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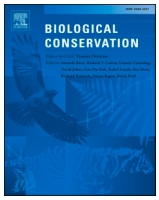

Policy analysis

Historical data to inform the legal status of species in Europe: An example with wolves

Carlos Nores [a,1], José Vicente López-Bao [b,*,1]

[a] INDUROT, Oviedo University, E-33600 Mieres, Spain
[b] Biodiversity Research Institute (CSIC - Oviedo University - Principality of Asturias), Oviedo University, E-33600 Mieres, Spain

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ABSTRACT

Historical information is useful to set conservation baselines and, in turn, to inform the legal status of species and habitats. The conservation value of historic data has been acknowledged in international and national conservation laws, such as in the case of the implementation of the European Habitats Directive of 1992, and the guiding criteria for listing species and populations on the Spanish List of Threatened Species (BOE-A-2017-2977). We use the example of the debate on the appropriate legal status of wolves in Spain, and variation in wolves' range over the last two centuries, to illustrate the value of historical data to objectively inform legal decisions on the status of species. We carried out a quantitative analysis, using different methodological approaches, of the evolution of the range of wolves in Spain using historical information available in the geographical dictionaries edited by Pascual Madoz, in 1846–1850, and Germán Bleiberg, in 1956–1961 (>5800 and >7500 wolf records, respectively), as well as recent information on the range of the species in the last decade (2012–2020). Regardless of the approach used, or the historical time period considered, we estimated that, overall, wolves in Spain have not suffered a reduction in their historic range of ≥50 % over the last 100 years. We draw attention, however, to interpretative uncertainties of the law in relation to the interpretation of the term "historic range", which require clarification from the Scientific Committee advising the Spanish Government.

1. Introduction

Range variation over time is used as a key criterion to assess the conservation status of species. From a conservation point of view, historical information (for example written accounts; e.g., Boshoff and Kerley, 2010; Clavero and Delibes, 2013; Gallant et al., 2016) is useful not only to address gaps in knowledge and to assess changes in the range of species, but also to set baselines for species recovery or to inform conservation targets (e.g., Metzger et al., 2007; Lotze and Worm, 2009). Thus, historical information is useful to inform the legal status of species and habitats. The use of systematic historical information facilitates long-term perspectives (Willis and Birks, 2006) and prevents phenomena such as shifting baselines (i.e., the intergenerational loss of information about species abundances or range; Pauly, 1995). Furthermore, they avoid the influence of gaps in knowledge (e.g., on the impact of climate shifts in species range; e.g., Kharouba et al., 2009) or wrong assumptions about past ranges or abundances of species, due to biased and subjective interpretations. All of these phenomena have the potential to misguide public perceptions and conservation decisions (Swetnam et al., 1999). However, objective historical data on the range of species have only rarely, and recently, been integrated in conservation science (e.g., Swetnam et al., 1999; Willis and Birks, 2006; Szabó and Hédl, 2011; McClenachan et al., 2012; Clavero and Hermoso, 2015).

The conservation value of historic information is reflected in the IUCN Red List Criteria (IUCN, 2001), which include the past range of species, although these criteria are not legally binding. Such value is also acknowledged at the legislative level. In the European Union (EU), Member States are required to achieve or maintain a Favourable Conservation Status (FCS) for species and habitats listed in the annexes of the Habitats Directive of 1992 (HD, Directive 92/43/EEC). The concept of FCS has been subjected to interpretive uncertainties (e.g., Epstein et al., 2016; Trouwborst et al., 2017), which can impact the consistency and effectiveness of the application of the same directive across nations. Every six years, article 17 of the HD requires EU Member States to report on the implementation of the measures taken under the HD, as well as the assessment of the conservation status of species and habitats. For

* Corresponding author.
E-mail address: jv.lopez.bao@csic.es (J.V. López-Bao).
[1] These authors contributed equally to this work.

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these assessments, and according to the Commission's own guidelines, it is necessary to determine Favourable Reference Values (FRVs) for the range of species and habitats, for area of habitat types, or for population sizes (European Commission, 2006; Evans and Arvela, 2011; Bijlsma et al., 2018). These FRVs are set as targets against which current parameter values can be judged, and must be based on science (Bijlsma et al., 2018).

The Commission guidelines promote the concept of Favourable Reference Range (FRR) for species, and is defined as a "*range within which all significant ecological variations of the species are included for a given biogeographical region and which is sufficiently large to allow the long-term survival of the species*". The FRR must be, at least, the range of the species when the HD came into force (Bijlsma et al., 2018). If this range is insufficient to support FCS, the reference for favourable range should be larger; in such a case, information on historic distribution can be useful (Evans and Arvela, 2011; Bijlsma et al., 2018). In using historical information for setting FRRs, EU guidelines suggest a broad historical perspective, including about 50 years before the HD came into force, and the historical past, up to the last two or three centuries (Bijlsma et al., 2018). The "historical past" requires value judgments, since there is no single correct answer as to the appropriate time in history at which to set this reference baseline (Epstein et al., 2016). Although the use of historical distribution and potential range in determining FCS is recommended by the Commission guidelines (European Commission, 2006; Evans and Arvela, 2011), it is not legally required that species populations approach historical levels and utilize all potential habitat (Epstein et al., 2016). The historic distribution of species has been used by some EU Member States in setting reference values (Bijlsma et al., 2018).

In Spain, the guiding criteria for listing species and populations in the Spanish List of Threatened Species (BOE-A-2017-2977) consider for *Vulnerable* species three alternative sub-criteria for range reduction: firstly, a reduction ≥25 % in the last 30 years (sub-criterion B.1); secondly, an expected reduction ≥25 % in the next 20 years, or three generations (sub-criterion B.2); finally, an important reduction in historic range (≥50 %) over the last 100 years, or if the species is undergoing a recovery process, a recovery <50 % of its historic range (sub-criterion B.3). From a legal point of view, the historic range of species under sub-criterion B.3 would be the range in the first decades of the twentieth century.

Large carnivore conservation is challenging due to multiple political, socio-economic and conservation interests and the psychological (e.g., emotions, fear) dimensions involved (e.g., Chapron and López-Bao, 2014; López-Bao et al., 2017; Darimont et al., 2018; Lute et al., 2018; Rode et al., 2021). Information on species range or population size, and the evolution of these parameters over time, is in constant demand. Wolves (*Canis lupus*) are a good example of a species for which the estimates of these parameters are politicized, and where reliable assessments of their variation over time are frequently requested to justify and/or support policies and decisions (Duchamp et al., 2011; Darimont et al., 2018; López-Bao et al., 2018a). Previous publications suggested that Iberian wolves occupied almost all of mainland Spain until the late nineteenth century (Valverde, 1971) (Appendix A).However, after an intense period of persecution, only two wolf populations remained around the 1970s: the large north-western Iberian wolf population (shared with Portugal; Valverde, 1971; Chapron et al., 2014; López-Bao et al., 2018b), and three small nuclei in the Sierra Morena area, all of them now extinct (López-Bao et al., 2018b). After the 1970s, the north-western Iberian wolf population expanded (Chapron et al., 2014; Blanco and Cortés, 2009; López-Bao et al., 2018b), and since the late 1990s the species reached south of Castilla y León (Segovia and Ávila provinces; first confirmed wolf reproduction in Segovia province in 1998), north of Castilla-La Mancha (Guadalajara province) and Madrid (Blanco and Cortés, 2002, 2009). Genetic analyses have revealed that the wolf recovery toward central Spain resulted from the expansion of wolves from the south-eastern Cantabrian Mountains (Silva et al., 2018). Currently, this population appears to have stagnated in eastern Castilla y León, the Basque Country and north of Castilla-La Mancha (Guadalajara province), even though some of these areas have low human population densities and healthy wild prey populations (Blanco and Cortés, 2009).

The recovery process and status of wolves in Spain has been the subject of various controversies (e.g., Blanco and Cortés, 2009; López-Bao et al., 2018b; Quevedo et al., 2019). Applying the criteria of the IUCN Red List (IUCN, 2001), the recent evaluation carried out by Boitani (2018) included wolves in Spain in the category "*Near Threatened*", the same category previously assigned in 2006 by Blanco et al. (2007). More recently, following an official request to list the Spanish wolf population in the "*Vulnerable*" category of the Spanish List of Threatened Species, the Scientific Committee, advising the Spanish Ministry for the Ecological Transition and the Demographic Challenge (BOE-A-2017-2977; RD 139/2011; BOE-A-2011-89994), rejected the inclusion of the wolf on the Spanish List of Threatened Species as "*Vulnerable*". The committee considered the information submitted on the historic distribution of wolves in the early twentieth century to be inconclusive (MITECO, 2020). Taking this background into account, here we scrutinize the example of the debate on the long-term variation in the range of wolves in mainland Spain (ca., 494,000 km^2), and its legal conservation status, by analyzing available historical information on the range of the species. We illustrate the conservation value of historical data to inform policies (e.g., the convenience of updating the conservation status of wolves or not based on the best scientific evidence available).

We carried out a quantitative analysis to assess the evolution of the range of wolves in Spain using historical information from around the 1850s and 1950s, as well as recent available information (Boitani, 2018). To date, the main references used for the past range of wolves in Spain have been Valverde (1971) (Appendix A), Grande del Brío (1984), and Rico and Torrente (2000). However, these references are not comparable, and the different range maps generated were carried out using different subjective criteria and an insufficiently explained (or detailed) methodology. In this regard, to make available historic information comparable over time, we used municipalities as the common spatial administrative unit. We took advantage of >5800 and 7500 records of wolf presence and absence at this administrative level for the 1850s and 1950s, respectively. We discuss the conservation implications of the historical perspective gained from our analyses for wolves, and other species, under existing conservation laws.

2. Methods

2.1. Wolf information: past and present

Detailed historical geographical information that includes records of wildlife occurrence, and that refers to different administrative levels, such as parishes, municipalities or counties, is of paramount value to objectively reconstruct the past range of species. The most common sources of historical information about wildlife in Spain, covering the entire country, are the geographical dictionaries edited by Pascual Madoz (1846–1850), and Germán Bleiberg (1956–1961). Both geographical dictionaries were used in this study. In the first case, field information was collected beginning in 1835 and spanned almost a decade. In the second geographical dictionary, information was collected from approximately 1952 to 1955 (hereafter, we refer to the periods of 1846–1850 and 1956–1961 for simplicity). Geographic dictionaries are inventories ordered alphabetically by toponyms, which describe the characteristics of particular administrative levels (e.g., municipalities/parishes in our case), often including information on industry, agricultural and livestock production, as well as game or fishing species. Both dictionaries are comprehensive compilations of Spanish geographical information, comprising 16 (>11,600 pages) and 17 (>12,000 pages) volumes, respectively, and they represent good early examples of citizen science (e.g., Clavero et al., 2017). For example, the geographic dictionary edited by Madoz had 1484

contributors across Spain (Arroyo, 2019), avoiding potential biases due to a single or very few observers. In both geographical dictionaries, information can be referred to the level of current Spanish municipalities, which facilitates comparisons over time. The dictionary edited by Madoz also presents information at a lower administrative level, parishes. Both dictionaries included a list of wildlife for each municipality or parish, particularly exhaustive with species of economic interest, such as game. In Spain, historically, there have been some attempts to publish geographical dictionaries since 1579, with the publication of the "*Relaciones Topográficas*" ordered by the King Felipe II (Ortega-Rubio, 1918), the Geographical Dictionary by Tomás López, from the 18th century (López, 1772–1797), or the Geographical Dictionary of the Royal Academy of History, of which only a few number of volumes were published in 1802 and 1846 (Real Academia de la Historia, 1802; Govantes, 1846). However, these works were published partially or did not cover the entire country. Apart from the two geographical dictionaries used in this study, the Geographical-Statistical Dictionary of Spain and Portugal (published in 10 volumes between 1826 and 1828; Miñano, 1826–1828) covered the entire country, but information on wildlife is not exhaustive.

We searched for all records of wolf presence/absence included in all the volumes from both geographical dictionaries, resulting in 5864 and 7589 wolf references at municipality level for the periods 1846–1850 and 1956–1961, respectively. In the case of the dictionary edited by Madoz, when information on wolves was available at the level of parishes, we linked this information to the municipalities in which the parishes were located. For each municipality, we applied the following criteria to assign wolf presence/absence (Nores et al., 1995): i) when wolves were explicitly mentioned in the list of wildlife in a municipality, it was considered as "wolf presence"; ii) if the list of species in a municipality listed several species, but wolves were not mentioned, it was considered as "wolf absence" and iii) if for a given municipality information of wildlife was absent or uncertain, it was considered as a "municipality with no information on wildlife".

The recent wolf range for 2012–2020 was determined by analyzing the latest information on the permanent and sporadic presence of the species in Spain from the Large Carnivore Initiative for Europe IUCN/SSC Specialist Group (Boitani, 2018), at a resolution of 10 × 10 km grid cells. The information on wolf presence included in Boitani (2018) was collected between 2012 and 2016. We complemented this information with regional sources of information and unpublished information on wolf presence in some municipalities outside the current range of the species in north-western Spain, as a result of recent recolonization events (i.e., in the autonomous regions of Aragón and Catalonia; e.g., García-Lozano et al., 2015). The municipalities with recent wolf records in north-eastern Spain mainly correspond to wolves arriving from Italy, having passed through southern France (García-Lozano et al., 2015). A few individuals from the north-western Iberian wolf population had also been identified in Aragón (Martín, 2021). We used QGIS software (QGIS Development Team, 2018) to overlap all the 10 × 10 km cells of wolf presence with municipalities, to obtain a recent wolf range estimate comparable with past information. For comparison, we assumed that all municipalities overlapping with presence cells were municipalities with wolf presence. We made this assumption considering that the reported presence of the species in a municipality in the past could be due to a wide range of possibilities: from municipalities with wolf reproduction, or stable wolf presence in the entire municipality, to the sporadic presence of some wolves in some parts of a municipality.

2.2. Estimating wolf range variation over time

We carried out a quantitative assessment of the variations in wolf range over time using three different approaches. Municipalities were used as reference spatial units, allowing an estimation of the area occupied by wolves (i.e., the total area of all municipalities with wolf presence) in each time period: 1846–1850, 1956–1961 and 2012–2020. The use of municipalities also facilitated the assessment of wolf range variation among time periods. Differences in the proportion of municipalities with wolf presence across periods, and between pairs of periods, were evaluated using Chi-squared tests. Yates's correction was implemented in the case of between periods pairwise comparisons.

Apart from the sum of the area occupied by all municipalities with wolf presence in each time period, we added a biologically-informed buffer to municipalities. The IUCN has suggested the use of buffers with a methodological or biological foundation to obtain comparable range areas (IUCN, 2019). The use of buffers can reduce possible biases associated, for example, to the heterogeneity in the size of municipalities. Methods that use a buffer based on biological information can also have advantages in representing irregular distributions (e.g., Ostro et al., 1999). The difference in size and shape between the reference spatial units used over time (municipalities in 1846–1850 and 1956–1961 vs. 10 × 10 cells in 2012–2020) could lead to biased comparisons (Marboutin et al., 2011). The average size of mainland Spanish municipalities is 61.5 km^2 (±92.5), whereas the size of 10 × 10 cells is constant (100 km^2). Thus, to explore and to reduce potential biases in our estimations, we implemented a spatial correction in the three time periods taking into account the spatial ecology of Iberian wolves. To do this, we used information on the spatial behaviour of 85 wolves in Iberia published in Silva et al. (2018) involving individuals of different sex, age and social status, and collected between 1982 and 2015. The average size of the home range of these wolves was 408.3 km^2 (range 14–2810 km^2, estimates based on the Minimum Convex Polygon using 100 % of the locations; Silva et al., 2018). Therefore, we considered a radius of 11.5 km to simulate a buffer area for each municipality of a size similar to the average wolf home range mentioned above (i.e., 415 km^2). All simulated buffers were centred on the centroids of municipalities, their areas were merged and we did not consider those sections of the buffers outside the national borders for our analyses. After adding the buffer area to municipalities, we again calculated the range of wolves in each time period. Since the buffer area (415 km^2) was larger than the average size of sampling units (i.e., municipalities; 61.5 km^2), we assumed this conservative approach may facilitate the comparison between historic and current wolf information.

We complemented our assessment by calculating an alternative buffer, based on the concept of trees in graph theory (Rapoport, 1975). Based on the nearest municipalities with wolf presence, it is possible to obtain a tree of maximum propinquity, representing the minimum distances between municipalities with wolf presence. The mean value of all these minimum distances is then used as the radius of a buffer centred on the centroids of municipalities. Since the spatial distribution of wolves changed over time (see Results section), we calculated a different buffer radius according to the spatial distribution of municipalities with wolf presence at every time period. Thus, we used a radius of 10.3 km for 1846–1850, 8.9 km for 1956–1961 and 5.0 km for 2012–2020. When raw presence data is scarce, separate spatial units with confirmed presence increases the propinquity value used to calculate the buffers, which compensates for a small number of presence records (Rapoport, 1975). This approach also allows the identification of disjointed areas, which are of particular interest when analyzing range reductions (Rapoport, 1975). However, this approach tends to further overestimate the estimated range in the case of fragmented distributions, since the mean minimum distance will increase with increasing separation among municipalities with wolf presence. We acknowledge that the methods used for estimating the distribution of wolves based on buffers may be sensitive, both to the size of scattered municipalities (small isolated municipalities will show a larger area when overlapped with the buffer) and to the degree of fragmentation in the range of wolves, which causes the buffer circles to overlap less.

3. Results

Overall, the number of municipalities with information about wolf

absence was larger than with wolf presence for all the time periods considered (Table 1). For every municipality with records of wolf presence, there were 4.4 municipalities with wolf absence in 1846–1850 and 4.7 in 1956–1961. In recent times (2012–2020), this figure was lower, with 2.9 municipalities ($X^2 = 214.01$; df = 2; $P < 0.0001$, Yates's correction: 1846–1850 vs. 1956–1961, $P = 0.286$, 1956–1961 vs. 2012–2020, $P < 0.0001$).

The quantitative analysis of historical information at the level of municipalities shows that wolf distribution in Spain was not continuous in the past, but scattered and fragmented in 1846–1850 (Fig. 1). The most continuous presence corresponded to the main mountainous areas of the country, being absent, for example, from most of the plateaus in central Spain (e.g., Castilla y León and Castilla-La Mancha). From 1846–1850 to 1956–1961, wolves disappeared from most of the eastern and southern areas, only remaining in some places, while the species spread its range on the western side (Fig. 1). Since the mid-twentieth century, wolves almost disappeared from the entire central and southern areas (i.e., Extremadura, Castilla-La Mancha, Andalucía), and persisted mainly in north-western Spain, from which the species subsequently expanded after the 1970s (Fig. 1).

Regardless of the approach used to estimate the range of wolves, and its evolution, we estimated that wolves occupied less than half of the surface of mainland Spain either in the mid-nineteenth century or later (Table 2). Wolves could have occupied between 108,242 km^2 and 230,464 km^2 in 1846–1850 and between 131,241 km^2 and 216,513 km^2 in 1956–1961 (Table 2). Considering only the size of those municipalities with wolf presence, the range of wolves would have increased by between 32.8 % and 9.5 % in recent times, compared to 1846–1850 and 1956–1961, respectively (Table 3). However, applying the conservative buffers, its range would have reduced in recent times by between 19.3 % and 31.2 % (Table 3). Therefore, regardless of the approach used for wolf range estimation, or the historical time period considered, our estimates indicate that, in recent times, wolves have not suffered a reduction of ≥50 % of their historical range (Table 3).

4. Discussion

Wildlife information available in the geographical dictionaries edited by Pascual Madoz (1846–1850) and Germán Bleiberg (1956–1961) has served as the basis for multiple interpretations of the historical range of species in Spain, from carnivores and ungulates, to freshwater species (e.g., Valverde, 1971; Nores and Naves, 1993; Nores et al., 1995; Clavero and Hermoso, 2015; Clavero et al., 2017); including extinct species in Spain in recent historical times, such as the case of the Eurasian lynx (*Lynx lynx*) (Clavero and Delibes, 2013). Our analysis, at the administrative level of municipalities (which is also used to present the range of species; e.g., Gaston, 2003) is the most objective and quantitative analysis to date on the historical evolution of the range of wolves in mainland Spain. Núñez-Quirós et al. (2007) assessed the historical evolution of wolves in Galicia (north-western Spain), using as a territorial reference unit not only municipalities (or parishes), but also a grid of 10 × 10 km cells. These authors observed that the estimated range of wolves using the grid cells was higher than that resulting from municipalities. In our case, we believe that the transformation from grid cells to municipalities of recent wolf information is more appropriate rather than vice versa. Raw information at the level of municipalities was available in two of the three periods considered, and this improves the comparability of wolf ranges over time. Mapping the wolf range using an administrative unit level, such as municipalities, is also useful to better apply existing or future subsidies by governments or non-governmental organizations to favour coexistence scenarios, such as subsidies related to large carnivore presence (e.g., Macon, 2020), or to implement programs and interventions that reduce the vulnerability of livestock to predators (e.g., damage prevention measures, Van Eeden et al., 2018). In addition, this approach is consistent with the territorial units commonly used in wolf management and conservation plans, which are referenced at the municipal level, such as in the case of zoning (e.g., Decree 297/2008 from the Regional Government of Galicia) or subsidies to implement damage prevention measures (e.g., Order December 16, 2020, from the Regional Government of Galicia) or other measures associated with wolf presence (Decree 70/2021 August 19, 2021, from the Regional Government of Cantabria).

Valverde (1971) has been used as the main reference for the historic range of wolves in Spain, with this reference including wolf distribution maps in three periods (Appendix A). The first period was 1840s, and the source information came from the same geographic dictionary used in our study, edited by Pascual Madoz. The second period was during the 1950s, using information from the dictionary edited by Germán Bleiberg. The last one presented the status of wolves during the 1970s, based on his own data and some additional sources (e.g., Fernandez de Cañete, 1969). Interestingly, whereas the situation drawn by Valverde for the 1950s is similar to that obtained in this study (Fig. 1; Appendix A), we observed a mismatch between Valverde's interpretation for wolf status in the mid-nineteenth century, and our results. Valverde's own interpretation of the geographical dictionary edited by Pascual Madoz was that "*there were then wolves occupying the whole of Spain, with the sole exception of a coastline in Catalonia*". Valverde (1971) and subsequent studies did not analyze available information objectively nor did he provide details on how the different wolf maps were drawn (see also Grande del Brío, 1984). Valverde's interpretation perpetuated the idea that wolves were occupying almost all mainland Spain in the mid-nineteenth century, leading to a biased perception of the range of wolves that has persisted over time. Whereas it is true that wolves were present in all Spanish provinces at that time (Fig. 1), wolf presence was very small, scattered, or even marginal in several provinces. For example, only 7.5 % of the municipalities with wildlife information from Cáceres, Badajoz, Toledo, Ciudad Real and Córdoba provinces (central Spain) had records of wolf presence. Our results therefore highlight the need to prioritize the objective analysis of original sources of information whenever possible, in order to verify the accuracy of subsequent interpretations. After Valverde (1971), it is worth mentioning that some authors already suggested that the range of wolves was not continuous in Spain in the mid-nineteenth century (Bárcena, 1997; Rico and Torrente, 2000). In this regard, we found evidence to support previous doubts about a continuous range of wolves in the mid-nineteenth century (Fig. 1). Interestingly, available information from the sixteenth century ("*Relaciones Topográficas*" de Felipe II, 1574–1578) also supports the idea of a discontinuous range of wolves in Spain in historical times (Ortega-Rubio, 1918). Out of 425 localities in central Spain with wildlife records at that time, wolves were mentioned in 37.8 % of them.

From a legal point of view (criterion B of the *Vulnerable* category; BOE-A-2017-2977), the assessment of historical variations in wolf range should be based on the comparison between the present situation, and the wolf range around the 1920s. To our knowledge, there are no reliable sources of wolf information at that time. It is therefore not possible to establish the baseline for the range of wolves 100 years ago, as required by law. However, the geographic dictionaries of 1846–1850

Table 1
Number and proportion of municipalities with records of wolf presence and wolf absence in mainland Spain in the three time periods considered in this study. Only municipalities with wildlife information are considered. The proportion of municipalities with wolf presence has increased in recent times.

Period	Presence/absence	Proportion of municipalities with wolf presence	Proportion of municipalities without information
1846–1850	1062/4721	0.18	0.27
1956–1961	1315/6143	0.18	0.07
2012–2020	2759/7963	0.25	0.00

Note: For the period 2012–2020, the proportion of municipalities with wolf presence excluding information from Aragón and Catalonia autonomous regions was 0.25.

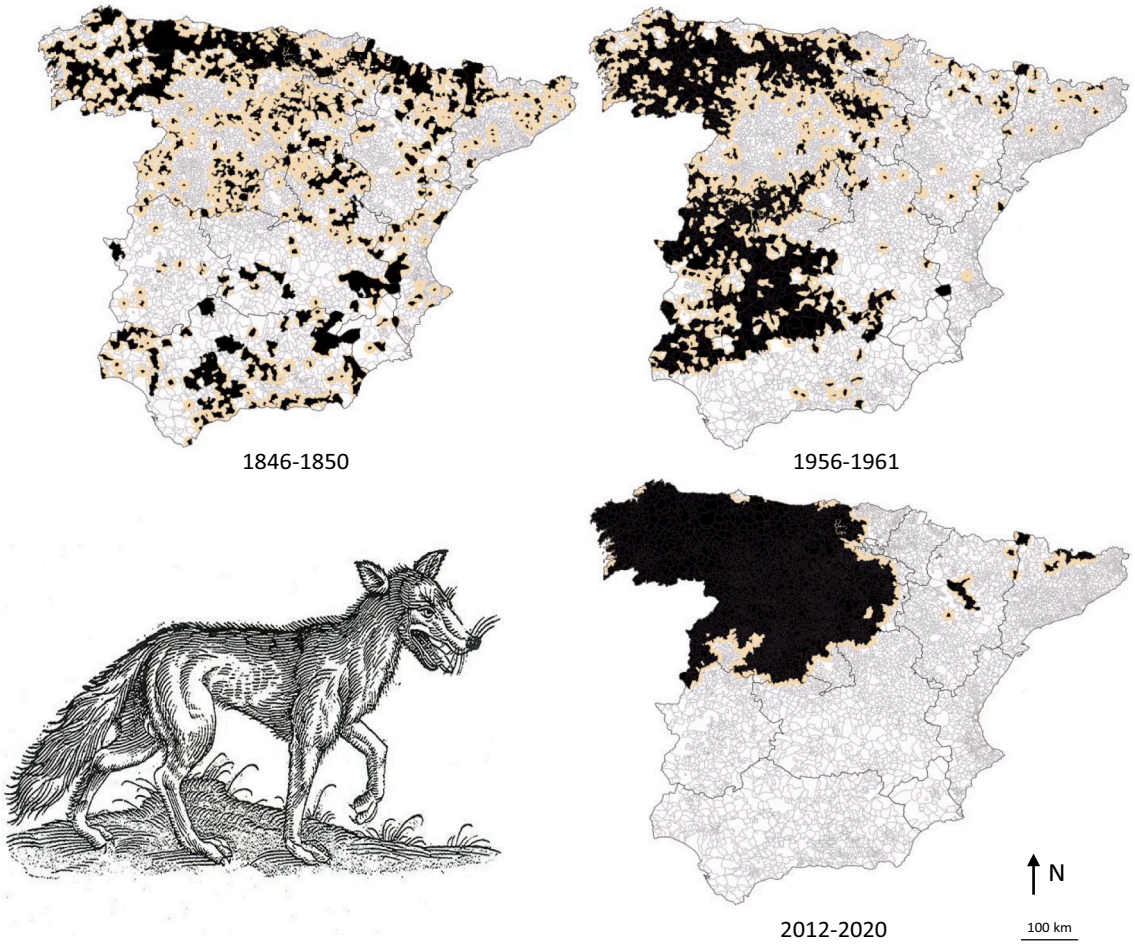

Fig. 1. Municipalities with wolf presence (black) in Spanish mainland in 1846–1850, 1956–1961 and 2012–2020. The resulting correction in range estimates after applying the buffer based on the spatial ecology of wolves is also shown (orange). Wolf drawing extracted from Gesneri (1551). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Estimated wolf range in Spain (km^2) in 1846–1850, 1956–1961 and 2012–2020, according to three different estimation methods. The percentage of the Spanish mainland area occupied by wolves in every period is shown between brackets.

Period	Approach used for wolf range estimation		
	Municipalities	Municipalities + buffer wolf spatial ecology	Municipalities + buffer nearest presence municipalities
1846–1850	108,242 km^2 (21.9 %)	230,464 km^2 (46.7 %)	208,676 km^2 (42.2 %)
1956–1961	131,241 km^2 (26.6 %)	216,513 km^2 (43.8 %)	181,286 km^2 (36.7 %)
2012–2020	143,699 km^2 (29.1 %)	158,586 km^2 (32.1 %)	146,334 km^2 (29.6 %)

Note: For the time period 2012–2020, the percentages of the Spanish mainland area occupied by wolves excluding information from Aragón and Catalonia autonomous regions were 28.4 %, 30.6 % and 28.8 %, respectively.

Table 3
Percentage changes in the estimated range of wolves between the historical references of wolf range in 1846–1850, 1956–1961 and 2012–2020, according to three different estimation methods. For the time period 2012–2020, the percentage change in the estimated range of wolves when excluding information from Aragón and Catalonia autonomous regions is shown between brackets.

Time periods compared:	Approach used for wolf range estimation		
	Municipalities[a]	Municipalities + buffer wolf spatial ecology	Municipalities + buffer nearest presence municipalities
1956–1961 to 1846–1850	+21.2	−6.1	−13.1
2012–2020 to 1846–1850	+32.8 (+29.5)	−31.2 (−34.4)	−29.9 (−31.7)
2012–2020 to 1956–1961	+9.5 (+6.8)	−26.8 (−30.1)	−19.3 (−21.4)

[a] Considering only those municipalities with information on wolf presence or absence in the period 1846-1850 as the reference area for temporal comparisons (5,783 municipalities, see Table 1), the percentage change in the estimated range of wolves was: -17.5% between 1846-1850 and 1956–1961, 20.8% between 1846-1850 and 2012-2020, and 46.6% between 1956-1961 and 2012-2020.

and 1956–1961 can be used to set such historic reference baselines. Considering the periods in which the information for every geographical dictionary was collected (see Methods), the closest available information on the range of wolves around the 1920s would be the one extracted from the geographical dictionary edited by Germán Bleiberg (1956–1961) (a difference of ca., three decades from 1920s). The status of wolves around the 1950s also fits with the EU guidelines for setting FRRs (Bijlsma et al., 2018), which suggest that historical perspectives to set reference baselines should include data from "*about 50 years before the HD came into force in the EU Member State*". In the case of Spain, where the HD entered into force in 1992, this would translate into the status of wolves in the early 1940s. Furthermore, both geographical dictionaries

are also in line with these guidelines in extending the historical range of species "*up to the last two or three centuries*" (Bijlsma et al., 2018). From our estimations, in the worst scenarios, between 1956–1961 and 2012–2020 the range of wolves would have been reduced by 26.8 % (Table 3; 30.1 % excluding information from Aragón and Catalonia autonomous regions). Worth mentioning, despite the expected differences in wolf range estimations from the different approaches used (the application of buffers led to higher range estimates in all cases, compared to the use of municipalities), wolves have not suffered a reduction of ≥50 % of their historical range. These results contrast with the expected output following Valverde (1971). Considering the estimated range proposed by Valverde in the 1840s (Appendix A; wolves ranging around ca., 480,000 km^2), between 1846–1850 and 2012–2020 the range of wolves would have been reduced by 69.5 % and 70.0 % (depending on the approach used to estimate the range of wolves at present; Table 2).

Traditional livestock practices have dominated rural activities in Spain for centuries. Around the mid-nineteenth century, a deep process of modernization of Spanish agriculture and farming practices occurred. After centuries, the Castilian sheep owner's guild (*Honrado Concejo de la Mesta*; i.e., *The Mesta*) was suppressed (it had existed from 1273 to 1836; García-Sanz, 1978). Traditional transhumance practices under *The Mesta* included the use of particular breeds of livestock guarding dogs (Spanish mastiffs) to protect livestock flocks from wolf attacks (Ruiz and Ruiz, 1986) and, even the number of dogs per flock was regulated (a flock or *rebaño* of about one thousand sheep heads was managed by a herder with several assistants and five mastiffs; Klein, 1920). Under the pressure of increasing agriculture demands, extensive livestock farming practices were reduced in favour of crop agriculture, and a rural exodus began, associated with the beginning of industrialization. Still, in 1860, 57 % of inhabitants lived in rural areas in Spain (this figure was 34.4 % in 1960, and only 15.6 % in 2011) (Goerlich et al., 2015). Furthermore, in 1900, the livelihood of 71.6 % of the Spanish population was still associated with agricultural and livestock practices (Goerlich et al., 2015). In 1865, there were more sheep in Spain than people, representing the maximum livestock census in the history of the country (Valle, 2011; currently, sheep and goats only represent 67 % of the 1865 livestock census; MAPA, 2020). Under this scenario, in a country dominated by extensive livestock practices based on small livestock, where livestock protection from wolf attacks was widely implemented and regulated (e.g., guarding, livestock guarding dogs, enclosures, *The Mesta*), and immersed in a deep crisis in the livestock sector, a remarkable knowledge of rural people about wolves and their presence/absence can be assumed (e.g., the majority of people in rural areas accurately identify a wolf based on color pictures, e.g., Mohammadi et al., 2021). Furthermore, the bounty system running at that time required a good knowledge on wolves (i.e., to receive a bounty, the body of every wolf had to be presented at the town halls, in order to be confirmed and receive the reward, which excluded the possibility of rewarding feral or stray dogs; Rico and Torrente, 2000). These facts additionally support the reliability of the data collected in the geographical dictionary edited by Pascual Madoz.

Wolves are highly capable of persisting in multiple types of landscapes (e.g., Mech and Boitani, 2003; Sazatornil et al., 2016). We believe there are multiple, but non-mutually exclusive explanations for why wolves were rarer in the past than previously proposed (Valverde, 1971). The combined action of large-scale shifts in land uses (extensive livestock vs. agricultural practices), wild prey scarcity (Munilla, 2017), and the deliberate removal of wolf refuge areas in order to facilitate persecution. This activity was widespread in Spain to facilitate wolf persecution, at least since the eighteenth century (Martínez-Marina, 1792–1805; Plantada i Fonolleda, 1903). All these factors may contribute to explain the observed fragmented range in the past. However, some of these factors are difficult to quantify spatially in all the historical periods considered, and therefore, they are difficult to test. On the contrary, accurate historical information is available to support the idea of a systematic and intense wolf persecution before the mid-nineteenth century. From 1829, a new model of intensive poisoning campaigns was promoted across Spanish municipalities (Anonymous, 1829). Explicit references were made to generalize the use of poisoned baits to eradicate wolves and other species considered as vermin at that time, establishing an obligation to buy poison, and explaining in detail how to set the poisoned baits properly. This was particularly the case for the new and imported vomit nut (i.e., poison nut, strychnine) as a "*safe, inexpensive and easy poison to use, mainly in the mountains, for the extinction of wolves and foxes*" (Ortiz de Zúñiga and De Herrera, 1832). These developments occurred at around the same time that the information used in the dictionary edited by Pascual Madoz was collected. Therefore, it is expected that after nearly a decade of promoting the systematic eradication of wolves, the species suffered important declines, fragmentation, and even local extinctions across the Spanish landscape, particularly in the most accessible and open areas. In fact, our estimates of the wolf range for 1846–1850 extensively overlap with the most remote and inaccessible mountainous areas of Spain, places where this species is relegated to after intense persecution (Chapron et al., 2014; López-Bao et al., 2017). It has been estimated that around the mid-nineteenth century this practice led to the death of 2000 to 3000 wolves annually (Rico and Torrente, 2000). Similarly, a government report from 1861 (Ministerio de Fomento, 1861) highlighted a generalized reduction of wolves in many Spanish provinces. Out of the 33 provinces covered, a dramatic decline or rarefaction of wolves was reported for 52 % of them.

From this point onwards, wolves continued to be persecuted legally, with an intensification of poisoning campaigns around the mid-twentieth century, under the creation of the Provincial Boards of Extinction of Harmful Animals and Protection of Hunting by the Royal Decree of August 11, 1953 (operating in some areas since 1944, up to 1968; Paulos, 2000). These provincial boards were heterogeneously implemented across Spain, with the boards from central-western Spain (e.g., Cáceres, Badajoz, Salamanca, Toledo, Ciudad Real or Córdoba) receiving the largest grants from the Spanish National River Fishing and Hunting Service to support their activities (Corbelle-Rico and Rico-Boquete, 2008). This fact, together with the main dominating landscape and land uses in this area, may explain the contrasting differences observed in the wolf range here between 1956–1961 and 2012–2020. The main dominating landscape here is the "*dehesa*", which is savannah-like (Parsons, 1962; Campos Palacín, 1992), and may facilitate wolf persecution (i.e., an open area with few wolf refuge) and is appropriate for letting livestock graze unattended (Blanco and Cortés, 2009). Previous authors have suggested that the *dehesas* in western Spain probably will delay or prevent the southward expansion of individuals (Blanco and Cortés, 2009). The southward expansion of wolves has been blocked in the *dehesas* of Salamanca province (Blanco and Cortés, 2009). On the other hand, there was a remarkable increment in the game hunting business and associated intensive game ranching, in central Spain and the Sierra Morena area during the 1970s, with an ensuing increase in the number of large fenced game areas (Alvarado-Corrales, 1991; Martínez-Garrido, 1991; López-Bao et al., 2015). This may have led to a resurgence of wolf persecution because of perceived competition for game species and other economic losses associated with this model of hunting business (Blanco et al., 1990, 1992; López-Bao et al., 2015).

From a conservation point of view, the wolf in Spain would not meet the conditions required to be included on the Spanish List of Threatened Species (BOE-A-2017-2977) as a *Vulnerable* species. Based on variations in the wolf range over time, it also would not meet the sub-criterion B.1 "*A reduction in the occupancy area ≥25% in the last 30 years*", since we have witnessed a recovery process in the last decades (e.g., Blanco and Cortés, 2002, 2009; Chapron et al., 2014; López-Bao et al., 2018b). There are also few reasons to anticipate such a decline in the next 20 years (sub-criterion B.2; *an expected reduction ≥ 25 % in the next 20 years, or three generations*). The species does not meet the first part of the sub-criterion B.3. In the worst case scenarios, the wolf range would have

been reduced compared to historic times by 19.3 % to 31.2 % (Table 3). Under the same sub-criterion, however, another listing criteria is included, and considers that: *being a species immersed in a recovery process, it has not recovered ≥ 50 % of its historic range*. Numerous examples illustrate how conservation norms do not escape from interpretative uncertainties (Epstein et al., 2016; Trouwborst et al., 2017; Trouwborst and Fleurke, 2019; Epstein et al., 2019). In this regard, we believe that the sub-criterion B.3 is also sensitive to multiple subjective interpretations. On the one hand, we could assume that the term *historic range* is not a spatially-explicit term; that is, what is important is the total area occupied by a species in the country as a whole, regardless of the geographical areas occupied (biogeographical regions are not taken into account in this case, as in the case of FCS; Epstein et al., 2016). Under this possibility, if we consider the wolf range estimations either in 1846–1850 or 1956–1961 (regardless of the approach used: 108,242 km^2–230,464 km^2; Table 2; Appendix B) as the baselines for the historic wolf range in Spain, for the estimated range of wolves at present (2012–2020) to meet the criterion of a recovery of <50 % of the historic range, they should be between 54,121 km^2 and 115,232 km^2. However, the estimated ranges for wolves in recent times exceed these thresholds (Table 2). On the other hand, we could assume that the term *historic range* is a spatially-explicit term. According to the Oxford Dictionary of Environment and Conservation (Allaby and Park, 2013), historic range is defined as "*the natural range or geographical areas that a particular species was known or believed to occupy in the past*". The fact that "geographical area" is included in the definition supports the spatially-explicit character of the term. Legal terms are often spatially-explicit (e.g., Member States have an individual obligation to promote FCS of those populations within or partially within their borders, as well as in each of its biogeographical regions; Epstein et al., 2016). Following this direction, wolves would meet this criterion in 4 out of 6 scenarios evaluated (see Appendix B for details on non spatially-explicit and spatially-explicit range calculations).

The objective analysis of historical information is useful to set conservation baselines for wolves in Spain and, in turn, to inform its legal status. The strength of our comparison is remarkable because we applied the same criteria and methodology to three different time periods over the last two centuries, minimizing potential interpretative biases. Whether recovering ≥50 % of the *historic range* is satisfied based on the interpretation of a non-explicit total area occupied by wolves, or that is necessary for the species to have recovered ≥50 % of the geographical areas that it was known to occupy in the past, deserves further clarification. Our study draws attention to the different conservation outcomes based on interpretative uncertainties in conservation norms, using as an illustrative case the current debate on the most appropriate conservation status for wolves in Spain, which may require clarification from the Scientific Committee advising the Spanish Government, with consequences not only for wolves, but for other taxa.

CRediT authorship contribution statement

Both authors contributed equally to this paper.

Declaration of competing interest

There is not competing interests to declare in relation to the manuscript.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2022.109639.

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