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Are trellis vineyards avoided? Examining how vineyard types affect the distribution of great bustards

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ABSTRACT

A significant restructuring of vineyards is currently taking place in the European Union (EU) as a result of the implementation of a restructuring and conversion of vineyards regulation (CE 1493/1999) in southwest Europe, so that trellis vineyards are rapidly replacing traditional vineyards (e.g., surface area from 18.1 % in 2010 to 34 % in 2015 in Castilla-La Mancha, Central Spain). These changes may influence patterns of space use in birds, which may avoid modified habitats. We assess how the location of traditional and trellis vineyards might influence the distribution of great bustard (*Otis tarda*), a globally threatened species. We estimate Resource Selection Functions (RSFs) to quantify the relative probability of use of different areas by the great bustards, and use the RSF's to simulated scenarios of conversion from traditional to trellis vineyards (low - 10 %, medium - 30 %, and high rate - 60 %) to quantify the potential impact of such modifications on the availability of suitable great bustard habitat. Our results revealed that great bustards significantly avoid trellis vineyards, especially at closer distances. Transition scenarios show how an increase in the proportion of traditional vineyards converted to trellis vineyards greatly decrease the proportion of suitable habitat for great bustard. Compared to current conditions, the percentage loss of suitable habitat increased steadily with higher rates of converted vineyards, up to 60 % loss of suitable habitat at the highest rate of conversion. Because the effect of transforming traditional vineyards to trellis vineyards depends both on the amount of habitat available for bustards before the transformation occurs and on the overall area covered by vineyards, a correct estimation of transformable vineyard area will require a case-by-case assessment to assure a low impact on bustard populations. We identified alternative vineyard management options that would mitigate impacts on the great bustard populations.

1. Introduction

Agricultural expansion several millennia ago has led to a large-scale modification of landscapes favouring open-land species to spread in new humanized habitats dedicated to food production (Bota et al., 2005). By contrast, agricultural intensification during the last 60 years has led to a change of habitat favourability for several open-land species, leading to a widespread and sharp decline in farmland species populations and diversity (Hails, 2002; Green et al., 2005; Butler et al., 2010; Reino et al., 2010; Santana et al., 2017). In both cases, it seems clear that human action is the main driver of changes in the diversity and abundance of species in open-land arable crops (Donald et al., 2007). Given the increasing large extent of cultivated areas in the world, particularly in Europe, the future viability of many species depends on the sustainable human management of farmland habitats (Donald et al., 2001; Tilman et al., 2002; Bota et al., 2005; Ribeiro et al., 2016). Increased production demands, socio-economic changes, and technological improvements have promoted new agrarian management systems and changes in land use in the last decades, that can influence patterns of space use in birds, which would avoid the use of new or modified habitats, leaving even suitable areas unoccupied or under-used (López-Jamar et al., 2011; Benítez-López et al., 2014).

Despite the well-known impact of agricultural intensification on farmland species, most studies have focused on the effects of

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agricultural practices undertaken in herbaceous crops (cereal, grasslands, leguminous), while the effects of new management systems on other permanent crops such as vineyard remain less known (e.g. Acevedo 2006; Santiago, 2009; Salguero, 2010; Duarte et al., 2014). Extensive traditional vineyards have characterized Mediterranean landscapes for centuries, dominating the landscape in some areas. Traditional vineyards can feature greater species richness and higher densities of birds than intensive vineyards and other surrounding habitats (Verhulst et al., 2004; Acevedo et al., 2006), and are an important habitat for farmland birds, where they can find refuge and food (Acevedo et al., 2006; Palacín et al., 2012). Globally, Spain has the largest vineyards surface area of any country (13 %). Increasingly over the last 15 years, the implementation of trellis vineyards has been encouraged, as a result of the implementation of a EU regulation (CE-1493/1999) funding a large-scale restructuring program of vineyard exploitations, designed to increase the competitiveness of wine farmers, to adapt production to market demands and reduce harvesting costs (Ruiz-Pulpón, 2013; MAPAMA, 2017).

At the landscape level, the consequences of these regulations have been remarkable as trellis vineyards have already replaced most typical traditional vineyards in most of relevant and advanced wine-producing areas of the world, including Spain (Ruiz-Pulpón, 2013; Montero-García et al., 2017). This agricultural reform has arrived slightly later to the Southern Plateau of Spain (Castilla-La Mancha region, Central Spain), the largest wine-growing region in the world (Ruiz de la Hermosa, 2013), but is quickly spreading as trellis vineyards have increased from 18.1 % of regional vineyard surface area in 2010 to 34 % in 2015 (Ruiz-Pulpón, 2013; Cooperativas Agro-alimentarias CLM, 2016).

Traditional and trellis vineyards differ in morphology and management, the latter having taller and thinner vines, metallic guide wires and poles, larger distances between lines of vines, irrigation pipelines, and larger field sizes (Salguero, 2010; SM-Fig. 1). All these changes ostensibly reduce production costs (Ruiz-Pulpón, 2013; Ruiz de la Hermosa, 2013). However, the greater vine height and the presence of parallel wires can act as physical barriers, reducing visibility, impairing take-off of large-size species and increasing the risk of collision and injury (Palacín et al., 2012, 2017). Moreover, a generalized shift of traditional to trellis vineyards would not only reduce habitat available at field level, but also at landscape level, which may have a deeper impact on habitat availability (Concepción and Díaz, 2011; Berg et al., 2015).

The great bustard (*Otis tarda*) is a flagship species of agrarian ecosystems (Morales and Traba, 2016), globally threatened (classified as “Vulnerable”; BirdLife International, 2015). Spain is their main stronghold, with ca. 60 % of the world population (Palacín and Alonso, 2008; Alonso and Palacín, 2010). Great bustard habitat selection varies through seasons and among regions, selecting generally short- and long-term fallows, leguminous crops and cereal fields, and avoiding ploughed fields, forest and human infrastructures such as buildings, roads and tracks (Lane et al., 2001; López-Jamar et al., 2011; Torres et al., 2011). In winter, migratory great bustard females select traditional vineyards for feeding and resting (Palacín et al., 2012). In addition, during summer, great bustards use traditional vineyards during the central hours of the day, seeking refuge and shadow during the hottest hours (Alonso et al., 2016). In contrast, trellis vineyards have been argued to be unfavourable for this species, due to limited visibility and potential for collisions with wires, and there is concern that the rapid increase of trellis vineyard surface will significantly reduce the availability of favourable areas (Acevedo et al., 2006; Santiago, 2009; Palacín et al., 2012). Other researchers have suggested that in a given Special Protection Area (SPAs; Natura 2000 EU network of protected areas) of Castilla-La Mancha with high vineyard coverage, as much as 50 % of the protected area could be affected by vineyard reform (82 % of vineyard fields), without negatively affecting great bustard populations (Montero-García et al., 2017). These authors, however, assume that large continuous areas of traditional vineyard are not usable by bustards, though other studies indicate that traditional vineyards are, in fact, positively selected outside of the breeding season (Palacín et al., 2012).

Thus, there is an urgent need to improve the assessment of potential effects of this new agrarian management system and land use, to regulate adequately their development as sustainable as possible, without jeopardizing populations of species of conservation concern. For this purpose, a well-informed modelling exercise taking into account space-use by great bustards with respect to traditional and trellis vineyards is needed. Resource selection functions (RSF’s) are a widespread and versatile approach to model the relative probability of animal presence with respect to habitat covariates, and particularly adequate for resolving ecological conflicts between wildlife conservation and human activities (Manly et al., 2002; Johnson et al., 2006).

Our main goal was to evaluate what impacts the transition between traditional and trellis vineyards may have on the great bustard. First, we assess whether the location of both types of vineyards could have an effect in the distribution of great bustard flocks. Second, we explored the potential effects of future increases of trellis vineyard surface area using predictive models based on those empirical data. For this purpose, (i) we estimated RSF’s to quantify the relative probability use of different areas by the great bustards, and then (ii) simulated scenarios of conversion from traditional vineyards into trellis vineyards, at low (10 %), medium (30 %) and high rates (60 %) to quantify the potential impact of such modifications on the availability of suitable great bustard habitat.

2. Material and methods

2.1. Study area

We carried out this study in two separate study areas in Central Spain (Fig. 1): Campo de Calatrava (Ciudad Real province, 38° 54′N, 3° 55′W, 610 m a.s.l.; 5500 ha) within the SPA “Área esteparia del Campo de Calatrava” (hereafter CC), and La Mancha (Toledo province, 39° 44′N, 3° 19′W, 710 m a.s.l.; 6800 ha) within the SPA “Área esteparia de La Mancha Norte” (hereafter MN). The study areas are located within the Meso-Mediterranean climatic region of the Iberian Peninsula, and are slightly undulating agricultural pseudo-steppes dominated by a mosaic of crops, primarily dry-cereals with interspersed patches of leguminous crops (*Vicia* spp., *Pisum sativum*), olive groves (*Olea europaea*), vineyards (*Vitis vinifera*), fallows, pastureland and ploughed fields. The relative area covered by vineyards was much higher in MN than in CC (Table 1). MN has been identified as one of the most important wintering areas of great bustards in the world, holding up to. 1500 individuals simultaneously in flocks as large as 200 birds (Palacín et al., 2012). CC great bustard population is one of the most important in the southern range of the species distribution in Spain, with up to 350 birds during winter (Alonso et al., 2005; Arredondo-Acero and López-Jamar, 2016).

2.2. Data collection

2.2.1. Bird surveys

We conducted bustard surveys monthly from January 2004 to December 2005 in CC (except in May and June 2004 and May 2005, due to vegetation height and weather conditions), and from April to November 2006 in MN. Although these data were not collected recently, fieldwork was conducted in both study areas in close dates, which allow us to compare bustard’s responses to differences in the proportion of trellis and traditional vineyard. Great bustard flocks were located along transects covering the whole study area, stopping on observation points separated between 500–750 m, depending on visibility of the surrounding area (Alonso et al., 2005). Transects were driven at low speed (30 km/h) using local track networks to cover the entire study area, during early morning (from dawn to ca. 3 h later) and

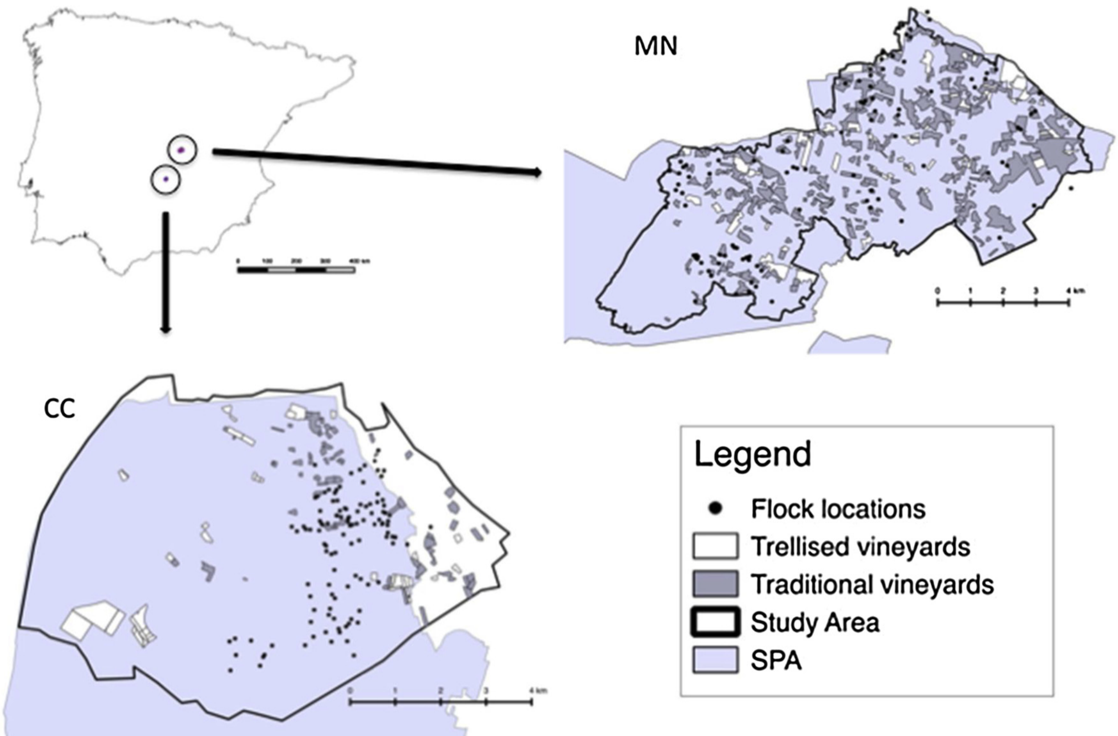

Fig. 1. Location of the study areas in Central Spain. The inset maps show the limits of our study area (black line) and the limits of the European Special Protection Areas (SPAs) [light grey]. Trellised (white) and traditional (dark grey) vineyard fields are located, and also the location of great bustard flocks (white dots).

late afternoons (3 last h before dusk), corresponding to the time of day when birds are most active and detectable. We considered bustard flocks (individuals showing similar behaviour and flock cohesion) as sample units (range: 1–80 individuals), since birds in flocks cannot be considered independent observations. Great bustard flocks visually detected from each point were plotted on a map. Double counting among consecutive points was avoided by cross-checking maps and considering those birds observed in the same place at different times as the same individuals.

2.2.2. Vineyard availability

Traditional and trellis vineyards coverage was recorded using digital aerial images and land-use maps elaborated from field surveys and subsequently mapped using QGIS (version 2.10, 2015). In CC habitat-availability maps were recorded every month that bird surveys were performed across the study period, however, since the availability of both types of vineyards did not change through the study period, we used the habitat-availability map of December 2005 to establish locations and to calculate the area covered by each type of vineyard. Similarly, in MN we only recorded the availability of both types of vineyards once, because their availability did not change through the study period.

2.2.3. Distance analysis

Distance of flocks to vineyards could be affected not just by the preference of the birds, but also by the density of vineyards and other landscape traits. Therefore, in order to avoid this potential source of error, it is more reasonable to compare the vineyard-flock distance in the two study areas relative to some null features within each study area. For this purpose, we drew 500 random points in each study area to compare with the location of flocks. The limits of the study areas enclose all flock locations through the study period and vineyard fields. Distance of each flock and random point to the nearest traditional and trellis vineyard were calculated. We also calculated the number of bustard flocks and random points located within a 500 m buffer of traditional and trellis vineyards, and used chi-squared tests to assess whether bustard flocks were more or less likely to be located within that buffer from traditional and trellis vineyards. We selected a radius of 500 m because this encompasses the bulk of bustard activity (Alonso et al., 2016), but to test the robustness of the test we also performed the analysis at buffers of 300 and 1000 m.

2.3. Resource selection functions (RSF)

Along with providing a versatile framework for assessing the preference of certain habitat types, RSF's can be used to anticipate relative distributions of animals over scenarios that simulate landscape

Table 1
Description of the availability of both types of vineyards (traditional and trellis vineyards), median distance and Inter Quartile Range (IQR) of great bustard flocks to traditional and trellis vineyards in Campo de Calatrava (CC) and La Mancha Norte (MN) study areas.

Location	Type of Vineyard	Number of vineyard fields	Area (km^2)	% Vineyard	Distance Median (m)	(IQR)
CC	Traditional	62	1.075	2 %	486	(240-1219)
	Trellis	42	1.527	3 %	1305	(1010-1516)
MN	Traditional	227	12.544	18 %	96	(42-238)
	Trellis	61	3.259	5 %	639	(362-989)

transformations or management strategies (Carroll et al., 2003; Carroll and Miquelle, 2006), much like closely related species distribution models (SDM's) (Guisan and Thuiller, 2005; Guillera-Arroita et al., 2015). Thus, RSF maps provide useful tools for managers to quantify the impacts of expected changes in land-use, helping to solve potential conflicts generated by economic and environmental trade-offs. Here we estimated RSFs to quantify the relative probability of using different parts of the study areas by the great bustards, considering proximity to traditional and trellis vineyards as response variables in both study areas. First, we evaluated the effect of both type of vineyards on the location of great bustard flocks. We modelled flock locations against the set of 500 random points draw into the area surveyed in each study area, using distance to nearest trellis vineyard (D_l), distance to nearest traditional vineyard (D_d), and percentage of traditional (S_l) and trellis (S_d) vineyard surface within a 500 m buffer surrounding each point. We compared models with linear and square root distance covariates as main effects. The square root is a transformation that models a greater response at shorter distances, matching our biological intuition (great bustards would avoid just the areas nearest to trellis vineyards, not so much for the case of traditional vineyards). We fitted the presence vs. random points models via logistic regression and selected the best models using ΔAICc as a criterion for model selection (Burnham and Anderson, 2002), and report the subset of models with ΔAICc < 2 as the "best" models.

2.3.1. Vineyard transition scenario analysis

We selected the best models from the respective RSFs for CC and MN to generate predicted resource selection surfaces across the landscape encompassed by the entire study areas. The surfaces were predicted on a 20 m x 20 m resolution raster. Distances to the nearest vineyards (traditional and trellis) were computed from the midpoints of each pixel, and predicted RSFs were computed at those locations. We did not use percentage of traditional and trellis vineyard surface within 500 m buffer, because those factors were not selected in the final models. Because the RSFs was generated using a 500 random locations as a null set for 112 and 98 flocks observed in CC and MN, respectively, we used as threshold of "suitability" a resource selection score corresponding to the proportion of observations to random points: 0.18 and 0.16 respectively. Under a null model of equal probability of occupancy across the study areas, these probabilities would represent the uniform probability of occupancy everywhere. Thus, locations with higher probability are "above average", and locations with lower probability are "below average". Thus, these thresholds are not entirely arbitrary. We chose three scenarios to simulate three rates of conversion from traditional vineyards into trellis vineyards: low (10 %), medium (30 %) and high (60 %). We generated these by randomly selecting 10 %, 30 % and 60 % of the traditional vineyards and reassigning them as trellis vineyards. These scenarios range from a high restriction to the reform within protected areas (10 %) to a situation of completely liberalized reform, since a recent survey performed in CC study area showed that approximately 60 % of farmers with vineyard fields are willing to transform them to trellis vineyard (authors, unpublished results). Therefore, this would show us the potential effect of the possible increase of the area covered by trellis vineyard at the expense of traditional vineyard in the near future. We recomputed the predicted resource selection surfaces over the transformed landscape at those three levels of conversion, and calculated the remaining percentage of suitable habitats according to the thresholds explained above. We repeated this experiment 1000 times, randomizing over the converted vineyards, and report the median and 95 % range of the loss of suitable habitat.

All statistical analyses were performed in R 3.2.2 (R Core Team, 2015) through the interface of RStudio (RStudio Team, 2015), using the rgdal (Bivand et al., 2017), rgeos (Bivand and Rundel, 2017) and raster (Hijmans, 2016) packages for spatial data processing and manipulation.

3. Results

3.1. Effect of vineyard type on great bustard distribution

We located 112 (1273 individuals) and 98 (669 individuals) flocks in CC and MN, respectively (SM-Tables 1 and 2). In both populations the number of birds located peaked during autumn-winter (SM-Tables 1 and 2). In CC, bustard flocks were significantly more likely to be closer to traditional vineyard than random points (300 m: $\chi^2 = 7.8$; df = 1, $p < 0.01$; 500 m: $\chi^2 = 10.1$; df = 1, $p < 0.01$; 1000 m: $\chi^2 = 15.8$; df = 1, $p < 0.001$), whereas flocks were significantly more likely to be at longer distances of trellis vineyards (300 m: $\chi^2 = 20.9$; df = 1, $p < 0.001$; 500 m: $\chi^2 = 29.3$; df = 1, $p < 0.01$; 1000 m: $\chi^2 = 70.6$; df = 1, $p < 0.001$). In contrast, in MN, where there was a much higher density of vineyards (Table 1), there were only 11, 3 and 0 flocks further away than 300 m, 500 m and 1000 m, respectively, from a traditional vineyard, being more or less likely to be significantly closer from random points regarding the distance (300 m: $\chi^2 = 2.6$; df = 1, $p = 0.11$; 500 m: $\chi^2 = 4.4$; df = 1, $p < 0.05$; 1000 m: $\chi^2 = 3.7$; df = 1, $p = 0.05$), whereas flocks were significantly more likely to be further of 300 m and 500 m from trellis vineyards (300 m: $\chi^2 = 7.2$; df = 1, $p < 0.01$; 500 m: $\chi^2 = 6.1$; df = 1, $p = 0.01$) than random points, but differences were not significant at 1000 m buffers ($\chi^2 = 0.3$; df = 1, $p = 0.61$).

3.2. Resource selection functions

There were four and nine RSF models with ΔAICc < 2 for CC and MN respectively (Table 2). All of best models included a positive square root nearest neighbour distance to trellis vineyard term. In CC, all of the best models also included a negative linear and positive square root distance to traditional vineyards, while all top models in MN included the linear distance to trellis term and four of the top five included a negative linear distance to traditional vineyard term. Few of the top models included any of the percentage coverage terms (Table 2). When both linear and square root terms were included, the linear coefficient estimates were negative, while the square root estimates were positive, indicating a strong short scaled avoidance tempered at longer distances (Tables 2 and 3).

3.3. Vineyard transition scenario analysis

For our three-scenarios analysis, we used a final RSF reflecting a "consensus" of the model selection results, which include distance only terms: linear and square root to traditional and square root to trellis for CC (Model 1), linear and square root to trellis and linear to traditional for MN (Model 3). Using a resource selection score corresponding to the proportion of observations to random points (0.18 for CC and 0.16 for MN) as the threshold of "suitability", we found that approximately 30.0 % (CC) and 49.5 % (MN) of the raster cells were deemed "suitable" (SM-Fig. 2). Predicted resource selection maps showed that the size of areas actually usable by the great bustard would largely decrease if traditional vineyards continued switching to trellis vineyards in the future (Figs. 2 and 3). The percentage loss of suitable habitat increased steadily with higher rates of reformed traditional vineyard fields in both study areas regarding the current scenario, with up to 65 % and 58 % loss of suitable habitat in CC and MN, respectively, at the highest rate of conversion (60 %). While in the low rate conversion scenario (10 %), the suitable habitat decreased by 20 % in CC, but just a 4 % in MN. However, if we just take into account the suitable habitat remained, we found as the percentage of traditional vineyards switched to trellis vineyards increased, habitat suitability decreased in both study areas severely (Fig. 4).

Table 2
AIC table for best resource selection functions (RSF) of great bustard presence data in two study areas, Campo de Calatrava (CC) and Mancha Norte (MN), accounting for nearest neighbour distances to traditional and trellis vineyards (nn.trad and nn.trel, respectively) and percentage of traditional and trellis vineyard areas within a 500 m buffer (prc.trad, prc.trel). Included are all models with ΔAICc ≤ 2 and the intercept-only model for reference. K = number of parameters. + : positive coefficient; - : negative coefficient.

Study Area	Model	nn.trad	$(nn.trad)_{sqrt}$	nn.trel	Variables $(nn.trel)_{sqrt}$	prc.trad	prc.trel	k	AIC	ΔAICc	Weights
CC	1	–	+		+			3	448.3	0.00	0.29
	2	–	+		+	–		4	449.5	1.25	0.15
	3	–	+	–	+			4	449.9	1.63	0.13
	4	–	+		+		+	4	450.0	1.75	0.12
	5	–	+		+	–	+	5	451.1	2.79	0.07
	Intercept							0	594.7	146.37	0.00
MN	1			–	+			2	505.0	0.00	0.15
	2	–		–	+	–		4	505.4	0.39	0.12
	3	–		–	+			3	505.9	0.91	0.09
	4	–	+	–	+	–		5	506.2	1.21	0.08
	5	–	+	–	+			4	506.3	1.26	0.08
	6			–	+	–		3	506.3	1.30	0.08
	7		–	–	+			3	506.6	1.61	0.07
	8		–	–	+	–		4	506.7	1.71	0.06
	9			–	+	–	+	4	507.0	1.99	0.05
	Intercept							0	535.5	30.48	0.00

Table 3
Values of the regression coefficients for the RSFs selected in each study area (Campo de Calatrava [CC] and La Mancha Norte [MN]).

Variables	CC Estimate	CC SE	CC P	MN Estimate	MN SE	MN P
Intercept	−2.21	0.18	< 0.001	−1.89	0.15	< 0.001
nn.trad	−3.58	0.73	< 0.001			
$(nn.trad)_{sqrt}$	2.18	0.65	< 0.001			
nn.trel				−4.01	0.89	< 0.001
$(nn.trel)_{sqrt}$	1.77	0.21	< 0.001	3.58	0.78	< 0.001

nn.trad = nearest distance to traditional vineyards; $(nn.trad)_{sqrt}$ = nearest distance to traditional vineyards (root square transformed); nn.trell = nearest distance to trellised vineyards; $(nn.trell)_{sqrt}$ = nearest distance to trellised vineyards (root square transformed).

4. Discussion

Our results revealed that great bustards clearly and consistently avoid trellis vineyards. First, no observations of bustards inside parcels of trellis vineyard were made, while they were sometimes detected using traditional vineyards or their edges, particularly in areas with higher vineyard coverage (Fig. 1). Second, great bustards avoided areas at short distances from trellis vineyards as compared to traditional vineyards, which were even positively selected (Santiago, 2009; Palacín et al., 2012). Additionally, the transition scenarios show that a potential increase in the vineyard conversions would greatly decrease the proportion of suitable habitat for great bustard, with potentially significant impacts in vital areas for this endangered species, including SPAs. This on-going shift toward more mechanized and intensive vine cultivation is likely to increase, since farmers with traditional vineyards are eager to convert to higher-yield trellis vineyards (authors, unpublished results). Increasing the area covered by human infrastructures and intensively managed crops may significantly reduce populations or even cause local extinctions due to an increase of human perturbation and loss of suitable areas (Sastre et al., 2009; López-Jamar et al., 2011; Torres et al., 2011).

The differences between the two study areas provide further insights into great bustard habitat preferences. In MN, where vineyards take up nearly a quarter of the land area and trellis vineyard fields are interspersed fairly uniformly in the territory (Fig. 1), the main response of great bustard flocks was avoidance of trellis vineyards at closer distances with a statistically neutral response to the traditional vineyard. This spatial arrangement in not unlike what might have been implemented in a designed experiment, i.e. there was weak correlation in the distances between the two types of vineyard. In contrast, in CC, only 5 % of the land is used for vineyards, and the majority of the trellis vineyards are in several larger fields to the southwest. Here, there was a still significant avoidance of trellis vineyards, but also a preference for proximity to traditional vineyards – these effects are possibly confounded by the greater spatial segregation of the two types of vineyard. While our scenario simulations indicate a similar absolute decline in percentage of available habitat with an intensive increase in trellis vineyards, the relative impact on CC is greater. This could be a reflection of the fact that in MN the overall tolerance of the birds to vineyards is necessarily higher due to their higher density. Thus, our results indicate that the effect of transforming traditional vineyards to trellis vineyards on habitat suitability of great bustards in a given area will depend both on the amount of habitat available for bustards before the transformation occurs and on the overall area covered by vineyards. This implies that a correct estimation of the amount of vineyard area that can be converted to assure a low impact on great bustards will require a case-by-case assessment.

Given that great bustards are known to prefer grasslands, fallow fields and low-lying crops, like legumes and cereals (Lane et al., 2001; López-Jamar et al., 2011; Torres et al., 2011), trellis vineyards provide particularly unsuitable habitat due mainly to their higher density of taller structure (1–2 m vs. < 1 m for traditional vineyards), and the presence of parallel wire fences, that prevent any movements, makes getting off the ground more difficult (great bustards need much open space to gain height), or even may lead to injury by collision with the wires (Palacín et al., 2017; SM-Fig. 1). Even at some distance from trellis vineyards, they can still reduce long-range visibility- as compared with traditional ones – important for an open-land species that relies on visual signals to communicate between conspecific (Olea et al., 2010), or to increase predator detection (Endler, 1992), which would explain why great bustard flocks have been more frequently detected at longer distances from trellis than from traditional vineyard. In contrast, traditional vineyards have an open and low enough height allowing great bustards use, in particular to seek shade during the middle hours of the day in the summer or to forage in the fall (Santiago, 2009; Palacín et al., 2012; Alonso et al., 2016).

On the other hand, great bustards have a strong conspecific attraction and site fidelity, tending to concentrate in occupied areas with good habitats conditions rather than unoccupied areas, even if the latter have better habitat favourability (Lane et al., 2001; Osborne et al., 2001; Alonso et al., 2004). This social behavior can increase the

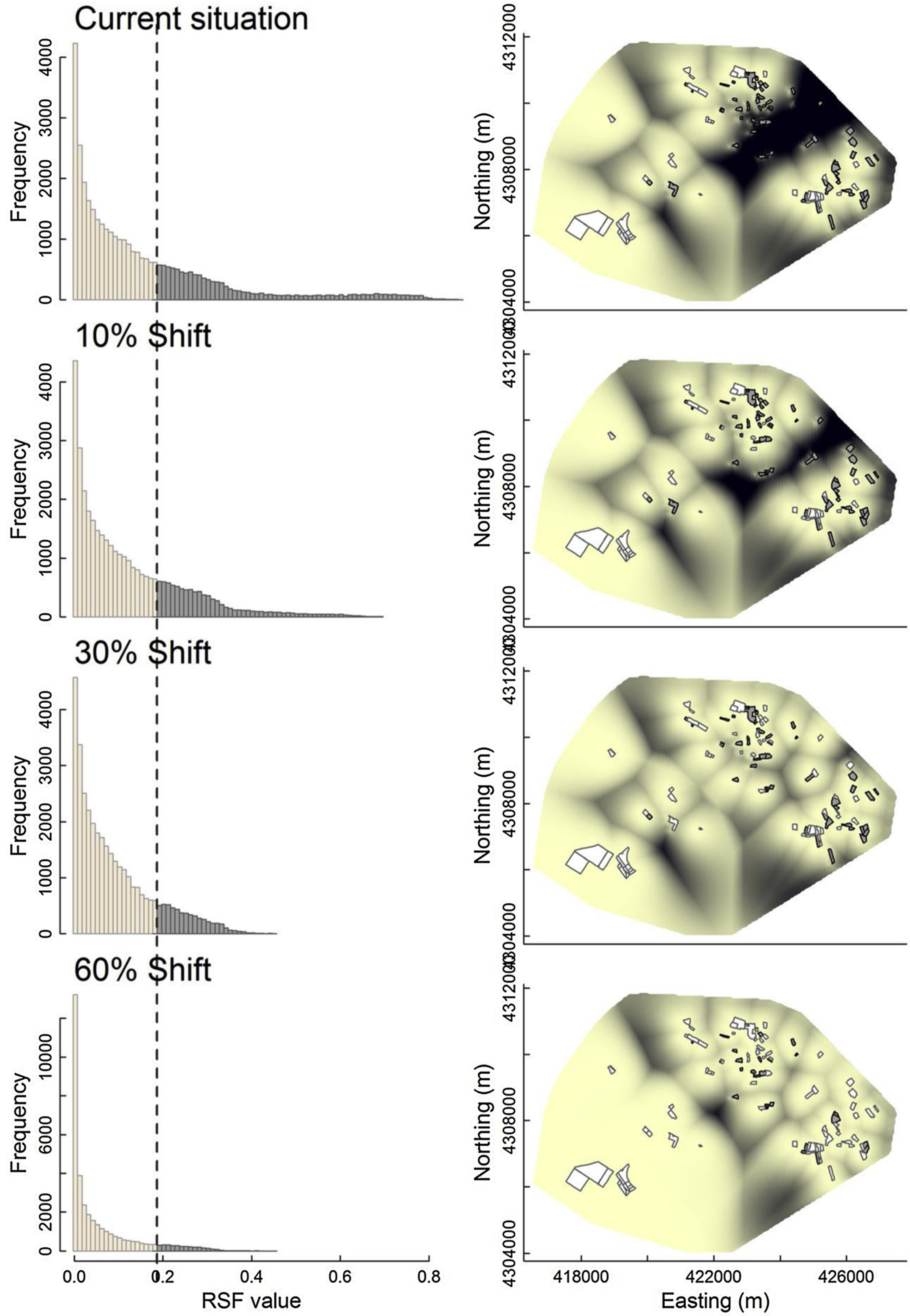

Fig. 2. Histograms (left panels) and map (right panels) of predicted resource selection function in the CC study area under the current situation (top row) and three scenarios in which there is a low (10 %) medium (30 %) and high (60 %) rate of transitions from traditional (grey) to trellis (white) vineyards (lower panels). In the maps, darker colours represent higher RSF values (interpreted as probability of use). In the histograms, the vertical dashed line represents the suitability threshold (see Methods).

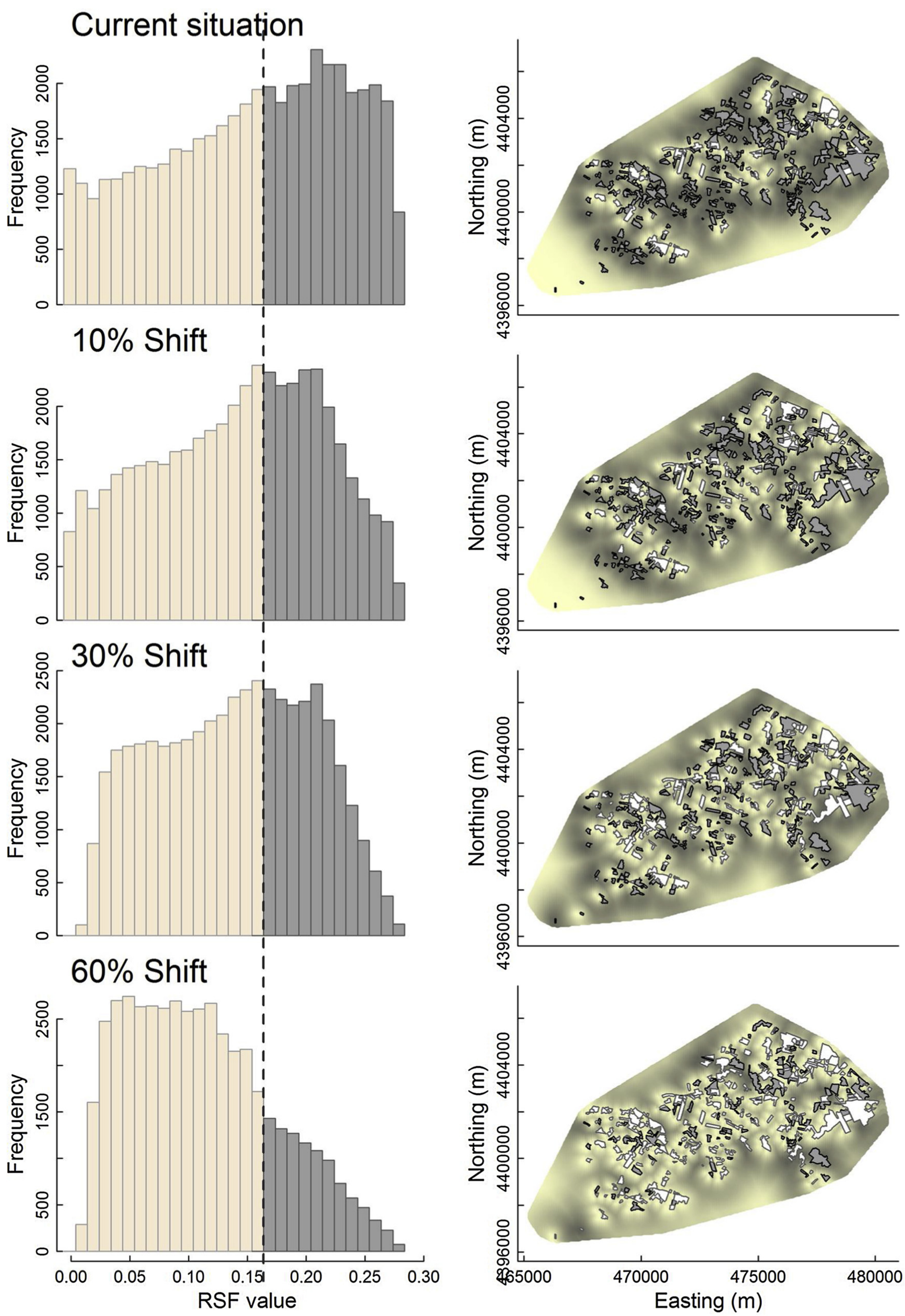

Fig. 3. Resource selection histograms and maps for MN study area. Explanation as in Fig. 2.

sensitivity of the species to the kind of loss of suitable habitat that our future scenarios indicate is possible. Reduced habitat can lead to population declines or even local extintions (Palacín et al., 2003; Torres et al., 2011), or, in the best of cases, would potentially contribute to greater aggregation of bustard populations in a reduced number of locations, which would, in turn, increase the vulnerability of this species against stochastic processes (Alonso et al., 2004). In fact, this agregation of great bustards in remaining suitable patches of land within a

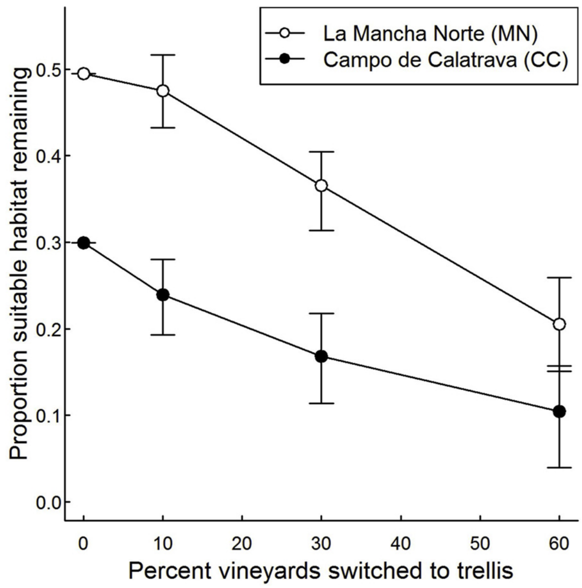

Fig. 4. Proportion of suitable habitat remaining (median and 95 % range of the loss of suitable habitat) for great bustard in the current situation, and under potential transition rates from traditional into trellis vineyards: low rate (10 %), medium rate (30 %) and high rate (60 %). These were computed from scenarios where 10 %, 30 % and 60 % of the traditional vineyards were randomly re-assigning as trellis vineyards (see Figs. 2 and 3), replicating the process 1000 times for each scenario.

larger area affected by human impacts seems to be already occurring in one of our study areas (CC, Casas et al., 2019). Therefore, we conclude that the maintenance of traditional vineyards and land-use planning decisions about conversion to trellis vineyards should take into account the potential impacts on great bustard populations, especially on SPAs of importance to the species.

When considering great bustard behaviour, the area affected by vineyard reform without seriously affecting great bustards' habitat suitability would be much lower than what has been recently claimed based on GIS-based models (Montero-García et al., 2017). These authors concluded that the 82.1 % of the vineyards in La Mancha Norte SPA (Toledo, Spain) were suitable for transition to trellis vineyards. However, they assumed that in areas with high vineyard cover (more than 20 % of the agrarian land occupied) the presence of great bustard is highly unlikely. This assumption is clearly incorrect following both previous studies (Palacín et al., 2012) and our own results. Therefore, it seems of critical importance to consider the use of biological information about the habitat requirement and behaviour of the species in the area subject to vineyard reform to assess properly the potential effects of vineyards on the great bustards. However, the models produced by Montero-García et al. (2017) contain valuable procedures, such as considering that vineyards near roads or villages can be considered as suitable for reform, given that great bustard avoid the areas near villages and roads (Lane et al., 2001, Lopez-Jamar et al. 2011). A combination of our methodology (predictive maps of affection under different scenarios of intensity of vineyard reform) along with that used by Montero-García et al. (2017) (GIS-based models determining suitable areas where vineyard reform may be allowed) would be the optimal solution to regulate this reform within SPAs. This would allow farmers to continue vineyard conversions while minimizing the loss of habitat suitability for the great bustard. These models could also guide the design of future vineyard management and expansion plans at large scale, that should take into account the habitat suitability for this species, so that new trellis vineyard would be placed in the less suitable areas for great bustards, reducing their impact. This is a plausible situation given that most of the area covered by vineyards in Castilla-La Mancha is out of SPAs, where there are significant great bustard populations (Traba et al., 2007) and that the reform to trellis vineyard implies complete replacement of vines (e.g. vineyards could be moved to other parcels where ecological impact is lower).

5. Conclusions

The application of predictive models of habitat requirements and simulation of plausible scenarios provide a versatile tool to assess the impact of an increase in the proportion of trellis vineyard before it has occurred, but also be adapted to propose the better management options for vineyard farmers that do not jeopardize the future conservation of the species occupying farmland habitats, as well as guiding the implementation of potential compensatory programs such as agri-environmental schemes (Bretagnolle et al., 2011). For example, certain spatial configurations of vineyard conversions, e.g. with more concentrated clustering, can mitigate the effect on available habitat, a hypothesis that can be easily tested with simulation scenarios. It should be noted that the models we applied here are highly simplistic, taking only distances from vineyards into account. While the avoidance effects are strong, the scenario predictions should be interpreted with some caution. More sophisticated models would take into account other habitat variables, in particular land-cover types (e.g. olive grooves, almond and pistachios trees) and human infrastructures (e.g. country houses). Taking additional variables into account in models may also be useful for management decisions if, for example, trellis vineyards are concentrated in areas which are already less optimal for the great bustards.

Practically, there are major challenges to managing vineyard locations and conversions, because existing fields dedicated to vine cultivation may already be in highly suitable areas for great bustards. Consequently, legislative changes would be necessary to facilitate the purchase of vineyard rights (allowing a relocation of vineyard fields) in less sensitive areas for birds. Since January 1st 2016, the sale and purchase of vineyard rights directly between farmers can occur only through administrative concessions reviewed by the European Commission (EU 1308/2013) and regulated by regional administration, a step that could potentially be used to introduce some ecological considerations to vineyard conversion.

Authors' contributions

FC, RS, and JV conceived and designed the study; FC, JV, IH and RS collected the data. FC and EG designed the statistical analysis and analysed the data, and FC led the writing of the manuscript. EM supervised the Andalusia Talent Hub project. All authors contributed critically to the drafts and gave final approval for publication.

Data accessibility

Data will be archived and available in Mendeley Data.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2019.106734.

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