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Can habitat suitability predict the presence of wild boar? Suitable land uses *vs.* georeferenced data in Bulgaria

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Abstract. The aim of this work was to use standardized digital cartography of vegetation coverage to test whether or not the predicted range of habitat suitability for wild boar in Bulgaria coincides with the georeferenced/presence records of this species. The predicted range of habitat suitability based on potential biological resources in Bulgaria encompasses 13 land uses from the CORINE program, being "Broad-leaved forests" (23432 km^2) the most representative. The total potential resources for wild boar correspond to 57.54 % of the country area. A high level of correlation (0.86) was found between inverse distance of wild boars presence and habitat suitability areas. A significant level of correlation (0.71, $p < 0.0001$) per Bulgarian region between area of habitat suitability category 2 (resources suitable for use as both food and shelter) and number of wild boar was also found.

Suitable wild boar habitat on borders appeared as the most relevant parameter for evaluating the risk of introduction of diseases by wild boar into the European Union from neighbouring countries. Despite being the longest (608 km), the Bulgaria-Romania border did not represent the most important corridor for wild boar since only 12.78 % of its surface is suitable habitat; the percentage of the importance of this border edges the passage of wild boar is 20.63 %. The Bulgaria-Macedonia (FYROM) border must be regarded as the most important passageway for wild boar (96.88 %), with 148 km of border and 12.34 % of its surface area of suitable habitat. Our findings could be highly useful for developing adequate strategies for wildlife management practices on large spatial scales, as well as for the control of wildlife and its habitats (territorial integration and spatial planning according to the casuistry of the zone), and relationships between wildlife and other human interests.

Key words: *Sus scrofa*, wildlife passage, spatial distribution, natural shared border, wildlife management

Introduction

Mapping and modelling the habitat distribution of wild animal species is increasingly important for a number of management and decision-making reasons (Aspinall et al. 1998). In the case of a wild boar (WB) population (*Sus scrofa* L.), it is especially important to be able to quantify the spatial distribution of suitable habitat on a large spatial scale to implement strategies that will minimize the economic and ecological impacts of this species on conservation management, animal health and hunting. In recent years a need has arisen in the field of animal health for improved knowledge of WB populations in Bulgaria. The eradication of animal diseases such as classical swine fever shared by domestic pigs and wild boars has prompted exhaustive sampling efforts in WB populations. Additionally, the recent appearance of the threat of African swine fever (ASF) (currently endemic in the Russian Federation), which can potentially cross national boundaries due to movements by wild boars (De la Torre et al. 2013), requires accurate knowledge of the location and density of wild boars in order to design active surveillance and control plans that will avoid the introduction and spread of this disease in Bulgaria. Imperfect surveying and incomplete biological records are inherent to models of wildlife distribution. However, certain tools such as statistical and spatial methods can cover these gaps and be applied to wildlife-environment relationships.

According to Kearney (2006), "habitat" is defined as the physical characteristics of the place where an organism potentially lives and thus a habitat suitability

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(HS) model is a projection of a suitable habitat for that organism. Vegetation cover has a major influence in the distribution of an animal species since it determines a terrain's ability to supply food and/or shelter for animals. Therefore, vegetation cover is a limiting factor for the spread of a species (Herrero et al. 2006). Remote sensing variables such as land use or vegetation coverage have been tested and applied to animal habitat modelling and generally improve the accuracy of the habitat model together with other environmental variables (Bradley & Fleishman 2008, Pettorelli et al. 2011). Depending on the species and target modelling study, some environmental variables are much more important and representative than others. In the case of the WB, the land use or vegetation cover indirectly incorporates and expresses other variables such as climatic, altitude, anthropogenic, etc. and it is valuable to predict spatially their distribution, presence or even their absence in the territory with a high accuracy.

In recent decades, improvements in and the greater availability of geographic information system technology and geospatial information have ensured that work on larger spatial scales is now feasible (Foody 2008). Standardized digital cartography of vegetation coverage such as the CORINE land cover database (EEA 2006) and the Global Land Cover Map-GlobCover (ESA 2009) guarantee cost-effective results (Belongie 2008). On the basis of habitat use by vertebrates such as WB, these databases are now able to offer information on where in a particular area a species is most likely to be found. However, in order to define WB habitat on a large scale, land uses must be selected with biological criteria in mind that are related to the ecological requirements of the species, that is, food and shelter. Bosch et al. (2012) assigned weights using the importance of land use for food and shelter on a map of suitable WB habitat in the Iberian Peninsula.

Aside from the usefulness of vegetation coverage in the study of the distribution of a wildlife species, the use of information derived from hunting bags wherever hunting is a common practice is very practical way of knowing the estimating abundances and densities of WB (Sáez-Royuela & Tellería 1986, 1988, Spitz & Vallet 1991, Lancia et al. 1994, Boitani et al. 1995, Honda & Kawauchi 2011).

The collating of hunting databases and presence data (coordinates) in hunting territories is a common procedure in many countries that use surveillance programs to control diseases in which game animals are implicated. The combination of the coordinates of geolocation and the use of standardized vegetation coverage could help in the analysis of suitable habitat as a mean of determining the distribution of an animal in a certain territory.

A large variety of methods that use ecological niche model and species distribution models are available for modelling distributions (Guisan & Zimmermann 2000, Chen & Peterson 2002, Peterson & Shaw 2003, Benito de Pando & Peñas de Giles 2007, Pereira & Groppo 2012, Chunco et al. 2013). Depending on the goals of the modelling exercise, each method requires different kind of data – presence/absence data (Guisan et al. 2002) or presence-only data (Phillips et al. 2006) – and each has an associated level of precision and margin of error (Lobo et al. 2008, 2010). Nevertheless, these methods also have drawbacks such as the difficulty of extrapolating and comparing results between different methodologies and areas of study (Jiménez-Valverde 2012, Wenger & Olden 2012).

To our knowledge, neither the ecological niche model nor species distribution models have been applied to WB, in part due to the species' extensive, wide-ranging habitat preferences and because the georeference absence records of the species are not available and estimating them accurately is difficult. Thus, the use of standardized land-use mapping on a large spatial scale to develop knowledge of suitable habitat offers not only the possibility of extrapolating to a large study area in which information on the WB is deficient, but also the possibility of comparing regions within the same country or between countries in which standardized information on land cover be defined. HS provides a biological interpretation of the vegetation resources related to existing land use or land cover and so the probability of developing biased models will be reduced and the overall model of interpretation and application will be improved (Bradley et al. 2012).

Furthermore, HS can be applied to identify wildlife-livestock interfaces and define potential hotspots on national or regional levels (http://www.svepm.org.uk/posters/2013/de%20la%20Torre.pdf). Likewise, HS can be employed to detect suitable habitat for WB along borders, a relevant risk parameter in an evaluation of the possibility of disease introduction by WB into neighbouring countries (De la Torre et al. 2013).

The main objective of this work was to evaluate the statistical association between suitable habitat for WB and presence records of the species in Bulgaria. This involves investigating whether the predicted HS of the considered species (WB) coincides with the

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occurrences of WB presence records for this area, a question that has to date been rarely examined. To answer this question, we focused on Bulgaria since estimating number of WB (counted data by hunters based on tracks) from several spring seasons and plentiful georeferenced presence records for WB are available from this country.

First, we elaborated a HS map of WB in Bulgaria and a unified habitat map, taking into account the home range of WB. Second, we analyzed the sites in which presence determined by georeferenced data coincided with suitable habitat to generate statistics to help evaluate this relationship. Third, we created an application for the HS map that focuses on the importance of borders in the passage of WB between Bulgaria and Greece, Macedonia (FYROM), Romania, Serbia and Turkey. The results presented here may help focus and design surveillance and control plans for significant diseases such as ASF, which could potentially be introduced by WB moving from infected neighbouring countries.

Material and Methods

Study area

Bulgaria has a surface area of 111903 km² and lies between latitudes 40° and 45° N in southeast Europe. It is bordered to the north by Romania, to the south by Greece and Turkey, to the west by Serbia and the Former Yugoslav Republic of Macedonia (FYROM), and to the east by the Black Sea.

Geographically, Bulgaria is characterized by the presence of the Danubian plain in the north and the Central System of the Balkan Mountains in the centre of the country that exceed 2000 meters in altitude. The Rhodope massif in the southwest is characterized by rounded peaks devoid of vegetation that reach more or less the same height as the Balkan Mountains. In the southeast lies Thrace, characterized by croplands and part of the Strandzha Mountains. Approximately 35 % of Bulgaria is covered by forests and woodlands: to the north of the Balkan Mountains the typical vegetation consists of mixed forests of conifers and broad-leaved trees with species such as beech, hornbeam and various coniferous. In the plains of the Danube valley, meadow steppe is found due to the low rainfall. In the south, Mediterranean species of tree such as *Quercus ruber* and *Quercus ilex* appear.

WB presence data (georeferenced records)

WB presence data (GPS coordinates in longitude and latitude) of the places where WB are shot have been provided by local official vets (Animal Health and Welfare Directorate, BFSA). They correspond to data from two studies of surveillance of infectious diseases (FMD and CSF) performed in the Bulgarian countryside and were collected for two years (2011-2012). The georeferenced presence data consists of 5125 records of which 2452 were associated with a single-value sampling (one WB per record). The data are distributed from all 28 Bulgarian regions (217 out of 263 municipalities). There are no differences in hunters' strategies in the different municipalities.

WB population data

Estimated population data for each of the 28 Bulgarian regions (2006-2012) were gathered from the State Forestry Agency dependent on the Ministry of Agriculture and Food of Bulgaria. A continual increase in the estimated WB population was observed over time (2006-2012) and around 20000 animals were hunted in each year of this seven-year period. The most recent data (2012) were selected for this study because they coincide with the date of vegetation cover data and expresses the best wild boar population trend collection for all sampling years in this territory. A total of 79281 WB were detected in Bulgaria in the spring of 2012. These data corresponded to the number of WB counted by hunters in regions where tracks and other evidences of WB presence had been previously reported.

Potential WB habitat based on potential resource value (PRV) in Bulgaria

As previously described, the map of HS reflects the distribution of WB (since it constitutes the basis of their biological requirements). A literature review by Bosch et al. (2012) considered ground cover and wooded areas to be suitable WB habitat since they provide a vital resource, diet and/or shelter. For this purpose, the CORINE program (EEA 2000, 2006), which contains ground cover (land use) information along standardized European Union guidelines to a spatial resolution of 1 ha, was employed. Following Bosch et al. (2012), we assigned weights to layers of land use. A categorical value was assigned to each potential resource according to the methodology of the aforementioned study (which was based on scientific literature, statistical analysis and expert opinion). In Bulgaria, a value of 2 was given to a location if it had resources suitable for use as both food and shelter, a value of 1 if it only had one of these two resources, and 0 if it possessed neither resource (unsuitable for food or shelter) (similar to Bosch et al. 2012). From a biological and natural standpoint, this third category

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could be considered as a WB passage, used neither for food nor shelter, but very close (usually less than 1 km) to land suitable for WB and, compared to other land uses, unaltered by human action. Finally, unfavourable terrains (UT) for WB derived from incompatible land uses for this species – built-up areas and certain types of agricultural areas that are highly anthropized and relatively distant from land suitable for WB – were excluded from the study. Ultimately, 13 land uses were selected for delimiting the HS in Bulgaria from the CORINE program.

Home range and unified habitat (HR and UH)

Literature on WB movements based on radiolocation, radiotelemetry and breeding habits was reviewed by Bosch et al. (2012) in order to select the most "natural" data, unbiased by anthropic factors such as intense pressure from hunters or by seasonal biological necessities such as mating, searches for food or water in times of drought. The distance roamed by WB under normal conditions has been calculated as two linear kilometres in a number of different geographic regions (Maillard & Fournie 1995, Soidekat & Pohlmeyer 2004, Markina-Lamonja & Telletxea 2006, Keuling et al. 2010, Podgórski et al. 2013). Therefore, fragmented patches of suitable land areas in CORINE (EEA 2006) situated at a distance of 2 km or less from each other were merged together into a unified habitat (UH) in order to provide a more realistic idea of the areas in which the WB population is distributed. Water bodies and watercourses in CORINE (EEA 2006) were considered as UH too.

Statistical analysis

– Association between habitat suitability (HS) and georeferenced presence records of species. The probability of association between WB locations (georeferenced records) and each habitat suitability category was analysed using a Pearson's Chi-squared test. The Spearman correlation was used to relate the inverse distance of WB presences to suitable habitat areas (categories 2, 1 or 0). The distances from suitable habitat areas for WB located outside these areas were tabulated into a histogram with distance groups with a maximum of 3 km.

– Association/concordance per region between the surface area of habitat suitability (HS) categories and WB population data. A Spearman correlation was used to examine the concordance between estimated WB population data and the surface areas of HS categories at regional level.

– Suitable WB habitat along the Bulgarian borders with other countries. Suitable habitat on the border (SH) was defined as the surface area (km²) with vegetation coverage suitable for WB along the Bulgarian border with neighbouring countries. The HS was obtained from CORINE (EEA 2006) (except for Greece, which only has the EEA 2000 version) considering the same land uses as described above. Potential resources that provide food and/or shelter for WB included in a buffer area extending 10 km inland from the border with each country were based on the average movement of 10.38 km + 2.84 km for wild boars of at least 17 months of age (Keuling et al. 2010). To quantify the importance of the borders with Romania, Greece, Serbia, Turkey and FYROM, the surface area of the suitability of habitat for WB extending 10 km inland from the border relative to the total area (SH + UT) was quantified for each of the countries sharing the border.

Geographical areas where physical barriers complicate or limit WB movement, such as highways which produce fragmentation in the terrain (Gurrutxaga & Saura 2014), were not taken into account especially due to the lack of spatial data of wildlife crossings structure associated to this kind of road allowing connectivity of land fragmented. Other barriers as rivers or water bodies could affect movements of the majority of the forest mammals depending on their different dispersal abilities (Bowman et al. 2002, Gurrutxaga et al. 2011). However, these type of barriers do not interfere the movement of WB, fact which was considered. For example, the northern border of Bulgaria is bordered by the River Danube, the natural border with Romania. The border follows the course of the Danube for 471.6 km as far as the town of Silistra in the northeast of the country and is approximately 800 meters wide. WB have been described as excellent swimmers and thus are able to regularly cross rivers and lakes (Leaper et al. 1999), sometimes accompanied by piglets, and even swim in coastal bays and out to sea (William 1993). They can cross water bodies and swim significant distances between islands (Albarella et al. 2006) up to 7 km apart (William 1993). This is regularly observed in summer and autumn by local Bulgarian hunters and forestry officers and, in fact, WB with GPS collar have been recorded as crossing the River Danube on two occasions (T. Alexandrov, pers. comm.). Moreover, WB are abundant on the islands in the Danube. Under these conditions we assumed that there was continuous habitat between the two countries. On the other hand, the Bosphorus Strait does not directly affect our study as natural barrier limiting the movement of the

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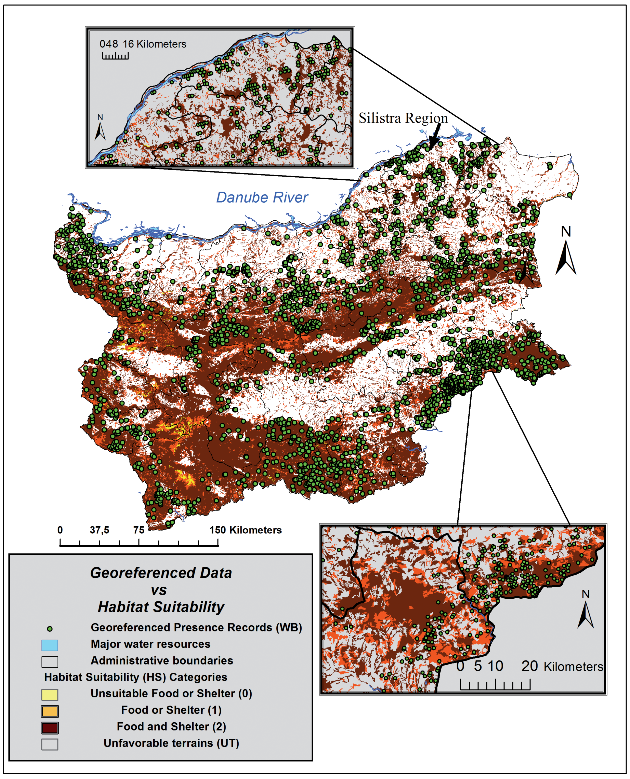

Fig. 1. Map of potential habitats for wild boar in Bulgaria based on an analysis of potential resources. Suitability for supporting wild boar assessed with CORINE by assigning potential resource values (PRVs) of 0 (unlikely suitable for food or shelter), 1 (suitable for food or shelter), or 2 (suitable for both food and shelter). White areas represent unfavourable terrains (UT). Georeferenced presence records of wild boar overlain on suitable habitat for the species in Bulgaria.

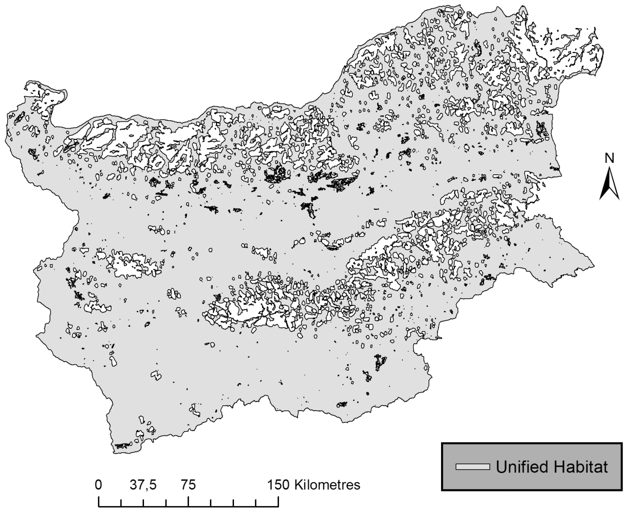

Fig. 2. Map of unified habitat for wild boar in Bulgaria obtained by applying a home range of 2 km to potential resources (considering water bodies and water courses).

wild boar because we only took 10 km inland from the Bulgarian border. We only considered the part of Turkey which border on Bulgaria on one side of the Bosphorus Strait.

All statistical analysis were conducted using Excel (Microsoft® Office 2003-2007) and SPSS v15.0 (SPSS Inc., 1989-2006). Spatial analysis and mapping results of WB on land use, presence data and the distances from suitable habitat areas for WB, habitat suitability, unified habitat and in the shared border in Bulgaria, were performed using ArcGIS 9.3 (ESRI®).

Results

Potential (WB) habitats based on potential resource values (PRV) in Bulgaria

Of the nineteen land uses playing a role as potential resources for WB (Bosch et al. 2012), only thirteen are represented in Bulgaria and are summarized in Table 1. The most representative of these land uses is the "Broad-leaved forest" (Grid_Code 23) with 23432 km^2 followed by "Land principally occupied by agriculture" (Grid_Code 21) with 10137 km^2. Areas with potential resources for WB correspond to 57.54 % of the total surface area of the country. Potential habitat for WB in Bulgaria based on potential resource values is depicted in Fig. 1 which also shows the georeferenced presence records of WB overlain on suitable habitat for the species in Bulgaria. According to UH (Fig. 2), the percentage of surface area in which WB can roam extends for 90000 km^2 or 80 % of the total surface area of the country. Potentially, two-thirds of Bulgaria could be occupied by WB and these animals are absent from just 21903 km^2 or a quarter of the country's surface area. In terms of the vegetation resources, a total surface area of 63850 km^2 was found to be adequate for WB, with 52783 km^2 providing both food and shelter and 10517 km^2 either food or shelter. The surface area that was not used for food or shelter (unsuitable for food or shelter), but which was very close to land suitable for WB and little alternated by human action, covered 549 km^2. The rest of the surface area in Bulgaria of UT for WB covers 48053 km^2 and contains no potential appropriate land use for WB from a biological, natural and conservative standpoint.

Statistical analysis

– Association between habitat suitability (HS) and georeferenced presence records of the species. A high level of correlation (Spearman correlation coefficient of 0.86) was found between an inverse distance of wild boar presences and habitat suitability areas (categories 2, 1 or 0). Suitability areas included 69.6 % of the locations for WB; 59.8 %, 9.4 % and 0.4 % of the locations coincided with suitability zones

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Table 1. Land uses selected as potential habitat for wild boar in Bulgaria according to the CORINE program. Potential resources (Grid_Code) for wild boar, potential resource values (PRV) and surface areas.

Potential resource (CORINE)		PRVs	Surface area (km^2)
Land use label	Grid_Code		
Pastures	18	1	4148.56
Complex cultivation patterns	20	1	2043.15
Land principally occupied by agriculture, with significant areas of natural vegetation	21	2	10137.65
Broad-leaved forest	23	2	23432.41
Coniferous forest	24	2	5364.64
Mixed forest	25	2	6405.63
Natural grasslands	26	1	4014.81
Moors and heathland	27	1	316.37
Transitional woodland-shrub	29	2	7454.47
Beaches, dunes, sands	30	0	15.61
Bare rocks	31	0	124.46
Sparsely vegetated areas	32	0	405.64
Burnt areas	33	0	3.7
All	∑	-	63867.1

Table 2. Surface areas and percentages of SH and UT on borders of Bulgaria, and linear kilometres of borders between Bulgaria and neighbouring countries.

Country border	(SH + UT) km² (%*)	(SH) km² (%*)	(UT) km² (%*)	Linear km of borders (%)	(SH)/(SH + UT) Percentage in buffer/borders**
Bgr-Gr	7432.82 25.44	6276.93 35.05	1155.89 10.22	494 (27.32)	84.45
Bgr-Mac	2280.69 7.81	2209.48 12.34	71.21 0.63	148 (8.19)	96.88
Bgr-Rom	11096.54 37.99	2289.11 12.78	8807.43 77.91	608 (33.63)	20.63
Bgr-Serb	4969.89 17.01	4381.77 24.47	588.12 5.20	318 (17.59)	88.17
Bgr-Tur	3431.45 11.75	2749.38 15.35	682.07 6.03	240 (13.27)	80.12
Total	29211.39 100	17906.67 61.3	11304.72 38.7	1808 100	

(SH) – Suitable habitat of wild boar in shared border.
(UT) – Unfavourable terrain for wild boar in relation to incompatible land use for the species along borders.
%* is expressed as the percentage of the total value for each parameter along border (SH + UT, SH or UT respectively).
** The percentage of importance of each border with Bulgaria for the passage of WB. Surface area of border of the suitable habitat (SH) for WB relative to the total area (SH + UT) of this shared. Percentage in buffer/borders = km² (SH)/km² (SH + UT).

2, 1 and 0, respectively, thereby confirming the accuracy of the classification into the three suitability categories. It should be noted that 30.4 % of WB were located outside the suitability zones, the majority of which (81 %) were located less than 0.5 km from a suitability area, either category 2, 1 or 0 (Fig. 3).

– Association/concordance per region between surface area of habitat suitability (HS) categories and WB population data. The Spearman correlation coefficients were 0.51 ($p < 0.005$) and 0.71 ($p < 0.0001$) for suitability categories 1 and 2, respectively, thereby showing a significant level of correlation at regional level in Bulgaria.

– Suitable habitat of wild boar (WB) along the Bulgarian borders (SH) with other countries. The surface area of the buffer zone along shared borders (Fig. 4) is 29211.39 km², corresponding to 61.3 % and 38.7 % of SH and UT, respectively (Table 2). An analysis of the surface area of SH for WB on the border between Bulgaria and all of its neighbouring countries (an area of 17906.67 km²) reveals that the most representative land use is "Broad-leaved forest" (Grid_Code 23) with

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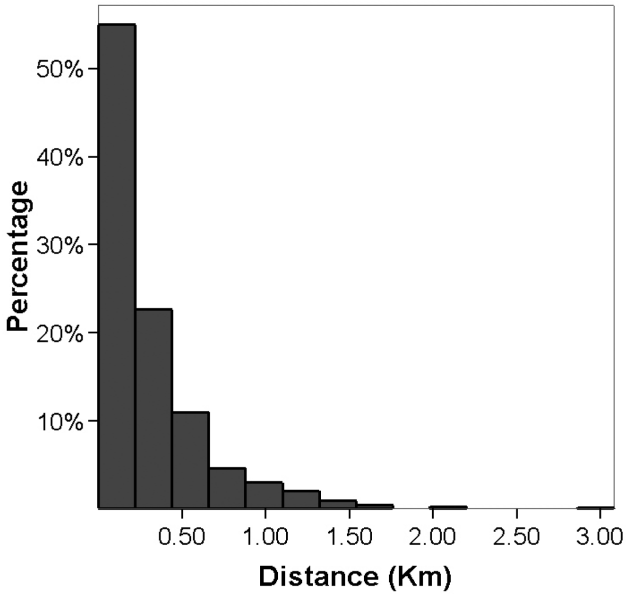

Fig. 3. Histogram of the distances to nearest suitability area of wild boar habitat for locations outside suitability areas (in distance groups with a maximum of 3 km).

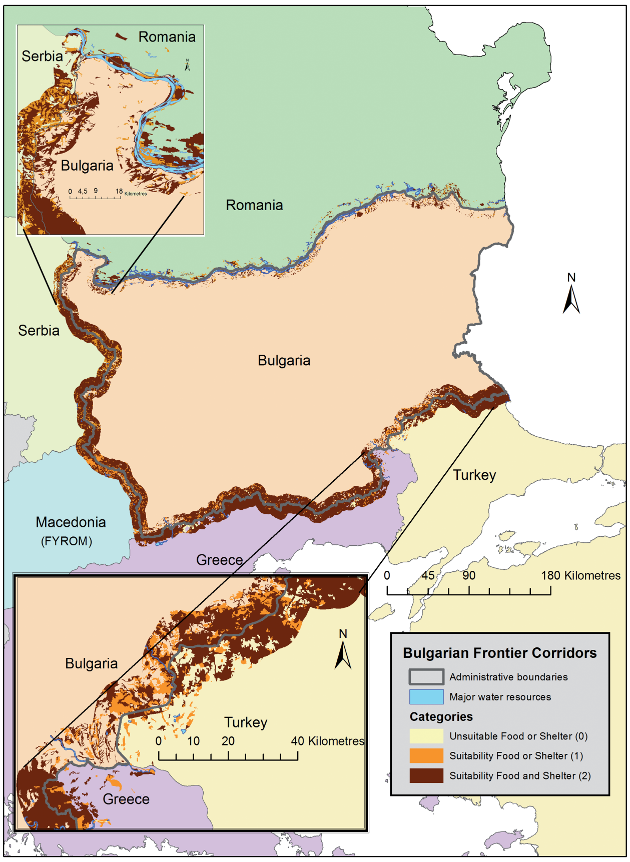

Fig. 4. Suitable habitat for wild boar along Bulgaria's borders with other countries.

7494.20 km² (41.85 %), followed by "Land Principally occupied by agriculture with significant areas of native vegetation" (Grid_Code 21), with 2378.99 km²

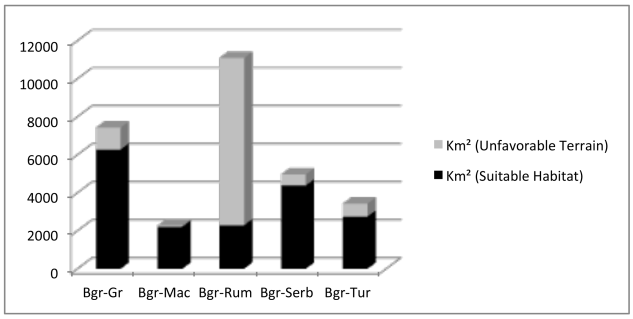

Fig. 5. Surface area of frontiers between Bulgaria and Greece, Macedonia (FYROM), Rumania, Serbia, and Turkey.

(13.29 %), and "Transitional woodland-shrub" (Grid_Code 29), with 2287.82 km² (12.78 %) (Table 3). Other land uses such as "Sclerophyllous vegetation" are virtually non-existent, only covering about 8 km² along the border with Greece.

Despite being the country's longest (608 km), the Bulgaria-Romania border does not represent the most important passageway for WB since only 12.78 % of its surface area is SH. By contrast, the border between Bulgaria and FYROM (148 km) is almost all suitable habitat on the borders with Romania and FYROM cover similar surface areas (2289 km² and 2209 km², respectively) (Table 2), which indicates that the Bulgaria-Romania border – but not the Bulgaria-FYROM border – has a large area of UT (Fig. 5). Thus, the percentage of SH in this latter border area relative to the total area is the greatest and more diverse for all land uses, with the highest relative importance percentage for the passage between countries (96.88 %) (Table 2) and should be regarded as the most important passageway for WB. The analysis of the percentage of SH on borders shows that the relative importance for the passage of WB between countries was as follows: Macedonia (96.88 %), Serbia (88.17 %), Greece (84.45 %), Turkey (80.12 %) and Romania (20.63 %) (Table 2).

Discussion

This study demonstrates the potential use of mapping and modelling the habitat distribution of species such as WB on a large spatial scale. The statistical analysis studying the association between HS and georeferenced presence records of WB show that there is a high level of correlation between the inverse distance of WB to suitable areas and the presence categories (correlation coefficient of 0.86). Moreover a significant level of correlation (0.71, $p < 0.0001$) per region (in Bulgaria) between the surface area of HS category 2 and WB population was also found. This information could be highly useful for developing adequate strategies for wildlife management on a large spatial scale when, for

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Table 3. Land use of suitable habitat for wild boar along Bulgaria's borders with other countries.

			Suitable habitat for wild boar along the Bulgarian borders with other countries (countries border)					
Label	Grid_Code	PR*	Bgr-Gr km² (%)	Bgr-Mac km² (%)	Bgr-Rom km² (%)	Bgr-Serb km² (%)	Bgr-Tur km² (%)	Shared Borders (Bgr) km² (%)
Pastures	18	1	52.57 (0.84 %)	125.07 (5.66 %)	462.37 (20.20 %)	118.88 (2.71 %)	52.43 (1.91 %)	811.33 (4.53 %)
Complex cultivation patterns	20	1	110.53 (1.76 %)	168.05 (7.61 %)	206.03 (9 %)	308.31 (7.04 %)	32.76 (1.19 %)	825.68 (4.61 %)
Land principally occupied by agriculture, with significant areas of natural vegetation	21	2	779.31 (12.42 %)	296.84 (13.43 %)	391.75 (17.11 %)	528.26 (12.06 %)	382.83 (13.92 %)	2378.99 (13.29 %)
Broad-leaved forest	23	2	2308.49 (36.78 %)	690.24 (31.43 %)	904.53 (39.51 %)	2046.28 (46.70 %)	1544.67 (56.18 %)	7494.20 (41.85 %)
Coniferous forest	24	2	673.36 (10.73 %)	201.89 (9.14 %)	0.69 (0.03 %)	157.40 (3.59 %)	32.50 (1.18 %)	1065.83 (5.95 %)
Mixed forest	25	2	669.19 (10.66 %)	212.16 (9.60 %)	2.69 (0.12 %)	207.12 (4.73 %)	128.27 (4.67 %)	1219.42 (6.81 %)
Natural grasslands	26	1	280.20 (4.46 %)	236.30 (10.69 %)	74.79 (3.27 %)	417.27 (9.52 %)	234.01 (8.51 %)	1242.57 (6.94 %)
Sclerophyllous vegetation	28	2	423.37 (6.74 %)	0.17 (0.01 %)	0 (0 %)	0 (0 %)	0 (0 %)	423.55 (2.37 %)
Transitional woodland-shrub	29	2	868.62 (13.84 %)	277.01 (12.54 %)	227.43 (9.94 %)	572.89 (13.07 %)	341.87 (12.43 %)	2287.82 (12.78 %)
Beaches, dunes, sands	30	0	1.40 (0.02 %)	0 (0 %)	18.81 (0.82 %)	10.46 (0.24 %)	0.04 (0 %)	30.72 (0.17 %)
Bare rocks	31	0	0.54 (0.01 %)	0 (0 %)	0 (0 %)	3.83 (0.09 %)	0 (0 %)	4.37 (0.02 %)
Sparsely vegetated areas	32	0	109.35 (1.74%)	1.76 (0.08 %)	0 (0 %)	11.07 (0.25 %)	0 (0 %)	122.18 (0.68 %)
Total			6276.93	2209.48	2289.11	4381.77	2749.38	17906.67

PR* – Potential resource. Vegetation that acts as a "potential resource" provides food and/or shelter for wild boar. Categories 2 (food and shelter), 1 (food or shelter) and 0 (neither food nor shelter).

example, it is important (a) to know the relevance of shared borders as the passageway for WB, (b) to conduct effective census in a region such as Bulgaria for different conservation management strategies (e.g. location of traps in strategic places that wild boars pass through), (c) to design and select locations for active sampling control strategies in animal health, (d) to make hunting more effective in areas with greater resources for WB, and (e) to control wildlife and its habitats (territorial integration and spatial planning in terms of the nature and the casuistry of the zone) and relationships between wildlife and other human interests (e.g. contact between wildlife and livestock, crop damage and road traffic accidents caused by collisions).

Modelling the distribution and abundance of WB is a challenge since it requires making assumptions that take into account the availability of data for developing models that synthesize on a large spatial scale the most important and representative variables and define the distribution, abundance and interaction of WB with their environment. As basic factors, vegetation cover plays an important role in the distribution of an animal species and is a limiting factor for the spread of a species as WB (Markina-Lamonja 1998, Herrero et al. 2006). Therefore, of all the methodologies available for estimating the distribution of WB on a large spatial scale, we chose to generate a habitat quality suitability index based on land use (standardized vegetation).

Potential wild boar (WB) habitats based on potential resource value (PRV) in Bulgaria and unified habitat (UH)

An important tool to solve the lack of data related to spatial distribution of the WB habitat is the use of databases and standardized digital cartography of vegetation coverage such as the CORINE land cover (EEA 2006) on a large spatial scale. This land

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cover has proven useful for analysing the potential distribution of WB in other countries (Massolo et al. 2007, Bosch et al. 2012, Podgórski et al. 2013). The latest version (17,12/2013) was used in this study and is more complete than older versions since it updates changes in land use to the present day and has mapped more countries. The only disadvantage is that Greece has not yet been updated and so the 2000 version was also used to be able to include Greece.

The HS defines directly the distribution of WB on a scale of 100 × 100 m using vegetation cover and indirect resources linked to environmental variables – ecoclimatic variables, topography, cartography/geographic – that condition WB distribution, and also considers the anthropic changes in land use that govern its distribution (Merli & Meriggi 2006).

Thanks to the georeferenced records of WB along the Bulgaria border that reveal the real presence of species, we have detected a direct relationship with the HS developed in this study. The statistical results show that the suitable areas (permanent vegetation patches) coincide with 69.6 % of trapping locations for WB in Bulgaria. Only 30.4 % of WB locations were outside the suitability zones; the maximum distance from suitability zones was 3 km (one record), the majority (81 %) being located less than 0.5 km from the suitability area (Fig. 4). These 30.4 % of locations outside the HS are mainly associated with agricultural areas (arable land, non-irrigated arable land). The edges around the HS are also a temporary source of food and shelter and can act as a passage (corridors), thereby affecting WB behaviour patterns (Sáez-Royuela & Tellería 1986, Keuling et al. 2009, Podgórski et al. 2013) and increase densities due to their high intrinsic capacity for population growth and their dependence on resources (Massei & Genov 2004, Cahill & Llimona 2004). In agroecosystem areas, HS is principally used as shelter (as natural foods are of little importance), while agricultural crop areas are used as artificial food source or supplementary feeding in certain periods of the year. These patterns and changes have been observed in WB in agroecosystems in the Spanish Ebro Valley (Herrero et al. 2006) and in other agricultural areas such as the Danube Plain (Genov 1987). For example, the adaptation of the species to supplementary feeding also increases the reproductive success of females (Neet 1995, Herrero et al. 2006) by leading to earlier reproduction and shorter reproductive cycles, a factor that is considered to be one of the main causes of the increasing densities of WB in Europe (Andrzejewski & Jezierski 1978, Sáez-Royuela & Tellería 1986, Fruzinski 1995, Bieber & Ruf 2005, Geisser & Reyer 2005). Alexandrov et al. (2011) conducted a study in an oak forest, a very suitable habitat for WB, that was surrounded by crops (mainly maize). They obtained high densities that would explain the similar high density obtained in a previous study in northern Bulgaria given that agriculture provides a potentially important food resource and the shelter areas (in this case, the oaks) are at saturation point in terms of the WB population. It is very important to know where high densities of WB can be found and also where they can be trapped more efficiently. In Bulgaria, trapping to reduce the WB population is very effective because exclusive refuge areas around patches near vegetation (forest islands) are selected and WB populations are reduced or eliminated over many square kilometres (Herrero et al. 2006) due to this animal's great reliance on this resource (Cahill & Llimona 2004). This trapping technique will decrease WB density (Alexandrov et al. 2011, EFSA 2014) and avoid potential migration to other areas.

In terms of the distance between separate roaming areas needed to create a UH, 2 km is a good conservative estimate for the movements undertaken by these animals. Other authors in other European countries (Boisaubert & Klein 1984, Briedermann 1990, Maillard & Fournie 1995, Caley 1997, Soidekat & Pohlmeyer 1999, 2004, Markina-Lamonja & Telletxea 2006, Keuling et al. 2010) have estimated similar ranges with a small degree of variability. More recently (Jerina et al. 2014) determinated that the maximum distance from a capture site with GPS-collared animals was 2.4-8.9 km (average 5.1 km), and gave a specific evidence of long-distance dispersal by WB. Most type of hunting techniques affect the behaviour of WB with implications for their movement and habitat use, but are not easily driven out their home range (Thurfjell et al. 2013). In a European context, the most representative average for minimum WB movements has been given as 2 km. The unified habitat map (Fig. 2) obtained in this study was similar to that of previous studies such as the IUCN distribution map for the Euroasian zone (Oliver & Leus 2008) (other than in some areas in northwest and southeast Bulgaria). Our current study, however, offers a larger area of potential habitat throughout the country, most likely a result of our use of a more accurate scale for the range data.

One of the advantages of HS – but also by UH – is its ability to detect on a large spatial scale at high definition the boundaries between natural environments and artificially created environments. It can also locate

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areas of transit or temporary use in which conflicts can cause damage to agriculture by their proximity to HS; this can also lead to traffic accidents caused by WB movements between locations with potential resources or by WB migration routes between forests (Caley 1997, Geisser & Reyer 2005, Herrero et al. 2006, Colino et al. 2012). When HS is compared with UH in Bulgaria it is clear that the latter is represented by agricultural areas, forest and semi-natural areas; HS covers 57.06 % of the total surface area of the country (Fig. 1), while UH (Fig. 2) with a greater WB distribution encompasses 80 % (90000 km^2) of the country's surface area.

Suitable habitat (SH) of wild boar (WB) along the Bulgarian borders with other countries

Specific suitable land use characteristics that facilitate or constrain WB movement can thus be described with high accuracy on maps of the borders of Bulgaria. For example, WB dispersal routes are generally sheltered by lines of trees and wood perimeters (Genov 1981b), and the presence of such habitat features will presumably encourage movement between sites in certain cases. Similarly, natural or artificial barriers may hinder the movement of the WB. The artificial "barriers" such a "walls or fences may inhibit movement between sites, although WB are large animals and able to demolish most fencing" (Leaper et al. 1999). Therefore, the identification of such features by mapping SH along the Bulgarian borders (Fig. 4, Supplementary material Fig. A1) may also be relevant in determining the importance of the borders that facilitate or hinder the passage of WB.

This approach and the results reported here may prove useful as guidelines for the monitoring and control of populations and diseases for which the WB acts as a reservoir. The SH along borders, which represents a first approach to potential corridors for WB populations given its continuity as a habitat, is an important parameter for estimating the risk that transboundary diseases will cross frontiers and for assessing the importance of an endemic situation in a particular country. Therefore, SH along borders should be regarded as the most relevant parameter for evaluating the risk of ASF introduction by WB into the EU from adjacent countries (De la Torre et al. 2013). Strategic passageways corridors between potential resources, provinces, regions and countries can thus be spatially identified and used for epidemiological purposes such as target surveillance e.g. allowing us focus locations to install traps in order to reduce WB populations. The value of mapping is that it enables investigators to quickly and easily appreciate where field studies using different techniques should be set up.

Future studies should focus on the analysis of ecological corridors and take into account potential resources obtained in this study, the edge effect, fragmentation and the connectivity between countries; they should implement methodologies that can assess more accurately and weigh spatially the connecting and ecological corridors that facilitate migration between countries. When data is needed, the connectivity between forest patches and forest islands and boundaries such as the natural boundary of the River Danube between Bulgaria and Romania can be analysed, and the weight of possible migration flows and routes most likely to be used (ecological corridors) between countries (e.g. FYROM and Bulgaria) can be determined more accurately.

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Supplementary online materials

Fig. S1. Land use and suitable habitat (SH) of each country along the shared border with Bulgaria (URL: http://www.ivb.cz/folia/download/bosch_supp.doc).

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