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Where wolves were: setting historical baselines for wolf recovery in Spain

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Abstract

Reference conditions are necessary to assess the conservation status of species, understand their declines, and manage their recovery. Historical documents offer large amounts of records of a wide variety of species, which may be used to generate reference baselines on the historical distribution range of species. We collected information on the Iberian wolf *Canis lupus signatus* presence or assumed absence for 6734 localities in Spain from the geographical dictionary edited by Pascual Madoz in the mid-19th century. We used probabilistic distribution models to estimate the wolf historical range with unprecedented detail, allowing the quantification of the historical reduction in occupancy area. Wolf records were widely distributed in mid-19th century Spain, being present in all its mainland provinces. The probability of occurrence was positively associated with landscape roughness and negatively with human population density and the landscape suitability for agriculture. The area estimated to be occupied by wolves ranged between 212 200 and 317 600 km^2, depending on the approach used to set cut-off values from the predictions. Our estimations represented an average range reduction of 68% between the mid-19th century and present time, resulting in the current restriction of the species to the country's north-western quadrant. The putative recent recovery of the wolf in Spain consists mainly of the accumulation of wolf records in areas where the species had persisted and the recolonization of some peripheral areas, but there is no indication of widespread recovery of the historical distribution range. We show that the compilation of historical species records allows producing baseline range scenarios with much higher resolution than usually available to inform species status and set recovery targets, an approach that can be implemented in other areas and taxa.

Introduction

Human activities have driven the decline in a myriad of species worldwide (Dirzo *et al*., 2014). The decline process involves widespread local extinctions and range contractions, to the point that many species persist nowadays within miniature representations of their historical distributions (Morrison *et al*., 2007; Yackulic, Sanderson, & Uriarte, 2011). Setting up species recovery targets requires an understanding of the magnitude of these contractions, including the natural and anthropogenic factors that drive them (Sanderson, 2019). However, the characterization of historical distributions is often elusive due to the scarcity of data from the past. Most often, historical ranges are depicted roughly following expert criterion approaches that allow for little spatial precision (e.g. Morrison *et al*., 2007; Lucas, González-Suárez, & Revilla, 2016), thus limiting the precise characterization of species declines. When available, historical species records can be used to produce a data-driven estimation of past species ranges and their environmental constraints to design better informed conservation plans (Kang *et al*., 2010; Rodrigues *et al*., 2019). Historical records are often abundant for wild species perceived either as useful, such as hunting, fishing and logging targets, or harmful, including plagues and predators (Clavero & Revilla, 2014), thus allowing for robust reconstructions of their past distribution ranges.

Large mammalian carnivores, with which humans often have a conflictive relationship (Treves & Karanth, 2003), are among the animal groups for which adequate historical distribution data may be available (e.g. Kang *et al*., 2010; Monsarrat & Kerley, 2018). Most large mammalian carnivore species have experienced widespread declines, due to the combined effects of direct persecution, depletion of prey populations and the intensification of human land use (Ripple *et al*., 2014; Wolf & Ripple, 2017). The wolf *Canis lupus* (Linnaeus, 1758) is a paradigmatic example of this process. Although the species is still distributed throughout the Holarctic, it has experienced widespread range contractions (Mech & Boitani, 2003). In Western Europe, the direct persecution of the species has been long lasting and intense, leading to a generalized decline and its extirpation in several countries since at least the 16th century (Dufresnes *et al*., 2018). The wolf is currently a conservation priority for the European Union under the Habitats Directive 92/43/EEC and is a focal species of the European Commission '*LIFE*' funds for biodiversity conservation (Hermoso *et al*., 2017). The recovery of the wolf would not only improve its conservation status but could also restore its important ecological roles (Ripple & Beschta, 2012). In the European context, wolf recovery would introduce a natural control to wild ungulate populations, which often reach high densities that result in overgrazing of natural vegetation (Borkowski *et al*., 2019) and conflicting interactions with humans (Carpio, Apollonio, & Acevedo, 2021). However, the lack of reference conditions about the historical wolf distribution precludes accurate evaluations of the favourableness of its conservation status (e.g. Trouwborst, Boitani, & Linnell, 2017) and hinders the planning and implementation of effective conservation actions (e.g. Grilo *et al*., 2018).

The Iberian wolf subspecies *Canis lupus signatus* historically declined in range to reach a minimum distribution range during the second half of the 20th century (Petrucci-Fonseca, 1990; Rico & Torrente, 2000). In Portugal, wolf decline is still ongoing (Torres & Fonseca, 2016), while in Spain the species seems to have remained in rather a stable state since the 1980s, both in terms of the number of packs and range extent (Ordiz, Canestrari, & Echegaray, 2022). Here, we use wildlife records from the mid-19th century to estimate the historical area of wolf occupancy in Spain as a baseline to assess the conservation status of the species. Our approach generates a data-driven, model-based range baseline that allows describing long-term spatial patterns in wolf decline and setting informed recovery targets. We illustrate how historical data collections can be used in conjunction with distribution models to effectively establish geographic baselines for evaluating the severity of species declines and for planning actions aiding the wildlife comeback.

Materials and methods

Historical wolf data

The geographical dictionary edited by Pascual Madoz (1846–1850; henceforth, 'the Madoz') is a vast work of 16 volumes and more than 11 000 pages, structured in articles that systematically provide geographical, historical and statistical descriptions of virtually all population centres, rivers, mountains and other topographical elements in Spain (Clavero & Revilla, 2014; Clavero & Villero, 2014). Pascual Madoz was a politician and military man who developed a strong interest in statistics (understood in a descriptive sense) during and exile period in France (1830–1832). Once back in Spain, he translated a French work on Spanish statistics (Moreau de Jonnès, 1835) and realized that collecting data to produce an accurate description of the Spanish territory would need a large collective effort. Thus, he developed a data collection initiative analogous to contemporary citizen science projects, since it involved the coordination of thousands of local informants and dozens of regional correspondents (Clavero *et al*., 2017).

Natural resources were among the main focusses of the Madoz, and information on them was often collected and provided in the dictionary. The Madoz describes population nuclei through articles with fixed sections, one of which, termed productions (*producciones*), often provides information on wildlife (mainly useful and harmful terrestrial species and fisheries), together with descriptions of crops and livestock (Clavero & Villero, 2014). Additional information on wild fauna is also provided throughout the Madoz in a less systematic way in articles describing mountain systems, rivers and other geographical features.

We compiled all references to the wolf included in the Madoz. The information on wolf presences should not be directly added up to the wolf distribution due to different spatial biases. For example, since each village is described in a Madoz article, the probability of obtaining a wolf record is higher in areas with a higher density of population nuclei. Also, there are differences in the frequency with which local informants and regional correspondents collected and reported species data for the geographical descriptions.

These biases can be overcome by collecting information on species absences to model the probability of occurrence and derive an imputed distribution range from these predictions. Explicit historical references to wolf absences are rare in the Madoz. Therefore, we selected pseudo-absences based on the information provided for other wildlife species assuming that wolf was likely absent in areas where other wildlife species were reported but not a wolf (see Clavero & Hermoso, 2015, for an equivalent assumption involving the European eel, *Anguilla anguilla*). This is a reasonable approximation to characterizing the realized distribution of the wolf in our study period since the species was, and still is, a socioeconomically relevant species (Boitani, 1995), and therefore it was very likely to be reported when its presence was known. However, it is also likely that wolves might have not been reported where the species or its damages to livestock were rare, which might lead to an underestimation of wolf presence. Wildlife records used to generate wolf pseudo-absences were obtained from the first 11 volumes of the Madoz. Generating pseudo-absences from the information contained in the Madoz guarantees that spatial biases would be similar to those affecting wolf presences, thus being similar to a weighted selection of background points in the modelling of presence-only data (Elith, Kearney, & Phillips, 2010).

Wolf records and pseudo-absences in the Madoz were geolocated to the centre of the corresponding village or landscape feature, using Google Earth. Geolocation was done manually because 19th place names often do not fully coincide with present-day ones, introducing uncertainty in automatic place matches. The Madoz provides information on the municipality in which each village was included and on the distances to neighbouring villages. This information was consulted when there were difficulties in locating a place, due to name changes, village disappearances (e.g. now submerged in reservoirs) or other reasons. Records associated with large administrative units (e.g. provinces and judicial districts) were excluded from our analyses. Records were finally translated to a 10 km grid covering continental Spain (ETRS89 Lambert Azimuthal Equal Area projection), assigning wolf presences to cells containing at least one georeferenced wolf record and pseudo-absences to cells containing other wild fauna records.

Environmental variables

To model the historical distribution of the wolf, we used a set of six variables grouped in three blocks characterizing: (1) topography; (2) suitability for agriculture; and (3) human population (Supporting Information, Table S1).

The topography variables included mean elevation and elevation range (maximum minus minimum elevation) of each 10 km cell, calculated from the 1-km-resolution Elevation Map of Europe (https://www.eea.europa.eu/data-and-maps/data/digital-elevation-model-of-europe).

Land suitability for agriculture included two variables (climatic suitability and soil suitability) calculated following a modification and a calibration in the Iberian Peninsula of the global agriculture suitability model proposed by Ramankutty *et al*. (2002). This model estimates the probability of agriculture as the product between the climatic suitability, determined by the number of degree days per year and the annual ratio of actual-to-potential evapotranspiration, and the soil suitability as defined by the carbon density and pH at the topsoil respectively. The climatic and soil suitability layers used in this study integrate, at 1-km resolution, global climate and soil–water balance surfaces and European-scale soil pH and carbon data (Fernández et al. in prep.). See Supporting Information, Box S1 for further information.

The human population variables included the population density in 1857, in individuals per km^2 (log_{10} transformed) and the number of population nuclei per cell. The variables were calculated after digitizing the Spanish National Population Census for the year 1857 at the municipality level and from the Spanish Nomenclator, both of them provided by the Spanish National Institute of Statistics (available at http://www.ine.es).

Model-based estimation of historical wolf distribution

We estimated the probability of historical wolf occurrence across Spain by fitting binomial generalized linear models (GLMs) with bootstrap resampling. The nature of our dataset, which does not include multiple visits to each locality, precludes the use of the site–occupancy modelling approach, as recommended for citizen science opportunistic observations (Kery *et al*., 2010) and historical data (Tingley & Beissinger, 2009). We fitted a GLM after standardizing all environmental predictors and using the complete sample of wolf presences and a sub-sample of pseudo-absences to explore the relative magnitude and the precision of the model coefficient estimates. The subsample of pseudo-absences was randomly selected to match the number of wolf presences, in order to achieve a balanced dataset (e.g. Salas-Eljatib *et al*., 2018). We then calculated a bootstrapping distribution for the occurrence probability in each cell and the accuracy of the predictions, as follows: (1) in each bootstrap iteration, we selected a random subset with two-third of the data for fitting a new GLM model and one-third for estimating the extrapolated predictions of the model; (2) in order to transform the model probabilities into predicted wolf distribution, we defined three different probability cut-offs and classified the probabilities into the predicted occurrence and non-occurrences for each cut-off; and (3) after 1000 iterations, we calculated the bootstrapped mean probabilities and standard deviations and we counted the number of iterations that each cell was classified as a wolf presence or absence for each cut-off. The cut-offs reflect different assumptions about the capacity of the models to accurately classify wolf presences and absences respectively. The first cut-off (hereafter conservative classification) corresponded to a probability value that maximized both sensitivity and specificity. However, since we had more confidence in wolf records than in the species omission in our dataset, we defined cut-offs rewarding for the correct classification of presences with sensitivity values = 0.7 and 0.8, hereafter intermediate and inclusive classifications respectively. Overall, this approach allowed us to estimate three different predicted distribution ranges according to varying criteria for maximizing the model sensitivity at the cost of reducing specificity while simultaneously accounting for the uncertainty of fitting models to different data sub-samples. We estimated GLMs using the R Statistical Software v.4.2 (R Core Team, 2020). We transformed GLMs results into range estimates through different cut-offs and calculated associated accuracy estimates with the R-Package OptimalCutpoints (López-Ratón *et al*., 2014).

Mapping historical change in wolf distribution

We described changes in the extent of wolf distribution in Spain since the mid-19th century by comparing the size and spatial configuration of wolf baseline range estimations derived from our model-based historical distribution estimations and the present species range. The present distribution was based on the data of the Spanish Terrestrial Species Inventory (available at https://www.miteco.gob.es/es/biodiversidad/temas/inventarios-nacionales/inventario-especies-terrestres/default.aspx), which uses a 10 km UTM grid. We converted information provided in UTM cells to our 10 km European standard grid by assigning the presences to the cells of the European grid that contained the centroids of the cells with the presence of the UTM grid. It results from the accumulation of wolf records since 1980 (Palomo, Gisbert, & Blanco, 2007), updated only by adding new records but without deleting any. As a result, the present distribution includes areas where the species may be no longer present and can thus produce an overestimation of the wolf range. We introduced the uncertainty in the Spanish present-day wolf range by considering three approaches (inclusive, intermediate and conservative, to follow the same classification used for the historical range). The inclusive range estimation included all wolf records provided by the Spanish Terrestrial Species Inventory. The intermediate estimation deleted wolf records from Sierra Morena, from where the species is likely extinct (e.g. López-Bao *et al.*, 2018), and from the Spanish Pyrenees, where the presence of individuals has not yet produced the establishment of packs. The conservative estimation considered that the species was present only in those cells in which the presence of wolf packs was confirmed in the 2012–2014 Spanish Wolf Census (MITECO, 2016), as mapped by Sáenz de Buruaga (2018).

We compared the area of the wolf range estimated through the inclusive, intermediate and conservative approaches in the historical (i.e. mid-19th century) and present situations, resulting in nine pair-wise comparisons. Thereby, we obtained a picture of the general long-term trend in the wolf range in Spain during the last 170 years, while introducing the uncertainties associated with range size estimates.

Finally, we used the wolf distribution map for 1970 produced by the Spanish government to contextualize range changes between the mid-19th century and the present-day situations. The 1970 distribution map was part of an initiative to map all game species in Spain (termed game maps, *mapas cinegéticos*) (SNPFC, 1968). We digitized the wolf's *mapa cinegético* and superposed on it the 10 km grid, marking as presence cells those with at least 25% of the area included within the distribution polygon.

Results

The wolf in 19th century Spain

Our final dataset comprised 6784 localities with information on wildlife, of which 1506 cited the wolf and 5227 did not (raw data provided as Supporting Information). The aggregation of this dataset in 10 km cells resulted in 2609 cells (around 60% of the mainland Spanish territory) with wildlife records, of which 929 (34.3%) had wolf records and were thus considered presence cells. Wolf records were widely distributed across mainland Spain in the mid-19th century, covering all its provinces (Fig. 1).

The GLM showed that the probability of wolf presence was higher in cells with a broader elevation range, with low suitability for agriculture of soils and with low human population density (Table 1). Elevation had a relatively small negative effect on the probability of wolf presence, and the influence of both the number of population nuclei and climatic suitability for agriculture was non-significant. The average AUC of the selected model, based on the 1000 randomized model runs, was 0.66 (±0.013 SD). The combined effects of topographic and anthropogenic factors on 19th-century wolf distribution coincide with the patterns reported based on contemporary data (e.g. Grilo *et al.*, 2018).

The projection of the selected model across mainland Spain showed relevant spatial variations in the probability of wolf presence, with the highest predicted values being recorded in mountain areas and across south-western Spain. The results suggest that by the mid-19th, the species was already rare or absent from several areas of mainland Spain, namely, the Mediterranean coast, the central areas of the two plateaus, the highly populated areas near Madrid and the two main river valleys (Ebro and Guadalquivir) (Fig. 2a). The predicted area of wolf occurrence varied widely in relation to the approach used to identify cut-offs to discern between estimated presences and absences, ranging between 212 200 and 317 600 km^2 (Table 2). This area was smaller when the cut-off selection aimed at maximizing simultaneously sensitivity and specificity. Fixing higher sensitivity values resulted in larger areas of occurrence, at the expense of specificity.

Characterizing wolf decline

The estimated Spanish present-day range of the wolf ranges from 28 900 to 109 700 km^2, after the inclusive and the conservative approach respectively. The intermediate estimation yielded a range of 103 300 km^2 (Fig. 2c). The nine possible comparisons among the historical and present-day wolf range estimations resulted in spatial declines ranging between 48% and 91%, with the average figure being 68%.

The present-day wolf range is concentrated in the north-western quadrant of Spain. There are recent wolf records in the eastern Pyrenees, apparently originating from the wolf population in the French Maritime Alps (Louvrier *et al.*, 2018), albeit neither packs nor reproduction has been confirmed yet. In any case, the large wolf decline recorded in Spain since the mid-19th results from the extinction of the species from all its presence areas except for the Iberian north-western quadrant. Some of these local extinction events have occurred recently, since 1970, when the area wolf presence arguably reached its minimum extent (estimated at 83 400 km^2; Fig. 2b). The larger wolf range in the present-day situation compared to the 1970 situation (a 23.8% increase, relative to the intermediate present-day range estimation) has occurred due to a denser occupation of the north-western quadrant of the country and in spite of local extinctions registered elsewhere.

Discussion

Setting recovery baselines

Species conservation and recovery should set clear targets, ideally evaluable by means of specific indicators. Historical baselines can be used as reference conditions to both identify conservation targets and develop associated indicators (Clavero & Hermoso, 2015). For many species and in many contexts, historical information allows identifying relevant

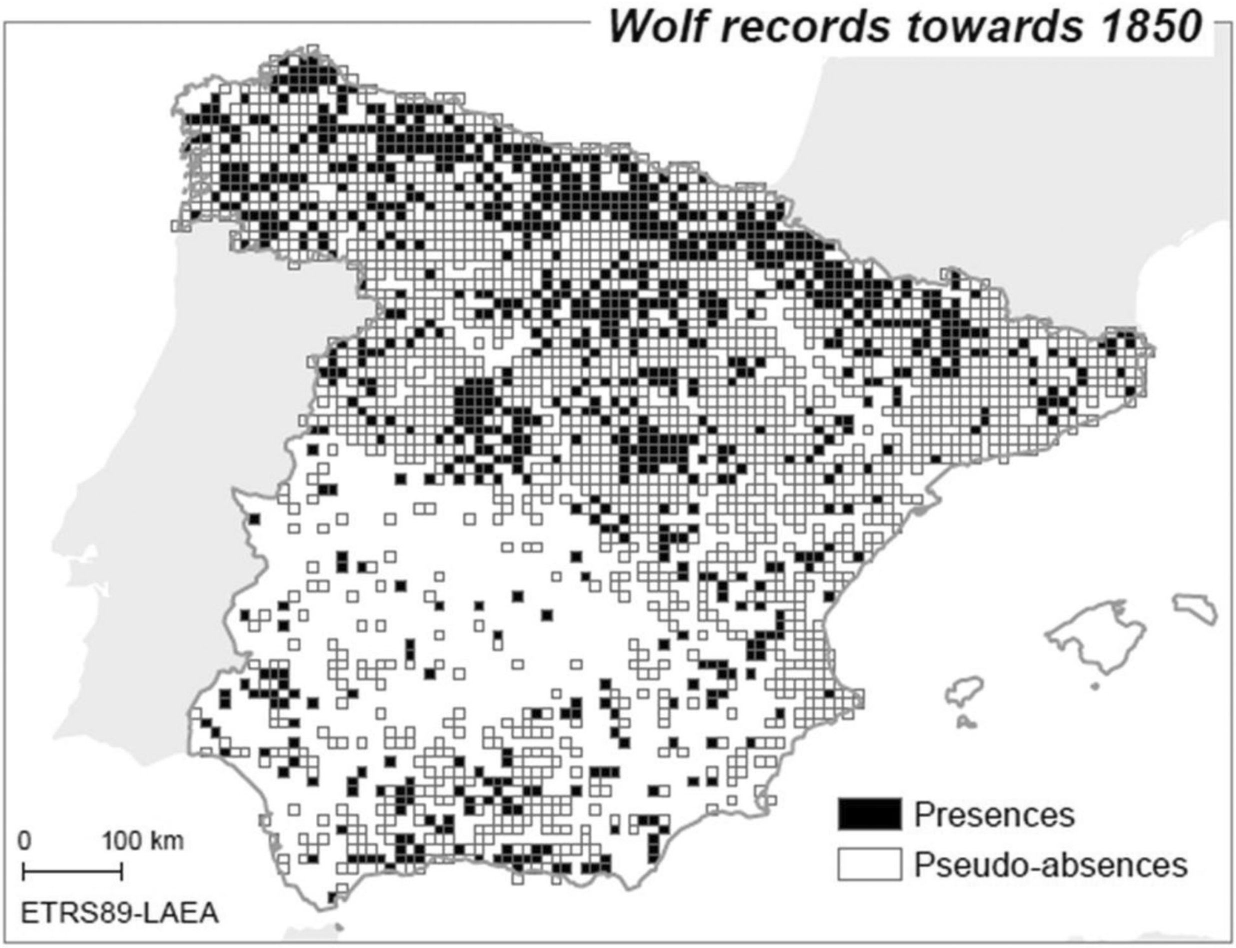

Figure 1 Distribution of the 929 10×10 km cells with reported wolf presence in the mid-19th century Spain and of the 1680 cells used as wolf absences (areas where there was information on the presence of terrestrial fauna, but no mentions of wolves).

Table 1 Results of the generalized linear model explaining the historical wolf occurrence in Spain

Block/variable	Coefficient estimate	SE	z-value	P
Intercept	0.006	0.048	0.126	0.90
Topography				
Elevation	−0.198	−0.082	−2.41	0.02
Elevation range	0.319	0.057	5.55	>0.0001
Human population				
Population density	−0.331	0.067	−4.92	>0.0001
Population nuclei	0.062	−0.065	0.96	0.34
Crop suitability				
Soil suitability	−0.359	0.063	−5.69	>0.0001
Climate suitability	−0.093	0.077	−1.21	0.23

historical baselines for aspects such as distribution, abundance, population age structure or intensity of human exploitation (McClenachan, Ferretti, & Baum, 2012). Disregarding the available historical information when setting baselines may involve identifying degraded ecosystem states as desirable and setting downgraded conservation targets, a process known as the shifting baseline syndrome (Baum & Myers, 2004). In the case of the wolf in the Iberian Peninsula, the risk of setting a shifted baseline is clear if the current situation is defined in terms of expansion since the 1970s, instead of as a decline since the 19th century.

Choosing a specific historical period to define range baselines is a tricky issue (Alagona, Sandlos, & Wiersma, 2012), which has been recently debated in the scientific literature (Grace et al., 2019; Sanderson, 2019). Humans have caused extinctions for millennia (McGlone, 2012), but the temporal sequence of these extinctions has varied greatly among continents and regions (Turvey, 2009; Bartlett et al., 2016). This general spatiotemporal variability is superimposed on the taxon-specific responses to human activities, which may drive the decline in several species while favouring others (Mason et al., 2021). Different taxa can also be sensitive to different human impacts and new environmental conditions, onset at different historical periods (hunter-gatherer societies, Neolithic innovations, industrial development, agricultural intensification and modern infrastructures), further complicating the scenario (Polaina, González-Suárez, & Revilla, 2019). On top of these difficulties, the availability of data to describe historical ranges

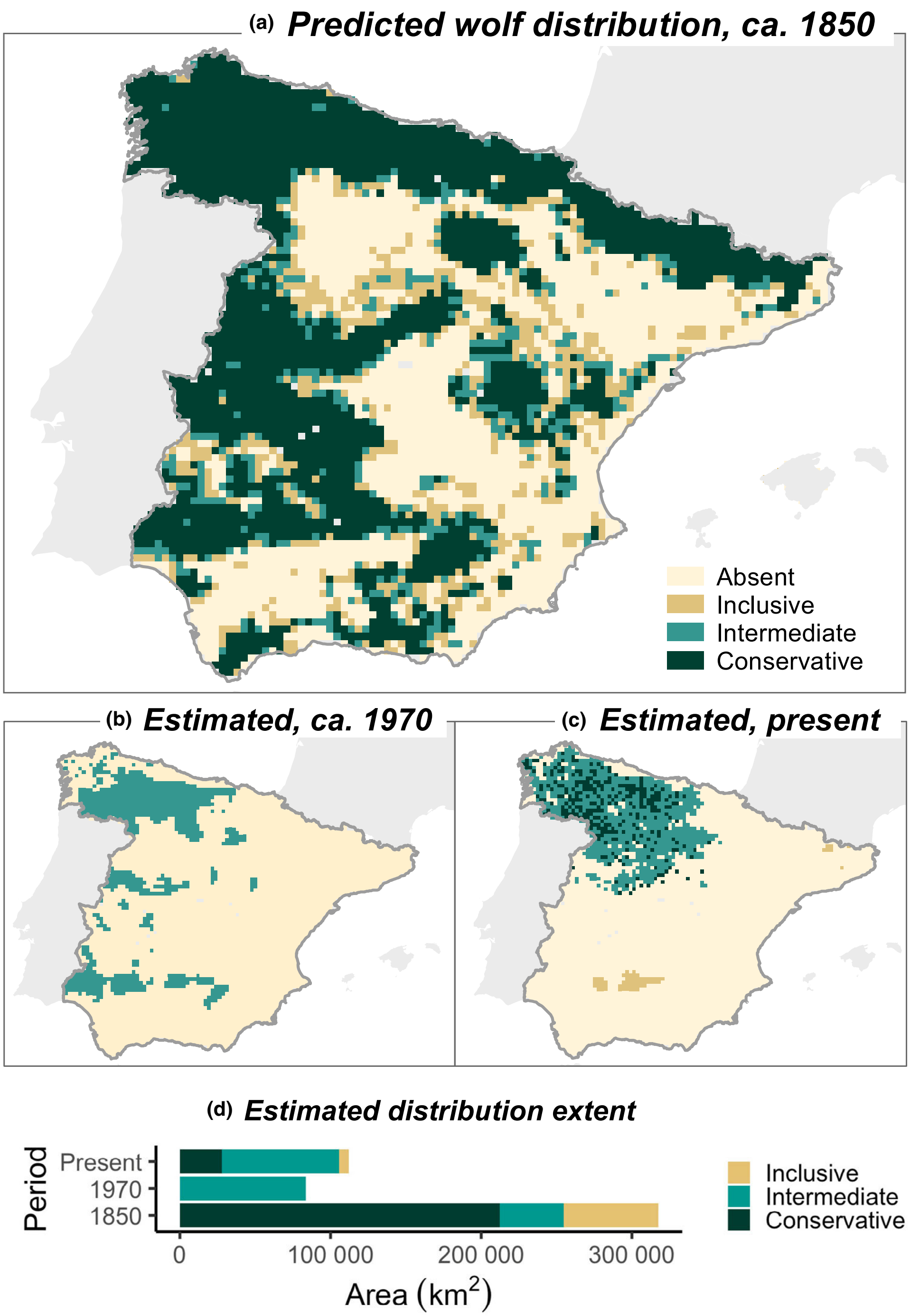

Figure 2 Evolution of the wolf range in Spain. (a) Estimated areas of wolf occurrence in the mid-19th century, generated by transforming the continuous prediction resulting from the model shown in Table 1 to a presence/absence dichotomous variable through three different methods of cut-off values selection (reported as inclusive, intermediate and conservative in Table 2). (b) Wolf range in 1970, after the map reported by the Spanish wildlife administration (SNPFC, 1968). (c) Present-day range, estimated following three approaches: inclusive (considering all available wolf records); intermediate (excluding records from Sierra Morena and the Pyrenees) and conservative (considering only areas where wolf packs have been detected). (d) Variation in the estimated area of wolf occurrence among study periods and methodological approaches.

Table 2 Area of wolf occurrence estimated through three different approaches to select cut-off points from the model probability of occurrence estimates, and sensitivity and specificity figures resulting from them. Shown figures are mean values (±SD) from 1000 model runs, randomly selecting two-third of the data for model fitting and one-third for model evaluation in each one of them

	Cut-off selection approach		
Metric	Conservative Sensitivity = specificity	Intermediate Sensitivity ≥0.7	Inclusive Sensitivity ≥0.8
Area of occurrence ($\times 10^3$ km^2)	212.2 (±5.0)	254.9 (±6.6)	317.6.7 (±6.0)
Sensitivity	0.628 (±0.011)	0.702 (±0.002)	0.802 (±0.002)
Specificity	0.628 (±0.011)	0.544 (±0.0278)	0.402 (±0.026)

imposes further restrictions on the election of a historical period to establish relevant conservation and recovery baselines (e.g. Boakes *et al.*, 2010). Thus, although the election of fixed baseline periods, either globally (Akçakaya *et al.*, 2018) or regionally (Sanderson, 2019), would make the measurement of historical range recovery more comparable across systems and species (Grace *et al.*, 2019), we argue that this baseline period should be taxon, region and information specific. The selected period would be chosen to maximize the quality and quantity of the available information on the status of populations, their trends and the drivers of these changes.

The mid-19th century is a reasonable period to set recovery baselines for the wolf in Spain for two main reasons. First, the 19th century is generally recognized as the onset of the strong recent decline of the wolf in the Iberian Peninsula (Petrucci-Fonseca, 1990; Blanco, Reig, & de la Cuesta, 1992). In the mid-19th century, the wolf was still widely distributed in Spain, after a millenary coexistence with agro-pastoral societies (García-Puchol & Salazar-García, 2017). Setting recovery baselines back to periods when humans were not a major driver of wolf distribution, as suggested by Sanderson (2019), might not provide applicable management tools. In that period the species was arguably present across the whole Iberian Peninsula, but the relationships of this ubiquitous occupancy with landscape features (e.g. regarding variability in human population density) are obscure, precluding the development of spatially explicit baselines. We agree that setting recovery baselines based on pre-major impacts situations or the whole Holocene (Sanderson, 2019; Monsarrat & Svenning, 2022) may be adequate at the global scale, but this approach may be inapplicable at more precise spatial scales.

Second, the Madoz dictionary provides the best available data to describe recent historical wolf distribution. Several historical documents describe the population, productive and environmental features of Spain or parts of it since the 14th century and many of them include records of the wolf and many other species (e.g. Clavero & Villero, 2014; Burgoyne, 2019). Of them, the Madoz is not only the most complete (both in terms of spatial coverage and data availability) but also the most recent piece of this heritage of historical sources. Comparable data sources do not exist until contemporary records, starting in the last quarter of the 20th century. The Madoz has been shown to be a robust source to set baselines for species declining due to recent habitat loss (Clavero & Hermoso, 2015) or global warming (Clavero *et al.*, 2017). However, it might not be an appropriate source to identify recovery targets for species such as the Eurasian lynx *Lynx lynx* (Clavero & Delibes, 2013) or the brown bear *Ursus arctos* (Revilla *et al.*, 2019), which by the mid-19th had already declined heavily, or several wild ungulates, which are much more widespread currently than in that period (Gortazar *et al.*, 2000).

Using baselines for wolf recovery

Our results show that the current range of the wolf in Spain is clearly smaller than what it was in recent historical periods. The contemporary presence of the species is concentrated in the country's north-western quadrant, outside which wolves have almost completely disappeared since the mid-19th century (Fig. 2). The historical distribution imputed after modelling the wolf records of the Madoz allows for setting recovery baselines, in terms of range extension, of spatial configuration of the range or both.

The Spanish legislation contemplates the use of historical baselines to include species in the National Catalogue of Threatened Species (NCTS). Specifically, one of the criteria established to categorize a species as vulnerable in the NCTS is that it has lost at least half of its historical range, which is defined as the one 'known in the beginning of the 20th century' (BOE, 2017). Describing wolf distribution at the beginning of the 20th century would involve having detailed distribution maps or modelling abundant and reliable fine-scale presence data from that period. However, we do not know of such data for Spain, albeit it is available for Portugal (Petrucci-Fonseca, 1990). The rigidity of the period established as a historical reference in the legal framework, set as unique for all species of conservation concern in Spain, hinders its adaptability to a complex reality with the many species-level specificities mentioned above (Oficialdegui *et al.*, 2020). If, as we suggest here, the mid-19th century is used to set the historical baseline, the present range would be around 30% of the historical one, being in 8 of 9 possible comparisons below the 50% threshold. There are reasons to think that the mid-19th-century scenario described here would not differ much from the early 20th-century situation. It is arguable that wolf decline accelerated due to the use of wildlife poisoning, onset by the end of the 19th century and became a widespread practice during the 20th century (Márquez-Cañas, 2015). Cabrera (1914) considered that wolves occupied most of Spain, except the Mediterranean coast, by the beginning of the 20th century and the species seemed to be still widely distributed by the mid-20th century (de Prada, 1947). These data suggest that its decline would have been sharpest during the decades of 1950s and 1960s (Valverde, 1971), when intense poisoning campaigns promoted by the administration also drove the precipitous declines in four vulture species in Spain (Donázar, 1993).

Setting a given conservation or protection status of the wolf in relation to the loss in range area is the simplest use of the historical baseline range provided here. But the historical baseline scenarios also allow for identifying more complex recovery goals and strategies. For example, range recovery could be measured not only in terms of total range area but also in terms of recovery of the configuration of the original range. The range of the wolf seems to have increased in the last decades within the Spanish north-western quadrant, a pattern that could be related to a denser spatial occupation or from the accumulation of wolf records, since a single wolf observation would render a cell as positive. This second possibility is supported by the stability in the number of wolf packs estimated by national wolf censuses since the 1980s. In any case, recent changes in wolf occupancy have not involved the recovery of several presence areas lost since the 19th century, and even since the 1970 situation. Indeed, the species range in Portugal, which shares the Iberian wolf population with Spain, has also contracted to the northern half of the country, having lost all the range in the south along the 20th century (Petrucci-Fonseca, 1990; Torres & Fonseca, 2016). More complete recovery targets would involve the reoccupation of at least part of those areas where the wolf had gone extinct (Diserens *et al*., 2017). Progress towards this target could be measured by using indicators derived from the historical distribution maps, such as the percentage of the original range recovered at smaller administrative units than that of the country (i.e. for Spain, autonomous regions or provinces). The range recovery targets derived from the historical baselines should be complemented with conservation planning methods to prioritize more suitable habitats (Grilo *et al*., 2018), more efficient management strategies (Rondinini & Boitani, 2007) and explicitly include human–environment relationships to anticipate and modulate conservation conflicts (Ban *et al*., 2013).

A hypothetical future recovery of the wolf historical range has the potential of conflicting with current livestock breeding practices in areas where the memory of the coexistence with wolves has been lost (Kuijper *et al*., 2019). The assimilation of the absence of large predators as the normal situation is a form of shifting baseline syndrome, which may hinder the recovery of the wolf and its crucial ecological functions (Soga & Gaston, 2018). The sustainable production of food needs to address the potential for social conflict in areas where large predators are recovering, involve local communities in the design of adaptation strategies (Hansen *et al*., 2022) and address the many-sided difficulties faced by European rural populations (Pettersson *et al*., 2021).

Conclusions

We demonstrate here how the mining and analysis of historical information can produce robust baselines to evaluate the conservation status of the wolf, which in Spain is clearly unfavourable. The present area of wolf occurrence is much smaller than it was in the mid-19th century and is concentrated in a small portion of the country. The historical baseline range provided here can be used to plan the recovery of the species in terms of the spatial configuration of the area of occurrence. Similar approaches could be developed for different areas and/or different species, taking advantage of the rich documentary heritage existing in several areas of the world (Turvey, Crees, & Di Fonzo, 2015; Viana *et al*., 2022). In regions and/or time frames for which written sources are not available, informative baselines for species or natural systems can also be generated from other sources, such as archaeological data (McKechnie *et al*., 2014; Reeder-Myers *et al*., 2022), historical maps (Kitazawa *et al*., 2022), pictorial sources (from rock art to photographs; Drake *et al*., 2011; Depauw *et al*., 2022) or from natural archives (e.g. palynological series; Szabó *et al*., 2017). Historical baselines, described at scales ranging from regional to global, can and should become one of the available guidance tools for the development of conservation targets for the recovery of wildlife.

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Authors' contributions

MC, AF and ER conceived the idea and designed the methodology. MC and AGR collected the data. NF analysed the data. MC and NF led the writing. All authors contributed critically to the drafts and gave final approval for publication.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Environmental variables and their calculation.

Appendix S2. Raw wolf presence-absence data, as extracted from the Madoz dictionary.