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Different criteria for implementing sanitary regulations leads to disparate outcomes for scavenger conservation

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Abstract

1. Integrating environmental concerns into sectorial policies is a priority for sustainable development. Despite environmental policy integration being established in Europe in 1998, major weaknesses still limit its effectiveness, such as poor coordination at national and subnational levels.
2. We use the integration of scavenger conservation into sanitary European regulations to illustrate how the adoption of different criteria when implementing the same legislation affects the effectiveness of the environmental policy integration process. We focus on the implementation across Spanish autonomous regions of Regulation EU 142/2011 allowing dead livestock to be left *in situ* for feeding scavengers. Using Asturias (NW Spain) as a case study, we provide spatially-explicit estimates of two key factors guiding the implementation of the legislation, the estimates of scavenger feeding requirements and the area designated as scavenger feeding zones, based on different criteria used across Spanish regions.
3. We detected a remarkable variation in both scavenger feeding requirements (up to 452%; ranging from 108 to 596 t/year) and scavenger feeding zones (up to 72% in size) depending on the implementation criteria used.
4. The concentration of scavenger feeding requirements per km² within scavenger feeding zones (i.e. carrion demand) varied up to 167%. Similarly, the concentration of carrion supply from livestock within scavenger feeding zones (i.e. carrion availability) changed up to 33%.
5. *Policy implications.* Criteria-dependent disparate outcomes might affect scavenger conservation through food shortages. Our results support the need for systematic evaluations to choose the best criteria for implementing sanitary regulations concerning scavenger conservation. Inter-regional coordination in implementing the agreed criteria emerges as a relevant issue to improve the effectiveness of environmental policy integration for transboundary conservation of European scavengers.

Keywords: human-mediated carrion, environmental policy integration, evidence-based conservation, Natura 2000, large carnivores, Regulation EU 142/2011, sanitary policy, vultures

Introduction

The integration of environmental issues into sectorial policies (i.e. environmental policy integration, EPI) is a cornerstone of sustainable development (Ross & Dovers 2008; Jordan & Lenschow 2010). However, even in regions such as Europe, where EPI was established two decades ago, several pitfalls still jeopardize the effectiveness of this process (Jordan & Lenschow 2010). Limited coordination among different levels of governance is a major weakness (EEA 2005a, b; Ross & Dovers 2008). For example, some countries organize into subnational governments (e.g. regional or state levels) that are responsible for policy formulation, implementation and/or monitoring (e.g. Spain, Germany, USA, Canada). This multi-level fragmentation challenges the effectiveness of EPI implementation as each government has specific administrative cultures, traditions and management trends (EEA 2005b), and environmental objectives may not always be given the highest priority within the government's portfolio (EEA 2005a, b; Ross & Dovers 2008).

Evidence-based approaches – e.g. the systematic comparison of alternatives – (Sutherland et al. 2004) can facilitate EPI coordination; enhancing policy coherence both domestically and abroad (EEA 2005b; Ross & Dovers 2008). The management of livestock carcasses as animal by-products of sanitary concern in Europe provides an illustrative example of the importance of evidence-based EPI. After the outbreak of the Bovine Spongiform Encephalopathy (i.e. BSE or “mad cow disease”) in 1986-1996, the European Union (EU) implemented sanitary legislation that prohibited the abandonment of livestock carcasses in the field without considering their importance for scavengers (Tella 2001). Negative impacts on vulture conservation arose soon after this legislation (e.g. decreasing productivity and population growth, vultures attacking livestock; Mateo-Tomás 2009; Margalida et al. 2010), forcing multiple changes in the regulations (i.e. seven times in ten years; see Appendix S1 in Supporting Information).

The current Regulation (EU) 142/2011 implemented the measures needed to guarantee food supply from livestock to up to 51 vertebrate species (Appendix S1). These species include vultures and other raptors listed in Annex I of the Birds Directive (Directive 2009/147/EC), and species of the order Carnivora listed in Annex II of the Habitats Directive (Council Directive 92/43/EEC). EU Regulation 142/2011 allowed carcasses of extensive livestock to be left uncollected within

geographically defined feeding zones authorised by the competent authorities for feeding scavengers (i.e. scavenger feeding zones, SFZs hereafter; Appendix S2). In order to implement this regulation, competent authorities must also estimate the likely mortality rate of livestock within SFZs and the likely feeding requirements of scavengers (i.e. scavenger feeding requirements, SFRs hereafter).

Although EU Regulation 142/2011 is directly applicable in all Member States (i.e. they do not need to transpose it into domestic laws), some countries such as Spain have developed their own national legislation (i.e. RD 1632/2011). Spain accounts for >90% of the populations of European vultures (BirdLife International 2017), and holds important populations of apex predators in western Europe (e.g. golden eagle *Aquila chrysaetos*, brown bear *Ursus arctos*, wolf *Canis lupus*; Chapron et al. 2014; BirdLife International 2017; Appendix S3). Reflecting its important role for scavenger conservation, Spanish legislation RD 1632/2011 established a general framework for the feeding of scavengers. Since biodiversity conservation in Spain is decentralized and under the jurisdiction of autonomous regions (n = 17), the national legislation (accompanied by science-based guidelines; Spanish Government 2011) tried to enhance the implementation of the EU regulation across the country.

Since 2011, most Spanish autonomous regions (i.e. 13 out of 17 to date) have transposed the European and national legislations to declare SFZs (López-Bao & Margalida 2018). The number of regions already enforcing the regulation covers most of the breeding distribution of the scavengers targeted by the legislation, particularly vultures (Morales-Reyes et al. 2017), leading to increased carrion availability. However, major limitations have been identified in policy implementation (Morales-Reyes et al. 2017). For example, despite coordinated efforts at national level, each autonomous region uses different criteria for designating SFZs (Table 1; Morales-Reyes et al. 2017). In a transboundary context, where the foraging range of scavengers transcend administrative borders (e.g. vultures forage across several autonomous regions and countries; the brown bear population in the Cantabrian Mountains inhabits four autonomous regions, and breeding females range over several regions; Olea & Mateo-Tomás 2014; Principado de Asturias et al. 2016; Morales-Reyes et al. 2017), the coordinated designation of SFZs and estimates of SFRs becomes a critical step to ensure the effectiveness of EPI implementation. Coordination may help to effectively integrate scavenger

conservation concerns (e.g. avoiding food shortages) into sanitary policies (e.g. minimizing risks of disease transmission via carcasses; Spanish Government 2011).

However, despite both SFZs and SFRs being identified as key elements for effective implementation and monitoring of this EPI process (EU Regulation 142/2011; Spanish Government 2011), where further coordination is supported through Spanish legislation (RD 1632/2011), the consequences of using different criteria for designating SFZs or estimating SFRs are still unknown. The lack of a systematic evaluation of the multiple criteria used could severely affect the expected EPI outcomes, thus undermining the effectiveness of this process for scavenger conservation.

Here, we show the extent to which the use of different criteria impact on the implementation of European sanitary regulations concerning scavenger conservation. We use the implementation of EU Regulation 142/2011 across Spanish autonomous regions (Table 1) as an illustrative example. We evaluate how different criteria influence the two key factors used for implementing and monitoring this regulation: i) the estimates of scavenger feeding requirements (SFRs), and ii) the area designated as scavenger feeding zones (SFZs). Focusing on the same autonomous region, (i.e. Asturias, NW Spain; 10,604 km²), we provide spatially explicit estimates of SFRs and SFZs under the different criteria used across autonomous regions (Table 1) and discuss the challenges of implementing this kind of legislation.

Materials and methods

Study area

Asturias is one of the few European regions holding breeding populations of obligate scavengers (i.e. vultures; Mateo-Tomás 2009) and apex predators (i.e. brown bear, wolf; Chapron et al. 2014), which are also facultative scavengers (Mateo-Tomás et al. 2015; Appendix S3). Cattle (*Bos taurus*) breeding – with ~413,000 heads in 2016 (SADEI 2017); of which 72% (~298,000 heads) are reared extensively – dominates livestock practices (see Appendix S3). After the BSE outbreak, thousands of livestock were removed annually and incinerated at authorized plants in Spain (Morales-Reyes et al. 2015). For example, 29,958 livestock were removed in 2015 in Asturias and

30,584 in 2016, resulting in >5,000 tons of carrion removed annually, mostly cattle (i.e. 80% of carcasses; Principado de Asturias 2017).

Study species and carrion consumption estimates

From the 19 species targeted in the EU Regulation 142/2011 and present in the study area (Appendix S1), we considered in our analyses seven frequent scavengers (i.e. griffon, Egyptian and bearded vultures, golden eagle, red *Milvus milvus* and black *M. migrans* kites, and brown bear; hereafter referred as target species; Appendix S4). Wolves in Asturias (i.e. north of the Duero River) are listed in Annex V of the Habitats Directive, so the species is not affected by EU Regulation 142/2011 (targeting only carnivores listed in Habitats Directive Annex II). However, we considered the wolf in our study (i.e. non-target species hereafter) because of its relevant role within the scavenging community (Llaneza & López-Bao 2015; Mateo-Tomás et al. 2015, 2017; see Appendix S4).

Annual estimates of scavenger feeding requirements (SFRs, see below) were calculated following Mateo-Tomás et al. (2017; Appendix S4). Although kites and golden eagles do not feed exclusively on carrion as vultures (obligate scavengers), we assumed all these species to fulfill their daily food intake (i.e. DFI, the quantity of food, in grams, that an individual should ingest daily to keep its basic metabolic functions) consuming carrion exclusively. Carrion consumption rates of brown bears and wolves were adjusted to 3-9.3 and 20% DFI, respectively (Appendix S4).

Criteria selection and design of scenarios

To assess how different criteria influence SFZs and SFRs estimates, we identified the main criteria used by the different Spanish autonomous regions that have transposed EU Regulation 142/2011 or have drafted proposal texts (Table 1; Appendix S5). The number and nature of the criteria varied among regions (i.e. mean and median: three criteria per region, range: 1-9; Table 1). We used these criteria to define six different scenarios for calculating SFRs and SFZs (Fig. 1), together with additional scientific recommendations on the topic (e.g. foraging ranges; Morales-Reyes et al. 2017). To simplify comparisons between scenarios, we estimated annual SFRs (kg) and

SFZs under a benchmark scenario for each (Fig. 1, Appendix S6). These benchmark scenarios were considered more realistic and complete according to the best evidence available (i.e. scavenger abundances, breeding parameters and foraging ranges; Mateo-Tomás et al. 2017; Morales-Reyes et al. 2017).

The estimates of SFRs and the area designated as SFZ under the benchmark scenarios were compared with those obtained from the other five scenarios defined in Fig. 1 (i.e. “basic”, “Natura 2000”, “Natura 2000 + conservation areas”, “non-target species (wolf)” and “nearby species” scenario). See details in Appendix S6.

Carrion demand and availability

EU Regulation 142/2011 requires Member States to estimate the likely mortality rates of livestock within SFZs. These estimations, together with those of SFRs, aim to be a basis for assessment of the potential risks of disease transmission. We therefore estimated the carrion biomass (in tons, t) that extensive livestock practices could supply annually to scavengers within SFZs designated under the different scenarios (Fig. 2; Appendix S3).

EU regulation aims to minimize the adverse effects of carcass concentration (e.g. local increases of generalist predators; Oro et al. 2013) by considering the natural consumption patterns of scavengers. We therefore assessed changes in the spatial concentration of SFRs (kg/km^2) and carrion biomass of livestock (i.e. carrion availability, in t/km^2) dividing the estimated SFRs and livestock carrion biomass by the area designated as SFZs under each considered scenario in a paired way (i.e. SFRs and SFZs “basic” scenarios, and so on; Figs. 1 and 2). From total carrion availability, we subtracted the percentage of carrion consumed by other scavengers not included in our SFR calculations (i.e. non-target species such as corvids or red fox *Vulpes vulpes*; Appendix S4; Mateo-Tomás et al. 2017).

To better approach carrion demand by scavengers, alternative carrion sources other than livestock should be considered when estimating SFRs. Wild ungulates subsidize vertebrate scavengers worldwide, particularly through hunting remains (Mateo-Tomás & Olea 2010; Mateo-Tomás et al. 2015). We used official hunting bags from the Government of Asturias, and previous

works (Mateo-Tomás & Olea 2010; Mateo-Tomás et al. 2017), to refine SFRs estimates calculated under the benchmark scenario by subtracting the estimated biomass resulting from big game hunting in Asturias on a monthly basis (Appendix S7).

Mapping SFRs and SFZs

We mapped SFRs estimates at a spatial extent of 1x1-km grid within SFZs under the different scenarios. Again, SFRs and SFZs scenarios were combined in a paired way (i.e. by rows in Fig. 1). After accounting for carrion consumption by other scavengers not included in our calculations, we obtained the spatial distribution of SFRs estimates relying on livestock carcasses. This was done by subtracting the spatiotemporal distribution of hunting remains from the map of SFRs within SFZs under the benchmark scenario.

Results

Changes in scavenger feeding requirements (SFRs)

Benchmark estimates of SFRs for the seven target species considered were ~238 t/year (Fig. 2). Such estimates were not homogeneously distributed over time, with a maximum peak from April to August (i.e. 22-24 t/month; Fig. 3), overlapping with the breeding season of most target species (Appendix S1).

Heterogeneous criteria led to remarkable variation in SFRs estimates, ranging from 108 to 596 t/year depending on the criteria considered. Setting the benchmark estimates as reference, SFRs decreased by 13% under the “basic” scenario (i.e. ~208 t/year) and by 54% under the “Natura 2000” scenario (Fig. 2). Worth mentioning, in the “non-target species” scenario, the inclusion of wolves increased SFRs estimates by 18% with respect to the benchmark scenario (~281 t/year; Fig. 2). The inclusion of target scavengers from neighboring areas (i.e. “nearby species” scenario) highly increased the estimated SFRs (i.e. up to 161%; Fig. 2). Nevertheless, it is important to note that these estimates are maximum figures, since scavengers breeding in neighboring areas (and within Asturias) may also feed outside the study area.

Changes in scavenger feeding zones (SFZs)

Almost all the study area (i.e. 99%; 10,598 km²) was designated as SFZ under the benchmark scenario (Figs. 2 and 4). The highest feeding requirements concentrated in the south-southeast of Asturias (Fig. 4a).

The benchmark area for SFZ designation decreased by 8% (~847 km²) when considering the breeding area of the target species (i.e. basic MCP scenario; Fig. 2). However, we observed an important reduction of SFZs (72%) when we considered the “Natura 2000” scenario, covering only 27% of Asturias (i.e. 3,016 km²; Figs. 2 and 4a). SFZs designated under the “Natura 2000 + conservation areas” scenario represented the 52% of the benchmark SFZs (i.e. 47% of decrease). The two “Natura 2000”-based scenarios concentrated feeding supplies for scavengers in the southern part of Asturias (Fig. 4a). SFZs estimated under the “non-target” and “nearby species” scenarios exactly overlapped the benchmark SFZs, keeping the maximum feeding requirements in the south and southeast of the study area, while slightly increased the feeding needs in the southwest (Fig. 4a).

The spatial concentration of the estimated annual SFRs within SFZs (i.e. kg/km²) was higher under the “nearby species” and “Natura 2000”-based scenarios, with the lowest concentration occurring under the “basic” scenario (Fig. 2).

Carrion demand and availability

The estimated total carrion biomass available from extensive livestock ranged between 276 and 1,161 t/year depending on the considered scenario (Fig 2). The spatial concentration of these livestock supplies within SFZs (i.e. t/km²) was higher under the “Natura 2000 + conservation areas” scenario, followed by the “basic” scenario (Fig. 2). The lowest concentration of livestock carcasses occurred under the “Natura 2000” scenario.

Although total carrion provided by hunting was estimated as ~164 t/year, considering the temporal asynchrony between SFRs peaks (spring-summer) and carrion supplied by hunting (fall-winter; 9-33 t/month; Fig. 3), hunting remains would cover <40% (96 t/year) of the benchmark SFRs. Therefore, at least 142 t/year (~60%) should be supplied by food sources other than hunting, such as livestock carcasses. As hunting activity concentrated in the center and east of Asturias (Appendix

S7), the spatial mismatch between SFRs and hunting would keep SFRs higher in the south after accounting for hunting supplies (Fig. 4b).

Discussion

Our results show how using different criteria results in marked variation in estimates of the two key factors considered when implementing the European sanitary regulation for feeding scavengers, i.e. SFRs and SFZs. These diverge up to 161 and 72%, respectively, relative to the benchmark scenarios depending on the criteria used. Consequently, the concentration of SFRs per km² (i.e. carrion demand) within SFZs vary from -6 up to >150%. Similarly, the concentration of carrion biomass from livestock within SFZs would also change up to 16%. These differences may be even larger if comparisons are made between the different scenarios considered, rather than the benchmark scenario (e.g. >450% in SFRs; 108-596 t/year; Fig.2).

The wide variation in SFRs and SFZs observed between scenarios calls for systematic evaluations of the criteria used for implementing and monitoring EU Regulation 142/2011 concerning scavenger conservation. Accordingly, further transboundary coordination of agreed criteria is urgently needed. Regarding the different type and number of criteria used by the Spanish autonomous regions (Table 1), noticeable differences are expected among regions concerning the feeding of scavengers. Considering the large foraging ranges of many scavengers (e.g. Spanish vultures forage across 3-14 autonomous regions, and 1-4 European countries; Morales-Reyes et al. 2017), these differences could jeopardize the effectiveness of EU sanitary policies for scavenger conservation not only at regional level, but also at national and supranational scales (Mateo-Tomás et al. 2018).

Taking into account the species breeding parameters, instead of species abundance only, SFRs estimates changed up to 13%. This difference would equal ~50 adult cows/horses or ~400 sheep/goats (i.e. ~30 tons; Appendix S3). The integration of breeding parameters when estimating SFRs would translate into increasing food availability, expected to benefit scavenger conservation (Morales-Reyes et al. 2017). But could also have positive effects on human health and wellbeing through, for example, reducing greenhouse gas emissions due to carcass collection and incineration

and the associated economic costs of hiring this service (Morales-Reyes et al. 2015). Only three of 15 Spanish regions with approved or drafted transpositions of the European legislation explicitly included breeding parameters into their estimates of SFRs (Table 1). Moreover, no explicit recommendation on this issue is included in EU or Spanish regulations, an action that could improve the estimation of SFRs across regions.

The use of the Natura 2000 Network, as the sole criterion for establishing SFZs, could be the most unfavorable scenario for scavenger conservation, as it reduced SFZs by 72% relative to the benchmark scenario. Underestimated SFRs estimates (i.e. 54% lower than those estimated under the benchmark scenario) are also observed under this “Natura 2000” scenario, which could severely mismatch the real demand of carrion by the scavengers of concern. Worth mentioning, two Spanish regions using the Natura 2000 criterion as the only one to designate SFZs, have already amended their legislation in order to enlarge SFZs beyond the Natura 2000 Network (Appendix S5). Furthermore, our results point out that using Natura 2000 Network plus the areas officially designated for conservation or recovery of threatened species has the potential to increase the spatial concentration of carrion demand (i.e. estimated SFRs) and its availability (i.e. livestock carcasses left in the field) within SFZs. This may increase carrion concentration and predictability in space, which is not in line with the objective of European sanitary regulations of considering the natural feeding patterns of scavengers (i.e. through increasing carrion unpredictability; Margalida et al. 2010; Mateo-Tomás et al. 2018).

A more detailed assessment of the potential ecological and socioeconomic consequences of changes in carrion availability is needed. For example, the inclusion of wolves in our calculations increased SFRs by 18% (i.e. ~43 tons, between ~70 and ~600 adult livestock heads depending on the species; Appendix S3). Considering this apex predator in the estimates of SFRs could affect the number of wolf attacks on livestock through, for example, increasing scavenging by the species (López-Bao et al. 2013; Llaneza & López-Bao 2015). Its inclusion could also benefit the conservation of those species targeted by EU Regulation 142/2011 through reducing retaliatory illegal poisoning related to wolf attacks on livestock (Mateo-Tomás et al. 2012). Finally, compensation schemes for large carnivore attacks on livestock could be also reduced if carrion

availability increase (Llaneza & López-Bao 2015). However, only two regions (Castilla y León and Castilla-La Mancha) explicitly mention this species when designating SFZs and only one (Castilla y León) out of the 15 here analyzed (Table 1) considers the wolf even where it is a non-target species (i.e. populations north of river Duero).

Give the divergent outcomes obtained depending on the criteria used to estimate SFRs and SFZs, we recommend policy-makers to revisit the current sanitary regulation to enhance its effectiveness not only in pursuing the objective of scavenger conservation, but also that of preserving public health. We argue that the use of agreed sound criteria to estimate SFRs and SFZs should be set as a priority. The low performance of the only criterion specifically set in both the EU Regulation 142/2011 and the Spanish RD 1632/2011, i.e. to consider Natura 2000 sites, in determining SFRs and SFZs strongly supports our recommendation.

Attention should be paid also to the estimation of SFRs. We acknowledge that our SFRs are not exact figures to stick to for managing carrion, but rather an approximation intended for comparing alternative scenarios under different criteria. Indeed, we estimated carrion availability from domestic and hunted wild ungulates, i.e. the main food sources for medium-large scavengers, but did not consider other carrion sources available, e.g. small carcasses. Accordingly, we suggest to not consider the estimates of SFRs to define, for example, the number of carcasses to be authorized at a concrete area or period. In this regard, Table 2 summarizes some recommendations on the criteria to consider for improving the integration of scavenger conservation concerns into EU sanitary policies. Although transboundary coordination on the criteria used would greatly benefit this EPI process (Mateo-Tomás et al. 2018), the competent authorities should perform cooperative systematic evidence-based evaluations to choose those alternatives that better fulfill the scavengers needs within and across their territories (e.g. Olea & Mateo-Tomás 2014). This would facilitate coordination across regions, by using repeatable criteria, which would enable adaptive management approaches (EEA 2005a, b). Systematic evaluations would allow scavenger conservation to be optimized based on transparent decision-making, which would in turn build trust and enhance engagement among stakeholders (e.g. other decision-makers, conservationists, farmers; Sterling et al. 2017).

Authors' contributions

PMT conceived the idea and did the analyses; PMT and PPO designed the study; PMT, JVLB, PGQ and PP acquired the data; PMT, PPO and JVLB wrote the article.

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Data accessibility

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Table 1. Criteria used for implementing EU Regulation 142/2011 by Spanish autonomous regions (i.e. 15 out of 17). We considered approved regulations (N = 13) and drafts available at official websites (N = 2; Balears and Murcia). We also considered other criteria relevant for scavenger conservation but not explicitly included in the existing regulations (see main text). Note that the same region can use several criteria simultaneously. Only criteria explicitly referred to in the approved/drafted legislation were included. Appendix S5 provides a complete list of regulations.

Criteria	Enforced/recommended by	Autonomous regions (% from total, N = 15)
Scavenger Feeding Requirements (SFRs)		
Abundance estimations of EU 142/2011 target species		All but Andalucía and Canarias (87 %) ^a
Breeding parameters of EU 142/2011 target species		Asturias, Castilla-La Mancha, Castilla y León (20 %)
Abundances and/or breeding parameters of EU 142/2011 non-target species		---
Nearby populations of EU 142/2011 target species outside the autonomous region		---
Scavenger Feeding Zones (SFZs)		
Breeding areas of EU 142/2011 target species	National guidelines ^b	All but Balears ^c , Cataluña and Comunidad Valenciana (80 %)
Foraging areas of EU 142/2011 target species	National guidelines ^b	All but Cataluña and Comunidad Valenciana (87 %)
Breeding and/or foraging areas of EU 142/2011 non-target species		Castilla y León (wolf) and Balears (raven <i>Corvus corax</i>) (13 %)
Natura 2000 protected areas declared because of the presence of scavengers of European conservation concern	National legislation ^d	Aragón, Cantabria, Castilla-La Mancha, Castilla y León, Comunidad Valenciana, Extremadura, La Rioja, Murcia ^c , País Vasco (60 %)
Conservation/recovery areas for scavengers of European conservation concern officially declared by regional governments	National legislation ^d	Aragón, Cantabria, Castilla-La Mancha, Castilla y León, Extremadura, País Vasco (40 %)
Mountain areas ^e	EU ^f and national legislation ^d	Cataluña, La Rioja (13 %)
Municipalities according to livestock rearing types ^e	EU ^f and national legislation ^d	Aragón (7 %)
Public terrains		Cantabria (7 %)

^aOnly considered if explicitly referring to estimate feeding needs for scavenger populations in their regulations; ^bSpanish Government (2011); ^cDrafted regulations; ^dRD 1632/2011; ^eCriteria used as a surrogate for identifying extensive farming and excluding intensive farming; ^fRegulation (EU) 142/2011.

Table 2. Recommendations to improve the effectiveness of EU Regulation 142/2011 regarding scavenger conservation according to the changes observed in our study when considering different criteria for implementation and monitoring (in brackets).

Estimates of scavenger feeding requirements (SFRs)	Designation of scavenger feeding zones (SFZs)
Considering breeding parameters and seasons of target species (e.g. 13% increase in SFRs estimates obtained with species' abundance only)	Considering foraging areas of target scavengers (e.g. 8% increase in SFZs obtained with species' breeding areas only)
Considering additional food supplies other than livestock (e.g. 36% decrease in SFRs after accounting for hunting remains)	Avoiding SFZs designation based only on Natura 2000 and/or conservation/recovery areas for threatened species (e.g. up to 77% decrease in SFZs)
Considering temporal availability of carrion sources (e.g. 49% decrease in SFRs supplied by hunting when considering its temporal distribution)	Systematic evaluation of the spatiotemporal concentration of SFRs within SFZs (e.g. changes in SFRs/SFZs ranging from 11 to >100%)
Transboundary coordination to assess nearby SFRs and carrion availability outside a given region (e.g. 161% increase in SFRs when considering neighboring scavengers in our study)	Transboundary coordination to assess breeding and foraging areas of nearby species
Systematic evaluation of SFRs of non-target species of conservation concern (e.g. 18% increase in SFRs when considering Iberian wolf)	Systematic evaluation of breeding and foraging areas of non-target species of conservation concern
Considering carrion consumption by other species (e.g. 35% decrease in carrion availability when considering facultative generalists, such as red fox, corvids or wild boar)	

Figure 1. Scenarios considered to assess how selecting different criteria (shaded blue and orange columns) could affect the implementation and monitoring of the EU sanitary regulation 142/2011 concerning scavenger conservation. The estimates of scavenger feeding requirements (SFRs) and the extension of scavenger feeding zones (SFZs) were calculated under each scenario as detailed in the far-left and far-right How-to columns, respectively. See breeding season duration in Appendix S1.

Figure 2. Changes (in %) in estimated SFRs (t/year) and SFZs (km²) under the different scenarios considered in this study when compared with the benchmark scenarios (top black bars; see Fig. 1). Spatial concentration of SFRs within SFZs (in kg/km²), annual estimates of biomass from livestock carcasses (t/year) and its spatial concentration within SFZs (t/km²) under each scenario are provided.

Figure 3. Temporal distribution of annual estimates of SFRs for target species (biomass in tons) obtained under the benchmark scenario before (i.e. total; dotted black line) and after (i.e. final; solid black line and dotted red line) accounting for hunting supplies (grey solid line). Hunting accounted for ~35.5% of carrion consumed by other scavengers not considered in our calculations (Appendix S4). Hunting remains could theoretically fulfill the SFRs of target species from September to January (dotted red line), but note that spatial mismatches between SFRs and hunting are not accounted for here (see main text, Fig. 4b and Appendix S7).

Figure 4a. Spatial distribution of SFRs (kg/km²) in Asturias, NW Spain (dark grey in top-left map), under the different scenarios considered in Fig. 1. **b.** Annual SFRs per km² after adjusting the benchmark scenario considering the spatiotemporal distribution of carrion supplied by hunting and the carrion consumed by other scavengers.

Figure 1.

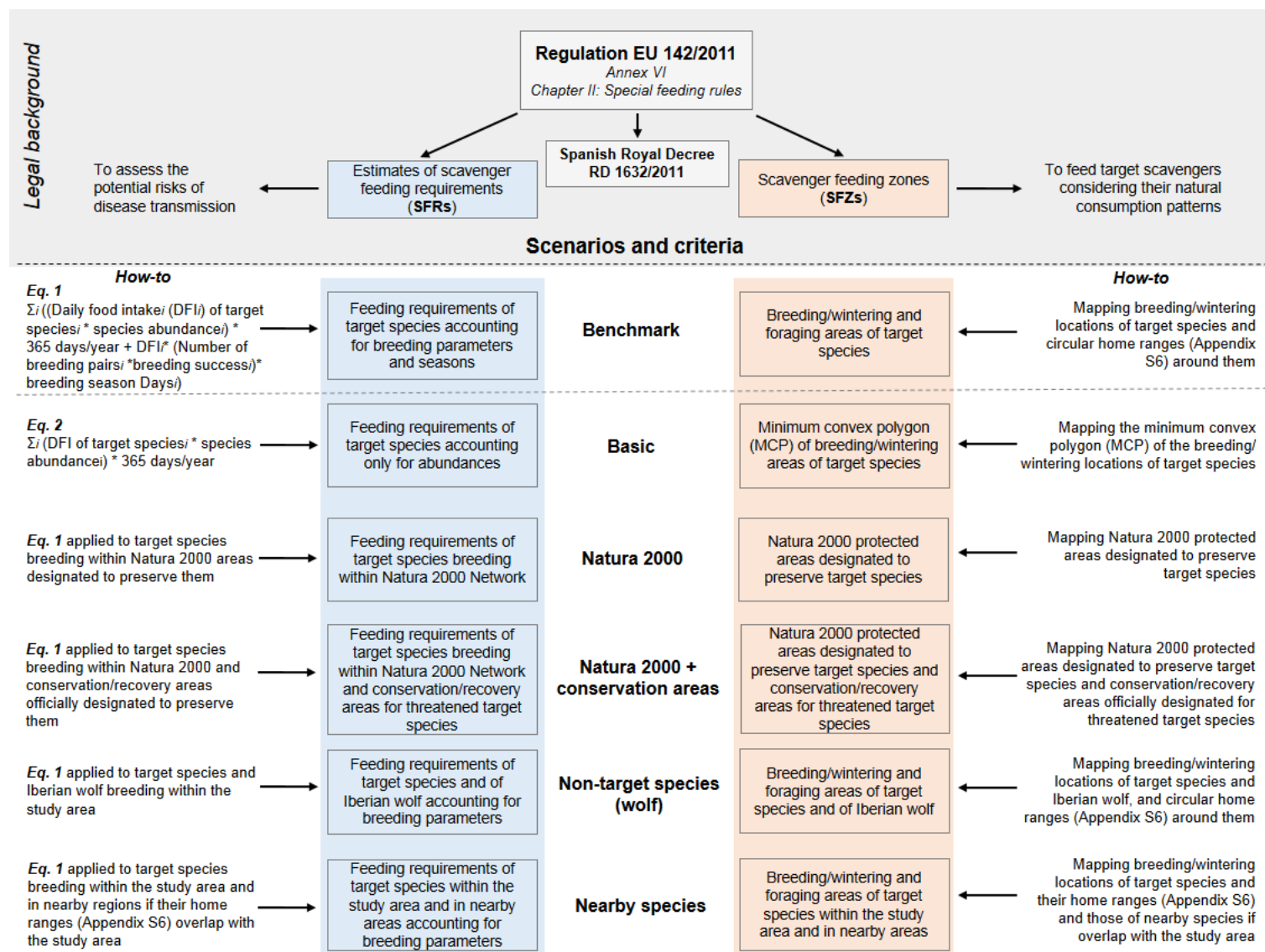


Figure 2.

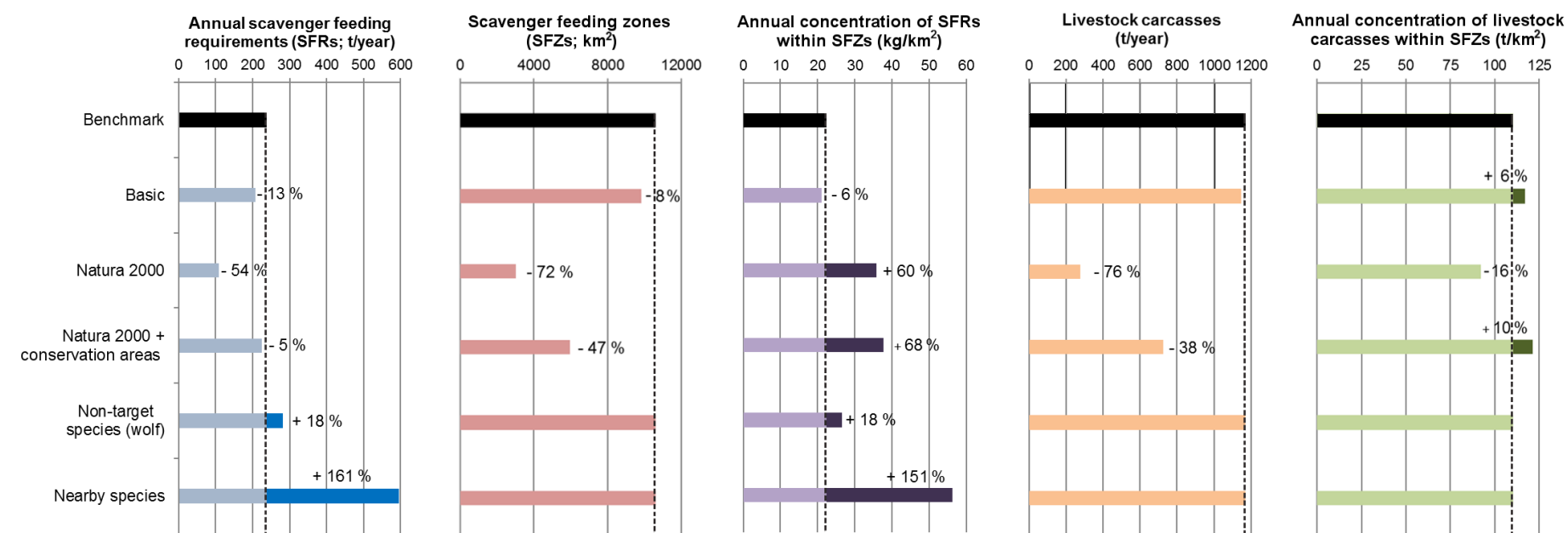


Figure 3.

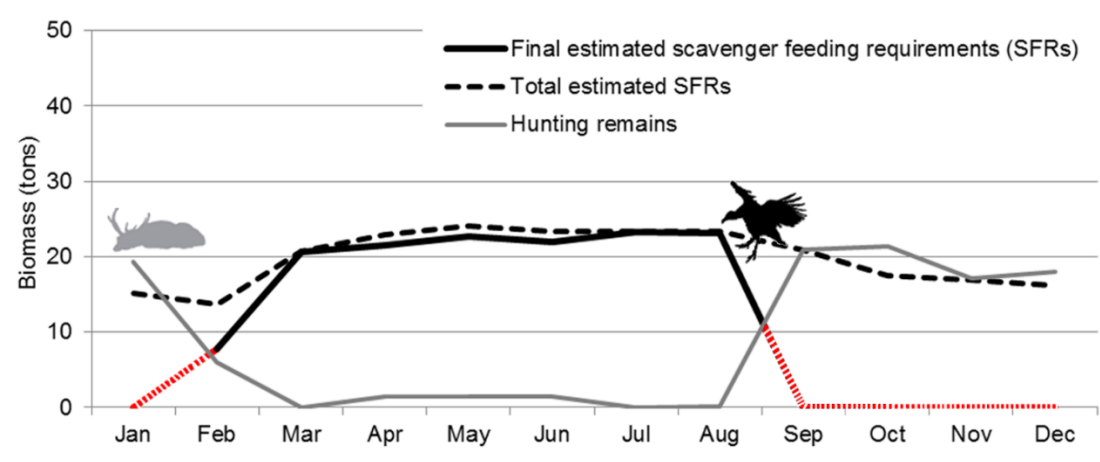
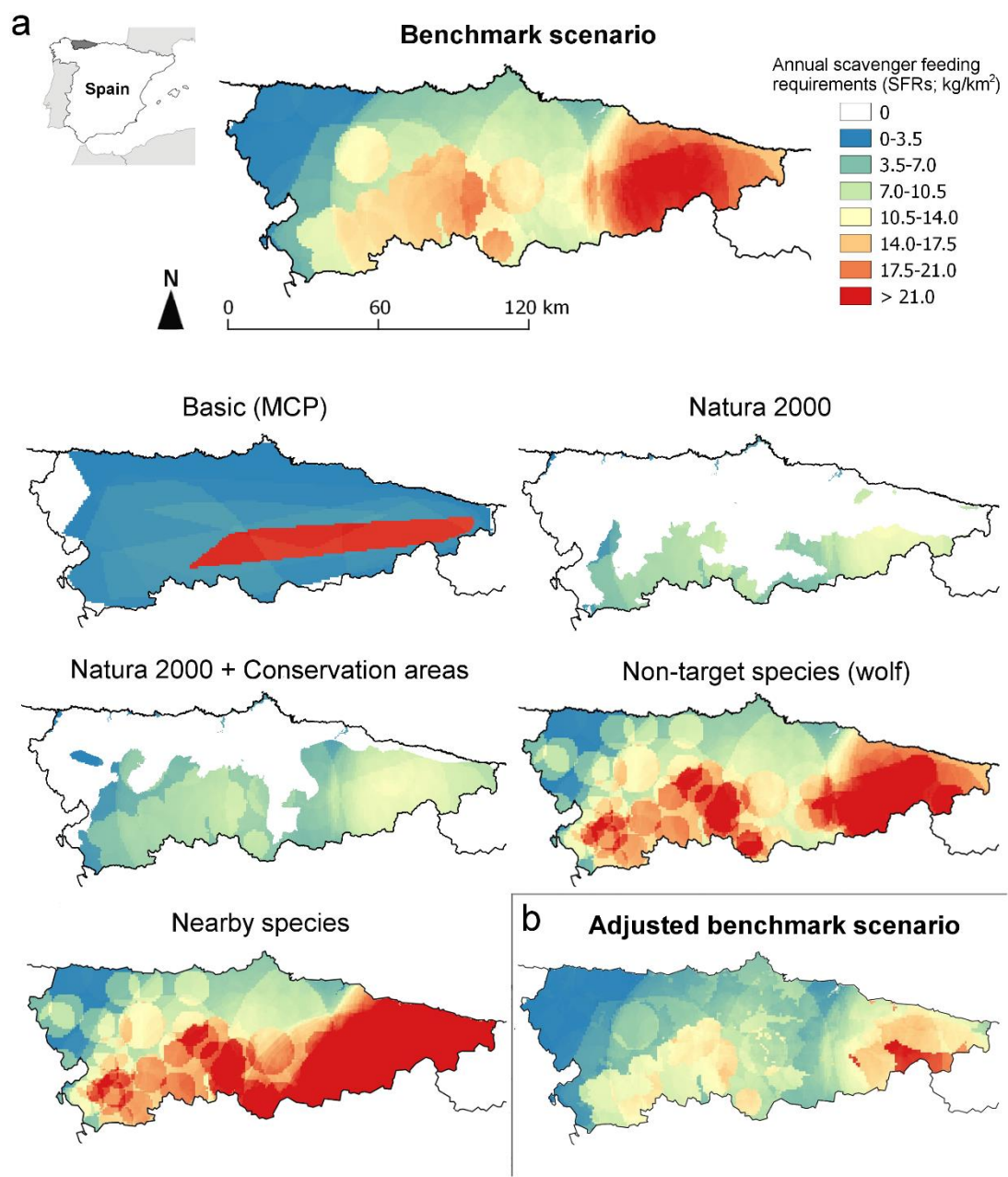


Figure 4.



Supporting Information

Additional information on the EPI process (Appendixes S1-S2), the presence of scavengers and livestock in the study area (Appendix S3), detailed calculations of species abundances and carrion consumption (Appendix S4), sanitary regulations enforced in Spain (Appendix S5), considered criteria and scenarios (Appendix S6) and hunting activity (Appendix S7) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.