/vegetation type. Five different habitat types were considered that expressed a gradient of land-use intensity: from the extensively managed hay meadows and tall scrub, to the more intensively managed grazed meadows, wet heaths and crop fields (see Table 1). The 35 surveyed plots were distributed as: (1) tall scrub (*n*=5), (2) wet heaths (*n*=5), (3) extensive meadows (*n*=15), (4) intensive meadows (*n*=5), (5) and crop fields (*n*=5). Though unbalanced, this set of habitats spanned

Table 1. Details on the surveyed sites with coordinates, number of 25 m^2 grid cells occupied by the population, environmental characterisation and dominant habitat type.

Site	Coordinates (UTM)	Number of grid cells	Area (m^2)	Total annual precipitation (mm)	Mean annual temperature (°C)	Altitude (m)	Habitat type
Louriça	29TNG7924	14	350	2600	11.25	1125	Tall scrub
Lagoas do Marinho	29TNG6630	208	5250	2600	8.75	1190	Wet heaths
Padroso	29TNG4143	226	5650	2200	11.25	655	Extensive meadows
Sá	29TNG3125	28	700	1800	13.75	20	Crop fields
Sezelhe	29TNG9329	74	1850	1800	11.25	990	Intensive meadows
Soutelo	29TNG6605	236	5900	1500	11.25	430	Extensive meadows
Videmonte	29TPE3687	141	3575	900	8.75	1050	Extensive meadows

Table 2. Traits measured for the *N. pseudonarcissus* subsp. *nobilis* populations.

Trait type	Population trait	Acronym
Population condition	Number of individuals	Ind
	Number of tuffs	Tuf
	Number of individuals per tuff	IndTuf
Population renewal	Number of juvenile individuals	Juv
	Number of sub-adult individuals	SAdul
	Number of adult individuals	Adul
	Number of individuals with flowers	Flow
	Number of individuals with capsules	Cap
Disturbance on population renewal	Number of individuals with flowers without capsules	NCap

through the whole range of ecological variation known for this taxon across the study area, and was thus considered suitable to address our research goals, as it expresses different levels of land-use intensity where the targeted populations occur.

In short, tall scrub corresponds to plant communities characterised by a canopy of *Genista florida* L. and *Erica arborea* L., and by an herbaceous undergrowth dominated by the bentgrass, *Agrostis* x *fouilladei* P. Fourn. These habitats are usually under low-intensity management, mostly controlled grazing and burning (Honrado & al., 2002). Wet heaths comprise temperate Atlantic low scrub dominated by *Erica ciliaris* Loefl. ex L. and *E. tetralix* L., and correspond to habitat type 4020* in Annex I of the "Habitats Directive" (EU Directive 92/43/EEC). Management often includes burning, domestic cutting and grazing (Hampton 2008). Extensively managed meadows are dominated by typical lowland mesohygrophilous grasses of the *Arrhenatherion* Koch phytosociological alliance (Rodríguez-Rojo & Sánchez-Mata, 2004), corresponding to habitat type 6510. These meadows are mostly managed for hay (Aguiar & al., 2000). Under more intensive management (often involving grazing and fertilising), meadows show the dominance of plants of the *Cynosurion cristati* Tüxen alliance, e.g. *Hypochoeris radicata* L. and *Cynosurus cristatus* L. (Rodríguez-Rojo & Sánchez-Mata, 2004; Aguiar & al., 2010). Finally, crop fields comprise cover crops usually used for silage, and dominated by corn (summer crop) or the annual ryegrass, *Lolium multiflorum* Lam. (winter crop); the corn marigold, *Coleostephus myconis* (L.) Rchb.f., is the prevailing ruderal weed (Honrado & al., 2002).

Environmental variables

Eighteen environmental variables were considered based on their potential effects on subsp. *nobilis* populations and coexistent plant community. Considering their spatial resolution, each variable was assigned to: (1) a regional context, mostly related to climate and topography, (2) a local context, related to land-use intensity, or (3) a sub-local context, related to soil properties (Lomba & al., 2010). Climatic variables were extracted from Atlas do Ambiente (1:1000000 resolution; http://sniamb.apambiente.pt/webatlas). Altitude was obtained from military maps (1:25000 resolution; http://www.igeoe.pt/). Land-use intensity was evaluated based on site-specific expert knowledge, considering the main land-use activities underlying each surveyed habitat: ploughing, seeding/planting, fertilising, irrigating, cutting, grazing, and burning. For each activity, a rank value of 0 (absent), 1 (occasionally) or 2 (frequently) was assigned, based on the relative intensity of each activity in each habitat. The final intensity value for each habitat was then computed by summing the rank values of each habitat, and then dividing it by the highest value attained (Table 3).

Soil properties were measured from soil samples (i.e., three to four cores 0.05-0.25 m horizon) for each 25 m^2 cell, and analysed following standard procedures from the IPVC laboratory (http://portal.ipvc.pt/portal/page/portal/esa). All variables were tested for pair-wise correlations using Kendall's τ tests (non-parametric, suitable for a low number of observations; Quinn & Keough, 2002). Variables with correlation values above 0.70 (i.e., Calcium content, Days of frost, and Insolation) were not considered in subsequent

Table 3. Habitat types and correspondent habitat code from the Annex I of the "Habitats Directive". The table shows the values attributed to each habitat type considering their land-use activities. The ranked values were assigned based on the relative annual frequency of each activity: 0, absent; 1, occasionally; 2, frequently. For each habitat, the final intensity value (expressed in a % scale) was obtained by summing all the ranked values per habitat and then dividing it by the highest value attained.

	Habitat				
Land-use activity	**Tall scrub**	**Wet heaths (Habitat code: 4020*)**	**Extensive meadows (6510)**	**Intensive meadows**	**Crop fields**
Ploughing	0	0	0	0	2
Seeding/planting	0	0	0	0	2
Fertilising	0	0	1	2	2
Irrigating	0	0	1	1	2
Cutting	0	1	2	1	2
Grazing	1	2	1	2	0
Burning	1	1	0	0	0
Sum	2	4	5	6	10
Intensity value (%)	20	40	50	60	100

Table 4. Environmental variables considered for analysing both population and community structure: type, units, acronym, and source/resolution.

Variable type	Variable (units)	Acronym	Source / resolution
Regional context			
Climate	Total annual precipitation (mm)	Ptot	Atlas do Ambiente; 1:1000000 resolution; http://sniamb.apambiente.pt/webatlas
	Days of precipitation	Pdays	
	Humidity of air (%)	Hum	
	Evapotranspiration (mm)	Evap	
	Mean annual temperature (°C)	Tmean	
	Days of frost (day)	Gea	
	Insolation (hours)	Inso	
Topography	Altitude (m)	Alt	Military maps; 1:25000 resolution; www.igeoe.pt/cartoteca/cartogramaM888.htm
Local context			
Land-use	Land-use intensity (ranked scale)	LUint	Land cover from aerial imagery and field validation
Sub-local context			
Soil properties	Soil pH	pH	Soil samples analysed for each 25 m^2 vegetation plot
	Organic matter content (%)	OM	
	Phosphorous content (ug/g)	P	
	Potassium content (ug/g)	K	
	Calcium content (ug/g)	Ca	
	Magnesium content (ug/g)	MG	
	Nitrogen content (ug/g)	N	
	Soil moisture (%)	H_2O	
	Soil density (g/cm^3)	Dens	

analyses (Lomba et al. 2010), resulting in a final set of 15 environmental variables (Table 4).

Analytical framework and statistical analyses

An analytical framework was applied for assessing both population and community structure against the considered environmental variables. Since the observed data did not follow a normal distribution, only non-parametric tests and descriptive statistics were considered. Furthermore, considering that the set of habitat types was unbalanced, and to avoid any negative effects on the statistical procedures, all analyses were performed at the site level. Accordingly, significant differences for the number of subsp. *nobilis* individuals and community species richness (expressed as median±interquartile) were analysed across sites, using

Kruskal-Wallis (*H*) and post-hoc Mann-Whitney (*U*) tests. A Detrended Correspondence Analysis (DCA) was implemented in order to analyse variations in population traits and community composition (i.e., species richness and abundance) along the considered environmental gradients (ter Braak & Smilauer, 2002; Kleyer & al., 2012). Finally, correlations between individual population traits and each environmental variable, as well as between community species richness and individual variables were analysed through Kendall's τ tests. For community composition, correlation values between DCA axes and environmental variables were assessed through weight correlation matrices as described in ter Braak & Smilauer (2002). Univariate and multivariate statistical analyses were implemented in IBM SPSS Statistics 20 software (IBM Corp. Released, 2011) and CANOCO 4.5 software (ter Braak & Smilauer, 2002), respectively.

RESULTS

Population size per site and habitat type

A total of 20319 *N. pseudonarcissus* subsp. *nobilis* individuals, organised in 4557 tuffs, was recorded. The highest median values of individuals per plot were observed for extensive meadows (Videmonte: 1025±3465, Padroso: 594±647 and Soutelo: 384±198), and tall scrub (Louriça: 588±559). The lowest values were found for intensive meadows (Sezelhe: 95±152), wet heaths (Lagoas do Marinho: 75±201) and crop fields (Sá: 7±45). With the exception of Soutelo, the inter-quartile range was higher than the median in all sites. Kruskal-Wallis and post-hoc Mann-Whitney tests indicated significant differences between most sites (Appendix 2).

Community structure along environmental gradients

Overall, 181 plant species were recorded (Appendix 3). Videmonte (extensive meadows: 22±7), Sezelhe (intensive meadows: 17±3), Lagoas do Marinho (wet heaths: 15±2) and Soutelo (extensive meadows: 14±3) were the sites with the highest median values for species richness per vegetation plot, followed by Padroso (extensive meadows: 13±10), Sá (crop fields: 12±1) and Louriça (tall scrub: 12±0). Kruskal-Wallis and post-hoc Mann-Whitney tests indicated significant differences among most sites, with the exception of Padroso (Appendix 2).

The projection of plant community composition in the ordination space showed that the surveyed plots were mostly distributed along the second DCA axis (DCA2; Fig. 2). From the top to the bottom, the DCA plot showed the segregation of plant communities from the different habitat types: (1) tall scrub, with *Agrostis* x *fouilladei*, *Genista florida* and *Erica arborea* for Louriça; (2) temperate Atlantic wet heaths, with *Erica tetralix* and *Ulex minor* Roth, for Lagoas do Marinho; (3) extensively managed meadows, with *Anthoxanthum odoratum* L. and *Plantago lanceolata* L., for Videmonte, Soutelo, Sezelhe and Padroso; and finally, (4) intensively managed meadows, with *Hypochoeris radicata* L. and *Cynosurus cristatus* L., for Sezelhe. From the left to the right and along the first DCA axis (DCA1), the segregation of crop fields, with

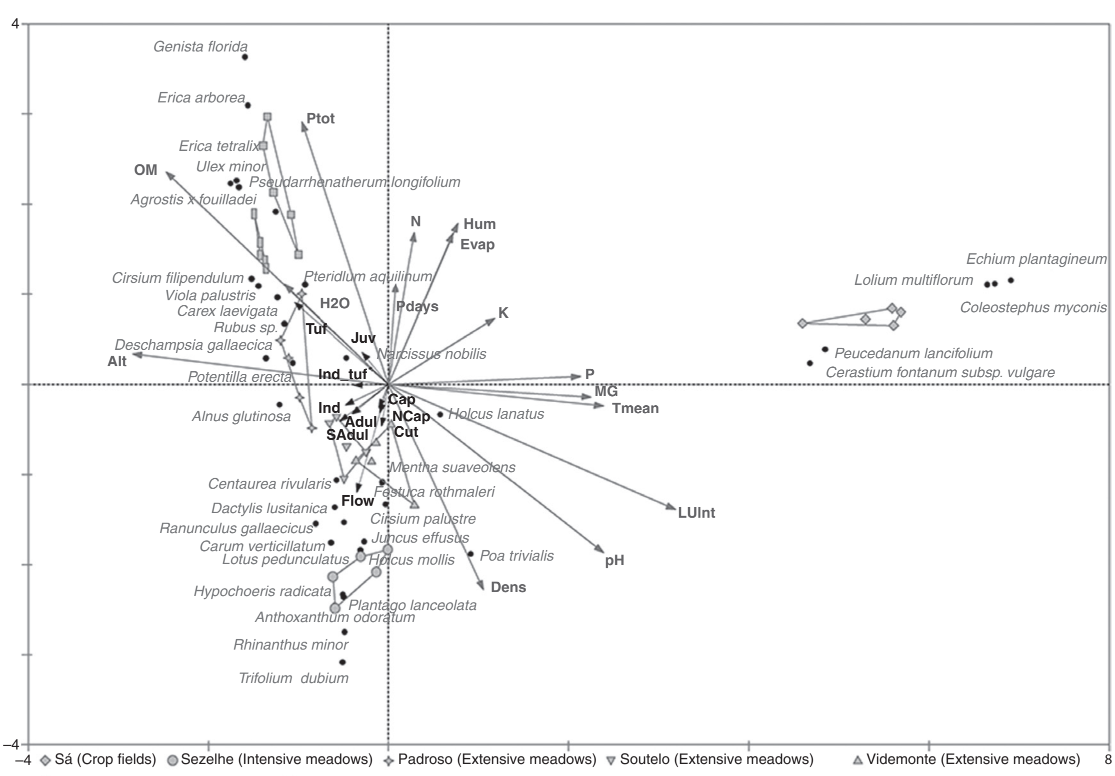

Fig. 2. Detrended Correspondence Analysis plot (DCA1/DCA2) of plant community composition across the surveyed sampling plots, with environmental variables and population traits. Only species with a minimum weight range of 10% are shown (ter Braak & Smilauer 2002). Distinct symbols represent different sites and are enclosed by the drawn polygons.

Lolium multiflorum and *Coleostephus myconis*, for Sá was observed relatively to the other habitats.

A value of 24% of cumulative variance explained was found for the four DCA axes (eigenvalues: DCA1, 0.80; DCA2, 0.57; DCA3, 0.36; DCA4, 0.23 standard deviation). The cumulative % variance of the species-environment relationship explained by DCA1 and DCA2 was 16% and 26%. Both axes depicted variations related to regional, local and sub-local environmental variables. DCA1 was mostly correlated with land-use intensity, soil organic matter, soil pH, and altitude. DCA2 had the highest correlation values with soil- (nitrogen, pH, potassium, and moisture contents) and climate-related (evapotranspiration) variables (Table 5).

Kendall's correlation tests between community species richness and individual variables resulted in significant and negative values for all regional variables ($p<0.05$), and for soil nitrogen content ($\tau = -0.37$, $p<0.05$).

Population structure along environmental gradients

In the DCA plot, values for all population traits were found to increase towards sampling plots from extensive meadows (Fig. 2). The significant correlations between each population trait and individual variables are presented in Table 6. At the regional context, most traits were significantly and negatively correlated with mean annual temperature. Traits related to population condition and population renewal were negatively correlated with other climatic variables (Ptot, Pdays, Hum, Evap). At the local context, land-use intensity showed negative correlations with traits from

Table 5. Correlation values obtained between the main Detrended Correspondence Analysis axes (DCA1/DCA2) and each environmental variable.

Variable type	Environmental variable	Acronym	DCA1	DCA2
Regional context				
Climate	Total annual precipitation	Ptot	–0.556	0.021
	Days of precipitation	Pdays	–0.176	0.174
	Humidity of air	Hum	–0.007	–0.175
	Evapotranspiration	Evap	0.004	0.366
	Mean annual temperature	Tmean	0.504	–0.218
Topography	Altitude	Alt	–0.712	–0.034
Local context				
Land-use	Land-use intensity	LUint	0.852	–0.194
Sub-local context				
Soil properties	Soil pH	pH	0.731	–0.400
	Organic matter content	OM	–0.795	–0.032
	Phosphorous content	P	0.501	–0.077
	Potassium content	K	0.257	0.367
	Magnesium content	MG	0.565	0.111
	Nitrogen content	N	–0.066	0.507
	Soil moisture	H2O	–0.405	–0.326
	Soil density	Dens	0.415	0.110

Table 6. Kendall's test results for the correlations between population traits and environmental variables. Only variables with at least one significant correlation with one population trait are shown. Statistical significance: *$p<0.05$, **$p<0.01$.

		Regional variables						Local variables	Sub-local variables			
Trait type	Traits	Ptot	Pdays	Hum	Evap	Tmean	Alt	LUInt	OM	pH	K	MG
Population condition	Ind	–0.13	–0.34*	–0.14	–0.14	–0.47**	0.19	–0.20	0.23	–0.11	–0.01	–0.36**
	Tuf	–0.10	–0.29*	–0.01	–0.10	–0.36**	0.19	–0.19	0.26*	–0.06	0.04	–0.32**
	IndTuf	–0.26*	–0.26	–0.39**	–0.25	–0.34*	0.04	–0.13	–0.07	–0.19	–0.19	–0.09
Population renewal	Juv	–0.01	–0.13	0.01	–0.04	–0.22	0.11	–0.10	0.10	–0.08	–0.10	–0.25*
	SAdul	–0.18	–0.36*	–0.11	–0.14	–0.38**	0.13	–0.17	0.17	–0.14	–0.03	–0.27*
	Adul	–0.13	–0.31*	–0.12	–0.07	–0.47**	0.18	–0.23*	0.24*	–0.12	0.02	–0.34**
	Flow	0.08	–0.13	–0.34*	–0.56**	–0.06	0.27	–0.10	–0.02	0.09	–0.39**	–0.13
	Cap	0.00	–0.25	–0.11	–0.11	–0.45**	0.27*	–0.26*	0.34**	–0.17	0.02	–0.34**
Disturbance on population renewal	NCap	–0.20	–0.26	–0.16	0.02	–0.42**	0.09	–0.24*	0.08	–0.32*	0.01	–0.22

population renewal and disturbance on population renewal. At the sub-local context, soil pH was only significantly correlated with traits from disturbance on population renewal; and potassium context only correlated with population renewal traits (negative correlations). Soil magnesium was negatively correlated with population condition and population renewal traits. Finally, organic matter content was positively correlated with population condition and population renewal traits, yet a negative correlation was found regarding traits from disturbance on population renewal.

Main factors influencing population and community structure

Table 7 shows the general results obtained when evaluating the structure of subsp. *nobilis* populations and plant communities in relation to their underlying environmental variables. Overall, higher values of both population and community structure were found in extensive meadows. Though the number of individuals was also found to be high in less managed habitats, plant community was found to be favoured by habitats under more intensive land-use.

Values for traits expressing the condition and the renewal capability of subsp. *nobilis* and for community species richness were negatively related with precipitation and temperature. Land-use was significantly and negatively related with population renewal traits and community composition. Organic matter related positively with population traits expressing subsp. *nobilis* current condition and renewal, and community composition. Other soil properties (mostly soil nutrients) were negatively related with both population and community structure.

DISCUSSION

Population structure of rare plants

Categorising and protecting rare species populations (e.g., the IUCN Red List) has been mostly based on information about their geographic range, population size and population structure (Fontaine & al., 2007; Bilz & al., 2011). Therefore, knowing the habitats and environmental requirements is essential to infer on rare species current and future dynamics, and thus to support effective conservation measures (Lomba & al., 2010; Wallin & Svensson, 2012).

For our test species, meadow and tall scrub habitats exhibited the highest and the most variable values for *N. pseudonarcissus* subsp. *nobilis* individuals. Furthermore,

Table 7. Overview of the main results attained for evaluating population and community structure across habitats and environmental variables (climate-, topography-, land-use-, and soil-related). +, positive relation; –, negative relation. Blank cells indicate no significant relation or that the analysis was not applied; DCA1/ DCA2, indicate the cases in which a significant relation was found for the first (DCA1) or second (DCA2) DCA axis.

	Population structure				Community structure	
		Population traits				
Habitats/environmental gradients	Number individuals	Population condition	Population renewal	Disturbance renewal	Species richness	Species composition
Patterns across sites						
Tall scrub	+				–	
Wet heaths	–				+	
Extensive meadows	+				+	
Intensive meadows	–				+	
Crop fields	–				–	
Patterns along regional gradients						
Total precipitation		–			–	
Days of precipitation	–	–	–		–	
Humidity of air		–	–		–	
Evapotranspiration		–	–		–	DCA2
Mean temperature	–	–	–	–	–	
Altitude					–	DCA1
Patterns along local and sub-local gradients						
Land-use intensity			–	–		DCA1
pH				–		DCA1
Organic matter		+	+	–		DCA1
Phosphorous						
Potassium			–			DCA2
Magnesium	–	–	–			
Nitrogen					–	DCA2
Soil moisture						DCA2
Soil density						

traits expressing population capability for future renewal were negatively related to the increase of land-use intensity and specifically, soil organic matter and nutrient inputs. These results are in agreement with those from Wallin & Svensson (2012), which reported higher population growth rates of a typical meadow plant (*Succisa pratensis*) in traditionally managed meadows from Gotland. Also, Lindborg & Ehrlén (2002) indicated the disappearance of *Primula farinosa* (a meadow herb) under increasing levels of land fertilisation associated to more intensive meadow management and grazing in Sweden. The traditional meadow management usually includes a mowing period, which contributes to soil nutrient enrichment, and can constitute an advantage for bulbous plants (Klimek & al., 2007; Winter & al., 2011; Wallin & Svensson, 2012). Our results seem to express the species preference for traditionally managed meadows (Honrado & al., 2002). Also, the species affinity for successional habitat types (tall scrub), suggests that even under potential scenarios of meadow abandonment (Bielsa, 2005; Lomba & al., 2012) the species could persist. Also, the high population variability observed (expressed by the inter-quartile range), might also highlight the fine-scale niche preferences and the ability of microhabitat occupancy by subsp. *nobilis*, suggesting a geographical heterogeneous expression of the populations' pool ("habitat filtering") even within the same habitat type (Kleyer & al., 2012).

The relations between individual population traits and regional environmental variables also suggest that climate is a significant factor for variations in population traits related to their current condition and future trends (renewal capability). These results likely indicate that future changes in climatic conditions, predicted to include a general increase of temperatures and a decrease of precipitation across the study area (Santos & al., 2001), could influence the dynamics of the targeted populations.

Community structure for multiple habitat types

Information on the factors which directly affect the structure of populations might not always be enough to support rare species monitoring, as changes in population dynamics may be recognised too late (Broennimann & al., 2005; Regnery & al., 2013). Accordingly, complementary focus on the habitat/community structure and determinants could allow the identification of early-indicators on potential threats to the rare species (Bilz & al., 2011; Halada & al., 2011; Lindborg & Ehrlén, 2002), as well as the accomplishment of further conservation goals such as those included in the "Habitats Directive" (E.U. Directive 92/43/CEE).

In our study, plant communities surveyed in sites dominated by meadows and wet heaths exhibited higher species richness compared to tall scrub and crop fields. These results are in agreement with those from Baur & al. (2006) which reported higher values for red listed plant in semi-natural and extensively managed hay meadows compared to abandoned habitats in Eastern Europe. Also, Lomba & al. (2012) highlighted extensively managed meadows as important habitats for the maintenance of plant diversity when forecasting the decline of species richness under scenarios of long-term meadow abandonment in Northern Portugal. Several researchers already highlighted traditional land-use as an important supporter of plant diversity (Baur & al., 2006; Klimek & al., 2007; Vassilev & al., 2011; González-Oreja & al., 2013). Traditional meadow management often comprises hay-cutting periods with aftermath raking, grazing and vegetation re-growth (Halada & al., 2011; Lomba & al., 2012; Wallin & Svensson, 2012). Also, wet heaths are usually under domestic cutting, grazing and burning episodes (Hampton, 2008). These management options, coupled with e.g., invasive plant removal (Wallin & Svensson, 2012) could promote intermediate levels of disturbance (Bratli & al., 2006; Klimek & al., 2007), and thus higher environmental heterogeneity e.g., related to distinct nutrient and light exposure conditions (Wallin & Svensson, 2012; González-Oreja & al., 2013). Accordingly, higher species diversity would be expected, as plant competitors would not be able to dominate, and thus an assortment of ecological niches for plant species with distinct resource needs and preferences becomes available (Enyedi & al., 2008; Wallin & Svensson, 2012). Shifts in these traditional practices, towards intensification or abandonment, have been reported as major determinants of plant diversity (Kleijn & al., 2011; Plieninger & al., 2014). This has been more explicit for land-use intensification, promoting landscape/habitat homogenisation (e.g., monoculture production; Bielsa & al., 2005), fragmentation (e.g., patchiness of agricultural fields; Bratli & al., 2006) and degradation (e.g., input of fertilisers or animal effluents; Vassilev & al., 2011; Lomba & al., 2012). For land-use abandonment, there is no agreement on its effects on plant diversity (Plieninger & al., 2014), as some studies have been reporting the decline of diversity at long-term (Halada & al., 2011; Vassilev & al., 2011), but others suggesting their increase at short-terms (Bielsa & al., 2005; Enyedi & al., 2008). In our case, the intensification of meadow management and the prevalence of rather intensively managed habitats (wet heaths) seem to support plant diversity. This suggests that under more intensive, yet traditional agricultural regimes, plant diversity might be benefited. Contrastingly, conversion from traditionally managed habitats to other successional habitats (tall scrub) appears to promote a decline of plant diversity.

In respect to the environmental variables considered, community species richness was found to relate negatively to climatic (temperature and precipitation) and altitudinal shifts. Nevertheless, variations in plant composition were observed across a land-use gradient, with topography, soil pH and organic matter also showing a relevant relation. These results partially converge with those from Klimek & al. (2007) which reported the joint effect of environmental context and management regimes as determinants of vegetation patterns along several managed grasslands in Germany. Also, Dietschi & al. (2007) reported differences between plant community diversity from mountain meadows and grasslands along gradients of management intensity in Switzerland. Our results likely express the fact that the surveyed sites spread over a geographically heterogeneous area (Klimek & al., 2007; Billeter & al., 2008). Nevertheless, they also seem to reveal the effects of multi-scalar environmental filters, with: (1) broad scale climate and topography acting as filters for the regional species pool which is able to occur at smaller scales (Albert & al., 2010; Kleyer & al., 2012), and (2) local land-use (and underlying regime options) limiting the abundance of each community plant species according to their ability for niche occupancy at fine-scales (Klimek & al., 2007). Accordingly, a deeper assessment of sub-local features of our habitats could provide deeper insights on community patterns, habitat quality, and environmental pressures (Dietschi & al., 2007; Halada & al., 2011; González-Oreja & al., 2013).

Implications for the conservation of **N. pseudonarcissus** *subsp.* **nobilis** *populations*

Extensively managed areas across rural landscapes often host species-diverse plant communities (Cousins & Lindborg, 2004; González-Oreja & al., 2013). Here, the diversity patterns of both plant population and community were found to be positively related to these traditional agricultural systems. Moreover, under the conversion of land-use regimes, a duality of situations appears to emerge. At the one hand, the intensification of such traditional practices seems to promote the diversity of plant communities. At the other hand, the extensification of agricultural practices could still allow the viability and prevalence of subsp. *nobilis* populations, as previously highlighted for other bulbous plants, such as *Colchicum autumnale* in Austria (Winter & al., 2011).

We suggest that conservation measures should aim to maintain traditional agricultural practices in extensive hay meadows in order to promote the stability of subsp. *noblis* populations, where clonal reproduction plays an important role. In order to avoid future declines in population viability within each surveyed site, appropriate management measures should be adopted to favour clonality and increase population sizes. Specifically, we suggest that management measures should avoid land use intensification, namely restricting fertilizer inputs and ploughing practices in the currently occupied hay meadows, since these land use practices could compromise the integrity of the bulbs and cause local extinctions in otherwise stable populations. By adopting these measures, both clonal growth within populations, and sexual reproduction between sub-populations could be promoted, as highlighted by Colling & al. (2010).

The conservation measures suggested are of high importance considering that agricultural change is a key determinant of current environmental shifts in the study area (Vassilev & al., 2011; Plieninger & al., 2014). In fact, the maintenance of traditional and low-intensive agricultural systems such as High Nature Value farmlands have being explicitly targeted by EU environmental policies e.g., through the Common Agricultural Policy and the Rural Development Programmes (Dietschi & al., 2007; Kleijn & al., 2011; Lomba & al., 2014). Accordingly, we support the fact that conservation efforts towards the maintenance of extensive land use practices in hay meadows from High Nature Value farmlands could constitute a win-win scenario for the subsp. *nobilis* populations and the habitats supported. This is also of high relevance considering not only the conservation status of the focal rare species, but also that the highly-rich habitats supported by the High Nature Value farmlands are under legal protection, E.U. Directive 92/43/CEE. The habitat types listed in Annex I of the Habitats Directive correspond to the surveyed habitats: 6510, "Lowland hay meadows (*Alopecurus pratensis*, *Sanguisorba officinalis*)" (hay meadows); and 4020*, "Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*" (Halada & al., 2011). Nevertheless, as a relevant influence from regional climate was perceived, the role of climate change should not be devaluated on the future trends for the populations and habitats.

Applying the framework to improve adaptive conservation management of **N. pseudonarcissus** *subsp.* **nobilis**

This research highlights the advantages of considering both population and community structure when planning conservation action aiming at fostering the persistence of rare species under multi-scale environmental change. For example, monitoring approaches targeting the effects of climate change on the populations of our test species could prioritise data collection on plant community species richness and on traits related to population condition; whereas management options involving land-use changes should consider information on community composition and on traits expressing population renewal.

Future efforts should focus on adapting the framework presented here for a wide range of species using spatially-explicit data and modelling techniques e.g., under scenarios of land-use and climate change over higher data resolution and through several periods of time (Lomba & al., 2010; Vicente & al., 2011; Lomba & al., 2012). Even so, we advocate that our framework provides a suitable approach for reporting the condition and dynamics of rare plants, with high potential to contribute to more effective conservation and management programmes targeting populations of rare plants, especially in those landscapes where human management shows a major influence on biodiversity.

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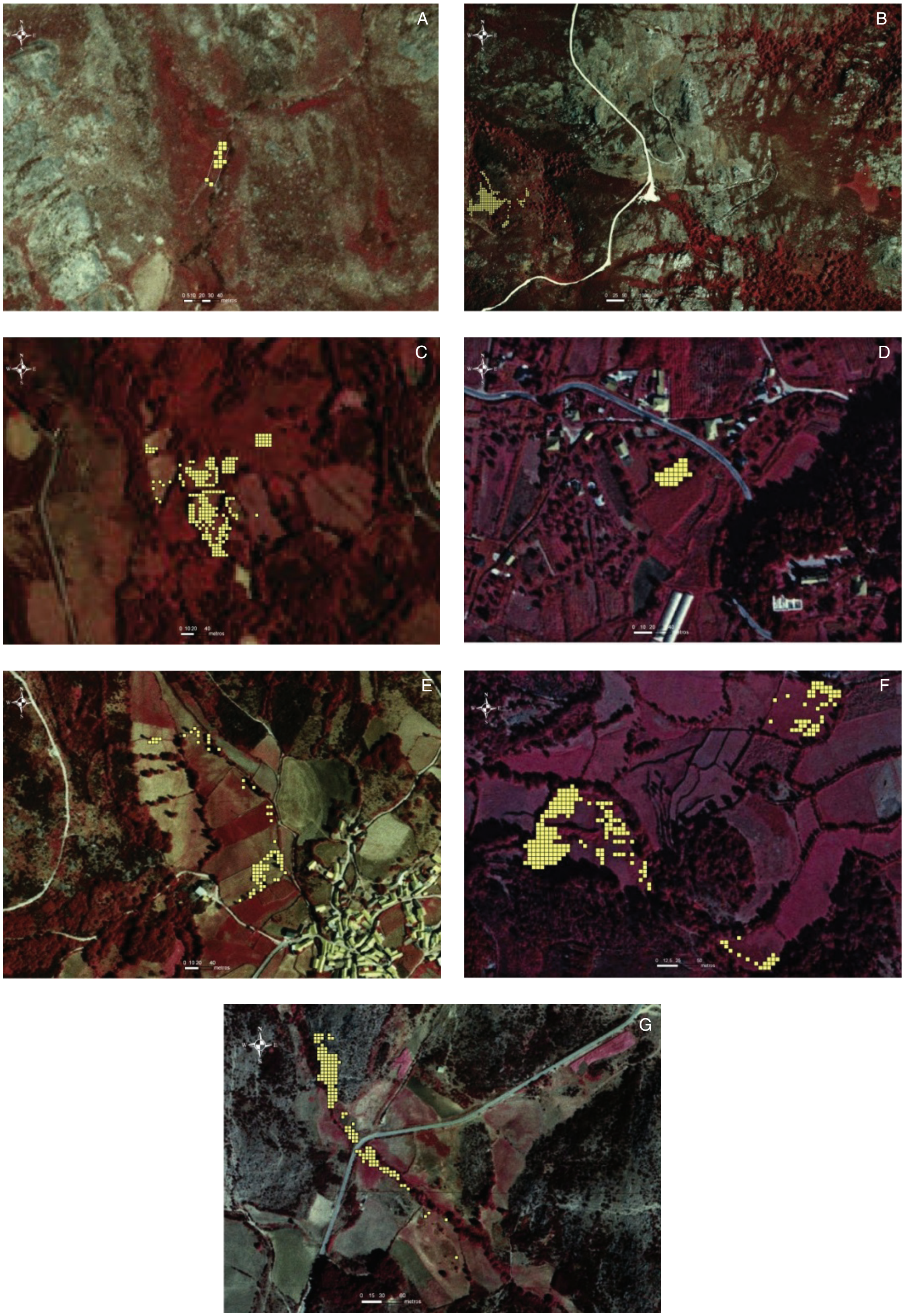

Appendix 1. Aerial imagery (http://scrif.igeo.pt/servicos/localiz/) considered for each *Narcissus pseudonarcissus* populations: Louriça, **A**; Lagoas do Marinho, **B**; Padroso, **C**; Sá, **D**; Sezelhe, **E**; Soutelo, **F**; and Videmonte, **G**. The fig. also shows the 25 m^2 grid cells which represent the location of *N. pseudonarcissus* subsp. *nobilis* individuals

Appendix 2. Results from the post-hoc Mann-Whitney tests regarding differences for the values of species richness and *N. pseudonarcissus* subsp. *nobilis* individuals across surveyed populations. [*n.s.*] stands for non-significant values. All the other values exhibited in the table refer to the statistical significance (*p*) of the pair-wise Mann-Whitney test.

Community species richness - Kruskal-Wallis: H (*n*=35) =22.44, *p*=0.001							
Surveyed sites	**Lagoas do Marinho**	**Louriça**	**Padroso**	**Sá**	**Sezelhe**	**Soutelo**	**Videmonte**
Lagoas do Marinho	-	[*n.s.*]	0.05	0.03	[*n.s.*]	[*n.s.*]	0.02
Louriça	[*n.s.*]	-	0.60	0.03	[*n.s.*]	[*n.s.*]	[*n.s.*]
Padroso	0.05	[*n.s.*]	-	0.02	[*n.s.*]	[*n.s.*]	[*n.s.*]
Sá	0.03	0.03	0.02	-	[*n.s.*]	0.02	0.01
Sezelhe	[*n.s.*]	[*n.s.*]	[*n.s.*]	[*n.s.*]	-	[*n.s.*]	0.03
Soutelo	[*n.s.*]	[*n.s.*]	[*n.s.*]	0.02	[*n.s.*]	-	[*n.s.*]
Videmonte	0.02	[*n.s.*]	[*n.s.*]	0.01	0.03	[*n.s.*]	-
Number of *N. pseudonarcissus* subsp. *nobilis* individuals - Kruskal-Wallis: H (*n*=35) =17.75, *p*=0.0069							
Surveyed sites	**Lagoas do Marinho**	**Louriça**	**Padroso**	**Sá**	**Sezelhe**	**Soutelo**	**Videmonte**
Lagoas do Marinho	-	0.01	[*n.s.*]	0.01	0.03	[*n.s.*]	0.01
Louriça	0.01	-	[*n.s.*]	[*n.s.*]	0.01	0.04	0.01
Padroso	[*n.s.*]	[*n.s.*]	[*n.s.*]	[*n.s.*]	[*n.s.*]	[*n.s.*]	[*n.s.*]
Sá	0.01	[*n.s.*]	[*n.s.*]	-	0.01	[*n.s.*]	0.01
Sezelhe	0.03	0.01	[*n.s.*]	0.01	-	0.01	[*n.s.*]
Soutelo	[*n.s.*]	0.04	[*n.s.*]	[*n.s.*]	0.01	-	0.01
Videmonte	0.01	0.01	[*n.s.*]	0.01	[*n.s.*]	0.01	-

Appendix 3. List of the recorded species at each surveyed site. Nomenclature followed was that of Flora Iberica (Castroviejo et al., 1986-2001*). Sites: LMA, Lagoas do Marinho; LOU, Louriça; PAD, Padroso; SA, Sá; SEZ, Sezelhe; SOU, Soutelo; and VID, Videmonte.

		Surveyed sites/populations						
Species	**Family**	**LMA**	**LOU**	**PAD**	**SA**	**SEZ**	**SOU**	**VID**
Achillea millefolium L.	Compositae			x		x		x
Agrostis capillaris L.	Gramineae			x				
Agrostis curtisii Kerguélen	Gramineae	x						
Agrostis x *fouilladei* P. Fourn.	Gramineae		x	x			x	x
Aira praecox L.	Gramineae		x					
Ajuga pyramidalis L. ssp. *meonantha* (Hoffmanns. et Link) R. Fernandes	Labiatae							x
Ajuga reptans L.	Labiatae					x	x	
Alnus glutinosa (L.) Gaertn.	Betulaceae			x				
Andryala integrifolia L.	Compositae							x
Anemone trifolia L. ssp. *albida* (Mariz) Ulbr.	Ranunculaceae	x						
Anthoxanthum amarum Brot.	Gramineae			x			x	
Anthoxanthum odoratum L.	Gramineae			x		x	x	
Aquilegia vulgaris L. ssp. *dichroa* (Freyn) T. E. Díaz	Ranunculaceae						x	x
Arenaria montana L. ssp. *montana*	Caryophyllaceae	x	x					
Arnica montana L. ssp. *atlantica*	Compositae	x		x				
Arrhenatherum elatius (L.) P. Beauv. ex J. et K. Presl ssp. *baeticum* Romero Zarco	Gramineae			x				
Arrhenatherum elatius (L.) P. Beauv. ex J. et K. Presl ssp. *bulbosum* (Willd.) Schübl. et G. Martens	Gramineae			x			x	
Asphodelus lusitanicus Cout. var. *ovoideus* (Merino) Z.Díaz & Valdés	Liliaceae			x				
Asphodelus macrocarpus Parl. var. *arrondeaui* (J.Lloyd) Z.Díaz & Valdés	Liliaceae		x					
Betula alba L.	Betulaceae			x				
Blechnum spicant (L.) Roth ssp. *spicant* var. *spicant*	Blechnaceae	x	x					x
Briza maxima L.	Gramineae			x				
Briza minor L.	Gramineae				x			
Bromus hordeaceus L.	Gramineae				x			x
Calystegia sepium (L.) R. Br	Convolvulaceae				x			
Calluna vulgaris (L.) Hull	Ericaceae	x						
Caltha palustris L.	Ranunculaceae							x
Campanula lusitanica L.	Campanulaceae							x
Cardamine hirsuta L.	Cruciferae							x
Cardamine pratensis L.	Cruciferae					x		
Carex binervis Sm.	Cyperaceae			x				
Carex demissa Hornem.	Cyperaceae	x						
Carex echinata Murray	Cyperaceae							x
Carex helodes Link in Schrad.	Cyperaceae	x		x				x
Carex ovalis Gooden.	Cyperaceae					x		x
Carex pilulifera L.	Cyperaceae							x
Carum verticillatum (L.) W.D.J.Koch	Umbelliferae	x		x		x	x	x
Centaurea rivularis Brot.	Compositae			x		x	x	
Cerastium fontanum Baumg. ssp. *vulgare* (Hartm.) Greuter et Burdet	Caryophyllaceae				x	x	x	X
Cerastium ramosissimum Boiss.	Caryophyllaceae							X
Ceratocapnos claviculata (L.) Lidén	Papaveraceae		x					
Chamaemelum nobile (L.) All.	Compositae					x	x	
Cirsium filipendulum Lange	Compositae	x		x				
Cirsium palustre (L.) Scop.	Compositae			x		x	x	x
Coleostephus myconis (L.) Rchb. f.	Compositae				x			
Crataegus monogyna Jacq.	Rosaceae							x

Appendix 3. (*Continued*)

Species	Family	Surveyed sites/populations						
		LMA	LOU	PAD	SA	SEZ	SOU	VID
Crepis capillaris (L.) Wallr.	Compositae			x	x	x	x	x
Crepis lampsanoides (Gouan) Tausch	Compositae					x		
Cruciata glabra (L.) Ehrend.	Rubiaceae							x
Cynosurus cristatus L.	Gramineae					x		
Cytisus striatus (Hill) Rothm.	Leguminosae							x
Dactylis glomerata L. ssp. *lusitanica* Stebbins et Zohary	Gramineae			x		x	x	x
Dactylorhiza caramulensis (Vermeulen) Tyteca	Orchidaceae	x		x		x		x
Dactylorhiza maculata (L.) Soó ssp. *ericetorum* (E. F. Linton) P. F. Hunt et Summerh.	Orchidaceae	x						
Danthonia decumbens (L.) DC. in Lam. et DC.	Gramineae	x					x	
Deschampsia flexuosa (L.) Trin.	Gramineae		x					
Deschampsia gallaecica (Cervi & Romo) G.	Gramineae			x				
Digitalis purpurea L.	Scrophulariaceae		x				x	x
Dryopteris filix-mas (L.) Schott	Dryopteridaceae		x					
Echium lusitanicum L.	Boraginaceae			x		x		x
Echium plantagineum L.	Boraginaceae				x			
Epilobium obscurum Schreb.	Onagraceae					x		x
Erica arborea L.	Ericaceae	x	x					x
Erica australis L.	Ericaceae	x						
Erica cinerea L.	Ericaceae	x	x					
Erica tetralix L.	Ericaceae	x						
Erica umbellata Loefl. ex L.	Ericaceae	x						
Eriophorum angustifolium Honck.	Cyperaceae	x						
Euphorbia dulcis L.	Euphorbiaceae			x		x		
Festuca nigrescens Lam. ssp. *microphylla* (St-Yves) Markgr.-Dann.	Gramineae					x		
Festuca rothmaleri (Litard.) Markgr.-Dann.	Gramineae			x				x
Frangula alnus Mill.	Rhamnaceae	x		x				
Fumaria bastardii Boreau	Papaveraceae				x			
Galactites tomentosa Moench	Compositae				x			
Galium helodes Hoffmanns. et Link	Rubiaceae			x				x
Galium palustre L.	Rubiaceae			x				
Galium pumilum Murray ssp. *rivulare* (Boiss. Et Reut.) O. Bolòs et Vigo	Rubiaceae							x
Galium harcynicum Weigel	Rubiaceae		x					
Genista anglica L.	Leguminosae							x
Genista florida L.	Leguminosae		x					
Genista micrantha Ortega	Leguminosae	x						
Geranium columbinum L.	Geraniaceae			x			x	
Geranium dissectum L.	Geraniaceae				x			
Geranium purpureum L. ssp. *purpureum* (Vill.) Nyman	Geraniaceae			x				
Gladiolus illyricus W. D. J. Koch	Iridaceae			x				
Halimium lasianthum (Lam.) Spach ssp. *alyssoides* (Lam.) Greuter	Cistaceae	x	x					
Hedera hibernica (G. Kirchn.) Bean	Araliaceae.			X				
Heracleum sphondylium L.	Umbelliferae					x		
Holcus lanatus L.	Gramineae		x	x	x	x	x	x
Holcus mollis L.	Gramineae					x		x
Hyacinthoides hispanica (Mill.) Rothm.	Hyacinthaceae					x		
Hyacinthoides paivae S. Ortiz & Rodr. Oubiña	Liliaceae		x					
Hyacinthoides sp.	Liliaceae	x						x

Appendix 3. (*Continued*)

		Surveyed sites/populations						
Species	**Family**	**LMA**	**LOU**	**PAD**	**SA**	**SEZ**	**SOU**	**VID**
Hypericum humifusum L.	Clusiaceae							x
Hypericum undulatum Schousb. Ex Willd.	Clusiaceae				x			x
Hypochoeris radicata L.	Compositae			x		x	x	x
Ilex aquifolium L.	Aquifoliaceae	x	x					
Iris pseudacorus L.	Iridaceae						x	
Jasione montana L.	Campanulaceae							x
Juncus acutiflorus Hoffm.	Juncaceae			x		x		x
Juncus bufonius L.	Juncaceae							x
Juncus effusus L.	Juncaceae					x		x
Leontodon taraxacoides ssp. *Taraxacoides* (Vill.) Mérat	Compositae	x						x
Linum usitatissimum L. *angustifolium* (Huds.) Thell.	Linaceae			x				
Linum sp.	Linaceae							x
Lithodora prostrata ssp. *prostrata* (Loisel.) D.C. Thomas	Boraginaceae	x						
Lolium multiflorum Lam.	Gramineae				x			
Lonicera periclymenum ssp. *Periclymenum* L.	Caprifoliaceae		x	x				
Lotus pedunculatus Cav.	Leguminosae			x		x	x	x
Luzula campestris (L.) DC. In Lam. Et DC.	Juncaceae							x
Luzula multiflora (Retz.) Lej.	Juncaceae			x				x
Malva tournefortiana L.	Malvaceae						x	
Mentha suaveolens Ehrh.	Labiatae				x	x	x	x
Montia fontana ssp. *amporitana* Sennen	Portulacaceae							x
Myosotis balbisiana Jord.	Boraginaceae							x
Myosotis discolor Pers.	Boraginaceae					x		
Myosotis secunda A. Murray	Boraginaceae			x				x
Myosotis stolonifera (DC.) Leresche et Levier ssp. *stolonifera*	Boraginaceae					x		x
Narcissus bulbocodium L. ssp. *bulbocodium*	Amaryllidaceae	x						
Narcissus pseudonarcissus L. ssp. *nobilis* (Haw.) A. Fern.	Amaryllidaceae	x	x	x	x	x	x	x
Nardus stricta L.	Gramineae							x
Oenanthe crocata L.	Umbelliferae			x				
Ornithopus compressus L.	Leguminosae					x		
Ornithopus perpusillus L.	Leguminosae					x		x
Paradisea lusitanica (P. Cout.) Samp.	Liliaceae							x
Parentucellia viscosa (L.) Caruel	Scrophulariaceae						x	
Peucedanum lancifolium Lange	Umbelliferae				x	x		x
Phytolacca americana L.	Phytolaccaceae				x			
Plantago lanceolata L.	Plantaginaceae			x		x	x	x
Poa trivialis L.	Gramineae				x	x		x
Polygala serpyllifolia Hose	Polygalaceae	x						x
Potentilla erecta (L.) Raeusch.	Rosaceae	x		x			x	x
Prunella vulgaris L.	Labiatae			x			x	x
Pseudarrhenatherum longifolium (Thore) Rouy	Gramineae	x		x				
Pteridium aquilinum (L.) Kuhn	Dennstaedtiaceae	x	x	x	x	x	x	x
Pterospartum tridentatum (L.) Willk. ssp. *cantabricum* (Spach) Talavera et P. E. Gibbs	Leguminosae		x					
Pyrus cordata Desv.	Rosaceae						x	
Quercus robur L.	Fagaceae		x	x			x	
Quercus x *andegavensis* Hy	Fagaceae			x				
Ranunculus bulbosus subps. *Adscendens* (Brot.) P. Silva	Ranunculaceae							x

Appendix 3. (*Continued*)

Species	Family	Surveyed sites/populations						
		LMA	**LOU**	**PAD**	**SA**	**SEZ**	**SOU**	**VID**
Ranunculus bulbosus L.ssp. *aleae* (Willk.) Rouy et Foucaud var. *gallaecicus* (Freyn ex Willk.) G. López	Ranunculaceae	x		x		x	x	
Ranunculus muricatus L.	Ranunculaceae				x			
Ranunculus omiophyllus Ten.	Ranunculaceae							x
Ranunculus repens L.	Ranunculaceae			x		x		
Raphanus raphanistrum L.	Ranunculaceae				x			x
Rhinanthus minor L.	Scrophulariaceae			x		x	x	x
Rubus sp.	Rosaceae	x	x	x		x	x	x
Rumex acetosa L.	Polygonaceae			x		x	x	
Rumex acetosella L. ssp. *angiocarpus* (Murb.) Murb.	Polygonaceae							x
Salix atrocinerea Brot.	Salicaceae	x		x				x
Sambucus nigra L.	Adoxaceae			x				
Saxifraga spathularis Brot.	Saxifragaceae		x					
Scutellaria minor Huds.	Labiatae							x
Sedum anglicum Huds.	Crassulaceae		x					
Sedum hirsutum All.	Crassulaceae		x					
Senecio sylvaticus L.	Compositae							x
Serratula tinctoria L. ssp. *seoanei* (Willk.) M. Laínz	Compositae	x						
Silene acutifolia Link ex Rohrb.	Caryophyllaceae		x					
Silene latifolia Poir.	Caryophyllaceae				x			
Simethis mattiazzi (Vand.) Sacc.	Asphodelaceae		x					x
Sonchus asper (L.) Hill subps. *asper*	Compositae				x			
Sonchus asper (L.) Hill subps. *glaucescens* (Jord.) Ball	Compositae							x
Stellaria alsine Grimm	Caryophyllaceae					x		
Stellaria holostea L.	Caryophyllaceae					x	x	
Teucrium scorodonia L. ssp. *scorodonia*	Labiatae					x		
*Thalictrum speciosiss*imum L. in Loefl.	Ranunculaceae			x			x	
Teesdalia coronopifolia (J.P.Bergeret) Thell.	Brassicaceae							x
Trifolium dubium Sibth.	Leguminosae					x		x
Trifolium pratense L. ssp. pratense	Leguminosae			x		x		x
Trifolium repens L. var. repens	Leguminosae					x	x	
Ulex europaeus L. ssp. *latebracteatus* (Mariz) Rothm.	Leguminosae			x				
Ulex minor Roth	Leguminosae	x	x					
Umbilicus rupestris (Salisb.) Dandy in Ridd.	Crassulaceae		x	x				
Veronica arvensis L.	Scrophulariaceae							x
Veronica chamaedrys L.	Scrophulariaceae					x		
Veronica micrantha Hoffmanns. et Link	Scrophulariaceae							x
Veronica officinalis L.	Scrophulariaceae	x						x
Vicia angustifolia L.	Violaceae					x		
Viola palustris L. ssp. *palustris*	Violaceae	x		x			x	
Viola riviniana Rchb.	Violaceae			x			x	
Vulpia muralis (*Kunth*) *Nees*	Gramineae							x

Castroviejo, S. et al. 1986-2015.