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 km^2 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*. 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

Resumen

1. La integración de la protección del medio ambiente y la conservación de la biodiversidad en políticas sectoriales se entiende como fundamental para el desarrollo sostenible. A pesar de que la integración ambiental en política se considera una necesidad en la Unión Europea desde 1998, este proceso presenta importantes carencias que comprometen su efectividad, como la escasa coordinación tanto entre países como entre regiones de un mismo país.
2. Tomando como ejemplo la integración de la conservación de especies carroñeras en las políticas sanitarias europeas, demostramos cómo la adopción de distintos criterios para implementar una misma política compromete los resultados esperados. Analizamos la implementación en las 17 comunidades autónomas españolas de la regulación europea 142/2011 que permite dejar carroñas de ganado *in situ* en el campo para la alimentación de especies carroñeras. Seleccionamos la comunidad autónoma de Asturias (NO España) como caso de estudio, para aplicar los distintos criterios seguidos en cada comunidad autónoma y calcular estimas espacialmente explícitas de los dos factores recomendados para implementar la citada normativa: los requerimientos tróficos de las especies carroñeras y la superficie designada como zonas de alimentación para estas especies.
3. Dependiendo del criterio, detectamos una variación considerable tanto en las estimas de los requerimientos tróficos de las especies carroñeras (hasta del 452 %; desde 108 hasta 596 t/año), como en la superficie designada para su alimentación (hasta del 72 %).
4. La concentración de los requerimientos tróficos de las especies carroñeras por km^2 en las áreas designadas para su alimentación (demanda de carroña) varió hasta un 167 % según los criterios usados. De igual modo, la concentración de la carroña de ganado disponible en las áreas de alimentación designadas (carroña disponible) varió hasta un 33 %.
5. *Implicaciones de gestión*: Nuestros resultados muestran la necesidad de realizar evaluaciones sistemáticas para seleccionar los mejores criterios a la hora de implementar políticas sanitarias que afectan a la conservación de las especies carroñeras. La coordinación transfronteriza en esta materia resulta clave para mejorar la efectividad de este proceso de integración ambiental destinado a la conservación de las especies carroñeras europeas.

Palabras clave: buitres, carroña de origen antrópico, conservación basada en la evidencia, grandes carnívoros, integración ambiental de políticas, Natura 2000, políticas sanitarias, Regulación 142/2011

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 km^2), 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 km^2) 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 km^2) 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 km^2; 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/km^2) 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/km^2) 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 km^2 (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 and approved its publication.

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Data accessibility

Data available via[KL1][KL2]

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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; Baleares 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 Baleares[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 Baleares (raven *Corvus corax*) (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 %)

[a]Only considered if explicitly referring to estimate feeding needs for scavenger populations in their regulations; [b]Spanish Government (2011); [c]Drafted regulations; [d]RD 1632/2011; [e]Criteria used as a surrogate for identifying extensive farming and excluding intensive farming; [f]Regulation (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 (km^2) 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/km^2), annual estimates of biomass from livestock carcasses (t/year) and its spatial concentration within SFZs (t/km^2) 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/km^2) in Asturias, NW Spain (dark grey in top-left map), under the different scenarios considered in Fig. 1. **b.** Annual SFRs per km^2 after adjusting the benchmark scenario considering the spatiotemporal distribution of carrion supplied by hunting and the carrion consumed by other scavengers.

Figure 1.

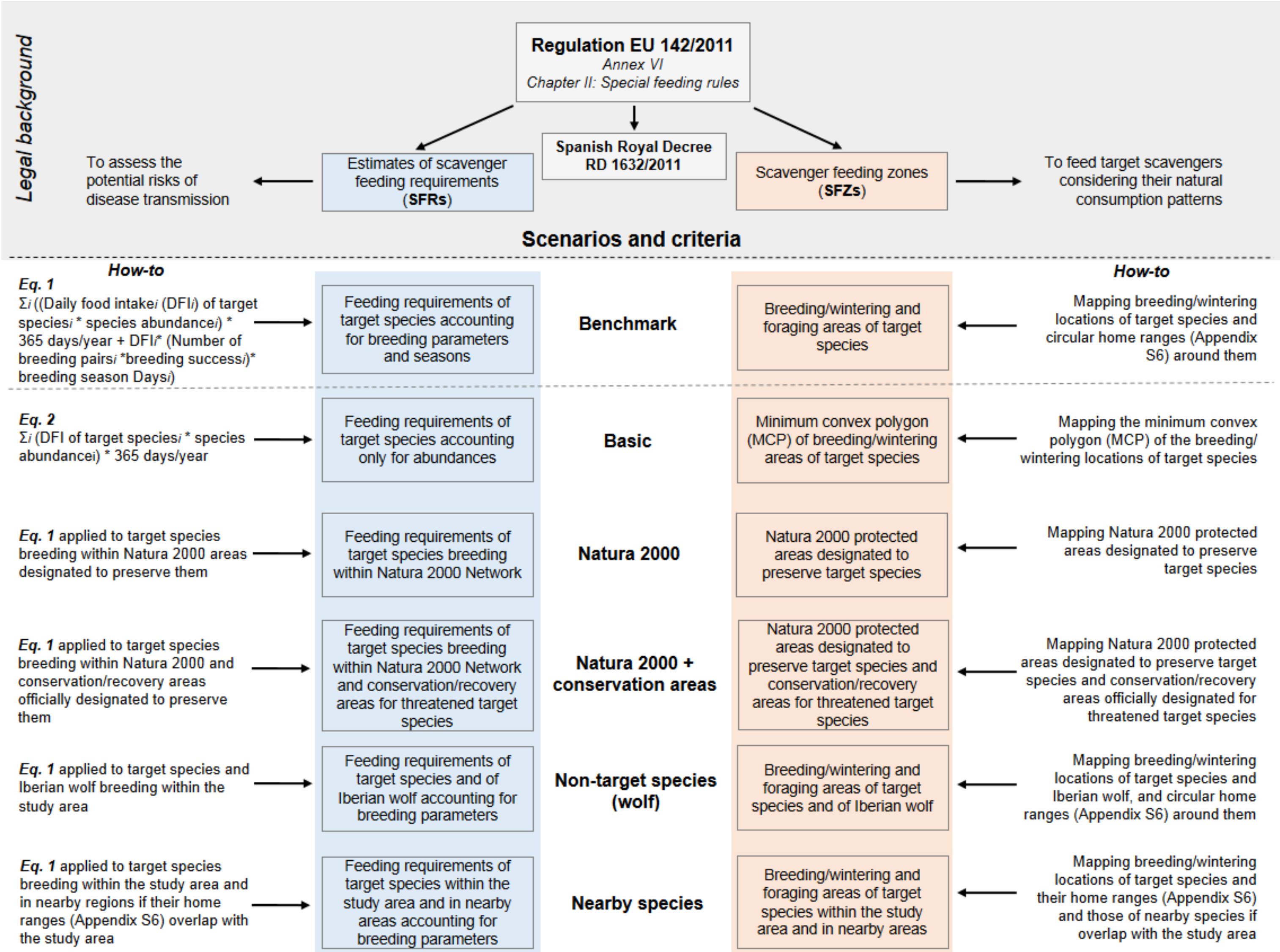

Legal background
Regulation EU 142/2011
Annex VI
Chapter II: Special feeding rules
Spanish Royal Decree RD 1632/2011
Estimates of scavenger feeding requirements (SFRs)
Scavenger feeding zones (SFZs)
To assess the potential risks of disease transmission
To feed target scavengers considering their natural consumption patterns
Scenarios and criteria
How-to
How-to
Eq. 1
Σi ((Daily food intakei (DFIi) of target speciesi * species abundancei) * 365 days/year + DFIi* (Number of breeding pairsi *breeding successi)* breeding season Daysi)
Feeding requirements of target species accounting for breeding parameters and seasons
Benchmark
Breeding/wintering and foraging areas of target species
Mapping breeding/wintering locations of target species and circular home ranges (Appendix S6) around them
Eq. 2
Σi (DFI of target speciesi * species abundancei) * 365 days/year
Feeding requirements of target species accounting only for abundances
Basic
Minimum convex polygon (MCP) of breeding/wintering areas of target species
Mapping the minimum convex polygon (MCP) of the breeding/ wintering locations of target species
Eq. 1 applied to target species breeding within Natura 2000 areas designated to preserve them
Feeding requirements of target species breeding within Natura 2000 Network
Natura 2000
Natura 2000 protected areas designated to preserve target species
Mapping Natura 2000 protected areas designated to preserve target species
Eq. 1 applied to target species breeding within Natura 2000 and conservation/recovery areas officially designated to preserve them
Feeding requirements of target species breeding within Natura 2000 Network and conservation/recovery areas for threatened target species
Natura 2000 + conservation areas
Natura 2000 protected areas designated to preserve target species and conservation/recovery areas for threatened target species
Mapping Natura 2000 protected areas designated to preserve target species and conservation/recovery areas officially designated for threatened target species
Eq. 1 applied to target species and Iberian wolf breeding within the study area
Feeding requirements of target species and of Iberian wolf accounting for breeding parameters
Non-target species (wolf)
Breeding/wintering and foraging areas of target species and of Iberian wolf
Mapping breeding/wintering locations of target species and Iberian wolf, and circular home ranges (Appendix S6) around them
Eq. 1 applied to target species breeding within the study area and in nearby regions if their home ranges (Appendix S6) overlap with the study area
Feeding requirements of target species within the study area and in nearby areas accounting for breeding parameters
Nearby species
Breeding/wintering and foraging areas of target species within the study area and in nearby areas
Mapping breeding/wintering locations of target species and their home ranges (Appendix S6) and those of nearby species if overlap with the study area

Figure 2.

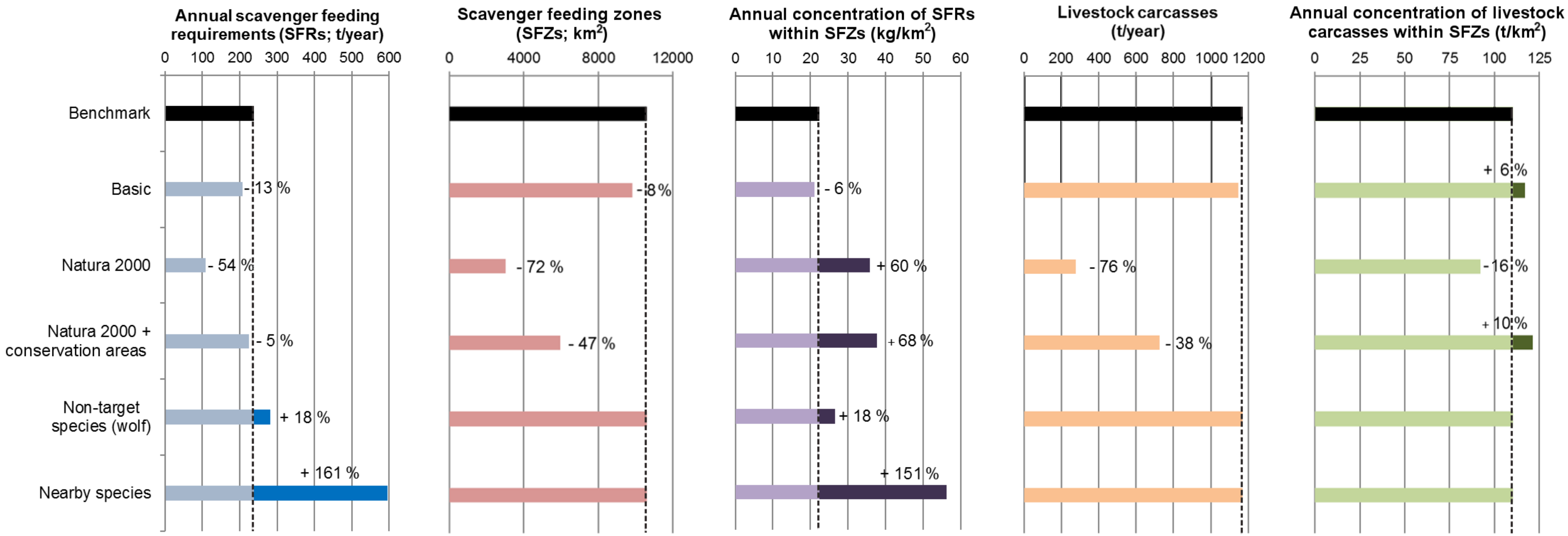

Annual scavenger feeding requirements (SFRs; t/year)
0 100 200 300 400 500 600
Scavenger feeding zones (SFZs; km2)
0 4000 8000 12000
Annual concentration of SFRs within SFZs (kg/km2)
0 10 20 30 40 50 60
Livestock carcasses (t/year)
0 200 400 600 800 1000 1200
Annual concentration of livestock carcasses within SFZs (t/km2)
0 25 50 75 100 125
Benchmark
Basic
Natura 2000
Natura 2000 + conservation areas
Non-target species (wolf)
Nearby species
- 13 %
- 54 %
- 5 %
+ 18 %
+ 161 %
- 8%
- 72 %
- 47 %
- 6 %
+ 60 %
+ 68 %
+ 18 %
+ 151 %
- 76 %
- 38 %
+ 6 %
- 16 %
+ 10 %

Figure 3.

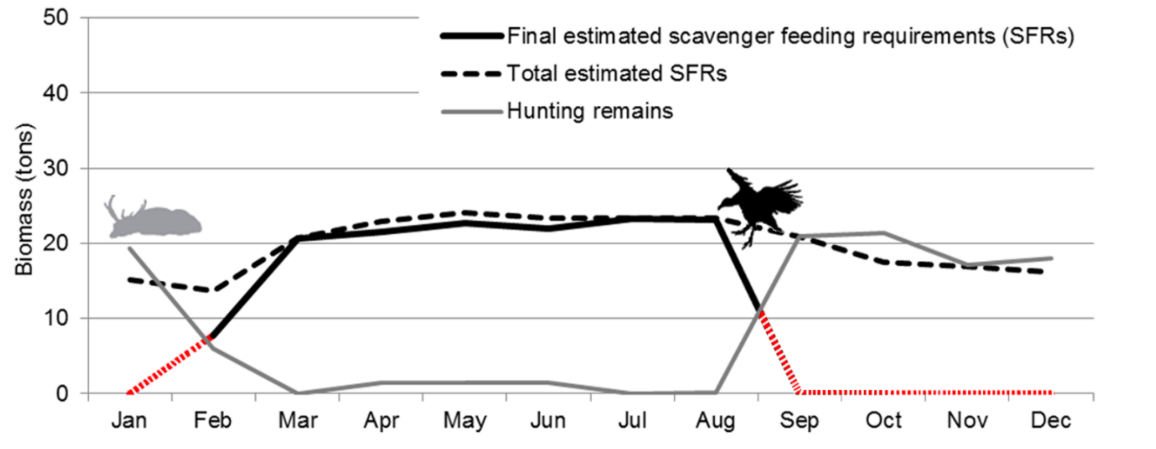
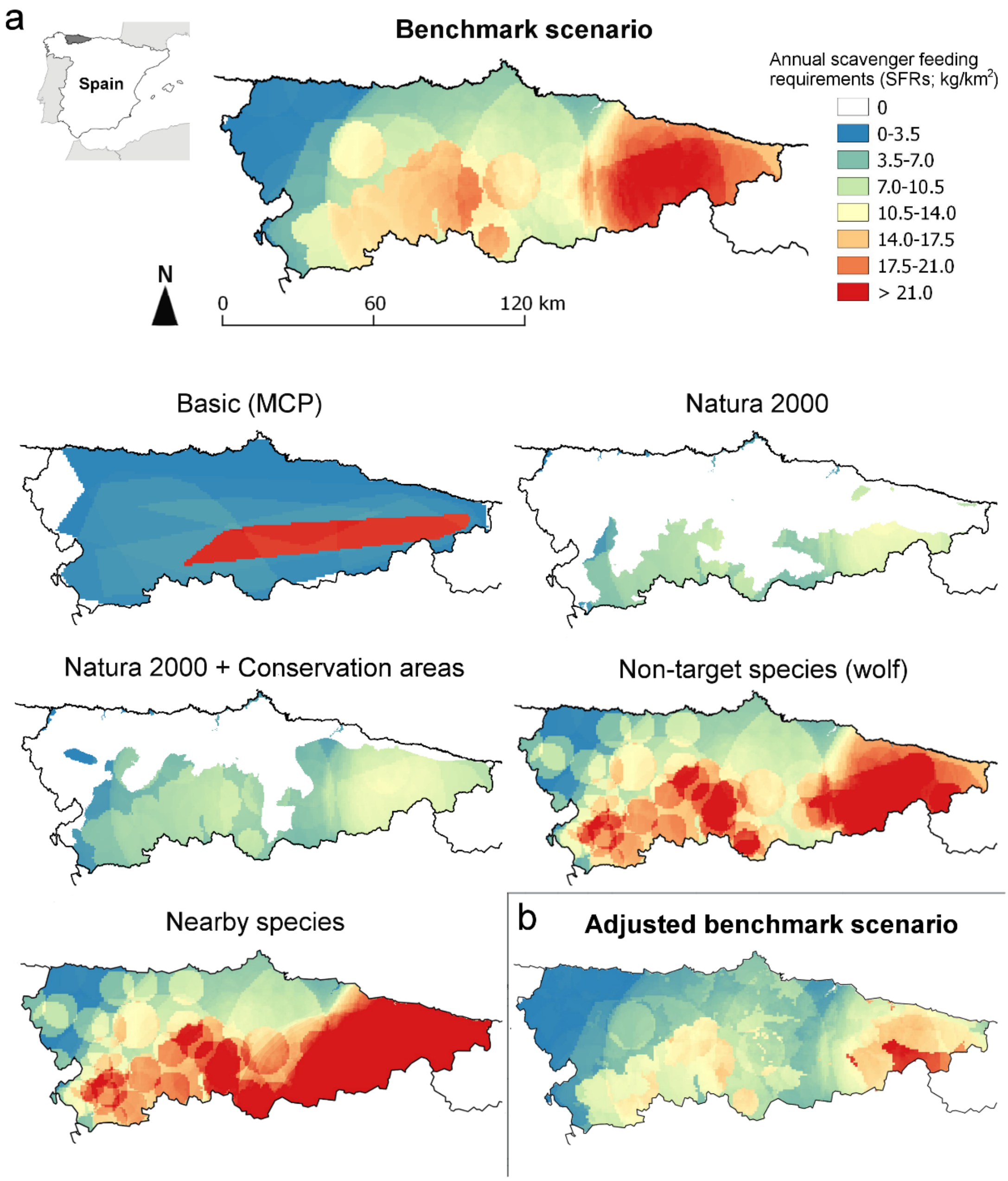

Final estimated scavenger feeding requirements (SFRs)
Total estimated SFRs
Hunting remains
Biomass (tons)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Figure 4.


a
Spain
Benchmark scenario
Annual scavenger feeding requirements (SFRs; kg/km²)
0
0-3.5
3.5-7.0
7.0-10.5
10.5-14.0
14.0-17.5
17.5-21.0
> 21.0
N
0
60
120 km
Basic (MCP)
Natura 2000
Natura 2000 + Conservation areas
Non-target species (wolf)
Nearby species
b
Adjusted benchmark scenario

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.

Appendix S1. Environmental policy integration (EPI) of scavenger conservation into EU sanitary policies

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 Bovine Spongiform Encephalopathy (i.e. BSE or "mad cow disease") in 1986-1996, the European Union (EU) implemented Decision 2000/418/EC that prohibited the abandonment of livestock carcasses in the field to protect animal and human health. Carcasses of bovine, ovine and caprine containing specified risk materials (i.e. those posing a risk for transmitting transmissible spongiform encephalopathies – TSEs –, such as skull, spinal cord or ileum) should be collected and destroyed by incineration. Neither this regulation nor the subsequent legislation developed at national level (e.g. Spanish Royal Decree, RD, 1911/2000) considered environmental issues associated with the importance of livestock carcasses for European scavengers (Tella 2001). Since scavengers (and especially vultures) in the Mediterranean countries have fed on carrion provided from livestock for centuries (Olea & Mateo-Tomás 2009), negative impacts of these sanitary policies on the conservation of vultures across Europe arose soon after the implementation of these legislation (Mateo-Tomás 2009; Margalida et al. 2010). Besides declines in breeding parameters and halts in population growth of some vulture species, unusual behaviours were reported (Mateo-Tomás 2009; Margalida et al. 2010). Increasing reports on vultures attacking livestock were given increasing media coverage, which attracted social and political attention (Margalida et al. 2014).

This context opened a window of opportunity for incorporating scavenger conservation into the EU sanitary policy. Formal and informal procedures developed by national governments, scientists and NGOs (e.g. official petitions to European and national authorities, scientific papers and conservation campaigns; Tella 2001; Donázar et al. 2009; Olea & Mateo-Tomás 2009) forced changes (i.e. up to seven in ten years; Mateo-Tomás 2009; Margalida et al. 2010) concerning the use of animal by-products for feeding scavengers. Initial outcomes (i.e. Regulation EC 1774/2002 and Decision 2003/322/EC) allowed the use of livestock carcasses with specified risk materials (i.e. Category 1 materials) to feed endangered or protected avian scavengers within fenced enclosures (i.e. supplementary feeding points) that prevented the access of mammalian carnivores. Nonetheless, scientific evidence highlights several major limitations of supplementary feeding for the conservation of scavengers (e.g. common species such as the griffon vulture *Gyps fulvus* outcompeting endangered ones such as the Egyptian vulture *Neophron percnopterus*; Meretsky & Mannan 1999; Cortés-Avizanda et al. 2016). Furthermore, carrion, including livestock carcasses, is also an important food resource for endangered vertebrates other than birds, such as mammalian carnivores of conservation concern in Europe (e.g. wolves *Canis lupus*, brown bears *Ursus arctos*; Llaneza & López-Bao 2015; Mateo-Tomás et al. 2015). New scientific evidence recommended therefore that livestock carcasses supplied to scavengers should imitate the unpredictable way in which carrion appears in natural ecosystems (Olea & Mateo-Tomás 2009; Margalida et al. 2010).

New scientific evidence for scavenger conservation was integrated into the EU Regulation (EC) No 1069/2009, which allowed the feeding of livestock carcasses with specified risk materials not only to endangered or protected species of necrophagous birds (as previous regulations did; see above) but also to other species, such as bear (*Ursus arctos*) and wolf (*Canis lupus*) populations listed in the Annex II of the Habitats Directive (Council Directive 92/43/EEC), in extensive grazing systems. Noteworthy, this regulation included for the first time the need of considering the natural consumption patterns of scavengers: "[…] It is important that such health conditions take into account the natural consumption patterns of the species concerned as well as Community objectives for the promotion of biodiversity […]".

Regulation (EU) No 142/2011 on animal by-products implemented the measures needed to guarantee such food supply from livestock to several vertebrate scavengers (see Table S1). These species included the four European vulture species (i.e. cinereous *Aegypius monachus*, bearded *Gypaetus barbatus*, Egyptian and griffon vultures), large eagles (e.g. golden eagle *Aquila chrysaetos*) and kites (e.g. red *Milvus milvus* and black *M. migrans*). Additionally, the regulation also considered protected birds of prey of the orders Falconiformes or Strigiformes listed in the

Annex I of the Birds Directive (Directive 2009/147/EC) in special protection areas which have been set up under that directive. Similarly, as mentioned above, species of the order Carnivora listed in the Annex II of the Habitats Directive in special areas of conservation, which have been set up under that directive.

Besides allowing the provisioning of livestock carcasses within supplementary feeding points, the EU Regulation 142/2011 allows carcasses of extensive livestock to be left uncollected *in situ* within geographically defined feeding zones authorised by the competent authorities for feeding scavengers (i.e. areas for feeding scavengers, SFZs hereafter, see Appendix S2). Importantly, for the feeding of scavengers to be allowed, the competent authority must also estimate the likely mortality rate of livestock in SFZs, and the likely feeding requirements of wild animals (i.e. scavenger feeding requirements, SFRs hereafter).

Regarding SFZs and SFRs, EU Regulation 142/2011 states (in Annex VI, Chapter II, Section 3):

"[…] The competent authority must identify in the authorisation, holdings or herds within a geographically defined feeding zone under the following conditions:

(a) The feeding zone must not extend to areas where intensive farming of animals takes place;

[…]

(e) Where the feeding is carried out without the prior collection of the dead animals, an estimate of the likely mortality rate of farmed animals in the feeding zone and of the likely feeding requirements of the wild animals must be carried out, as a basis for the assessment of the potential risks of disease transmission."

Table S1. Species present in the study area that could be fed in SFZs with livestock carcasses containing specified risk material according to EU Regulation 142/2011. These includes i) necrophagous birds directly listed in Annex VI of the EU Regulation 142/2011, ii) species of the order Carnivora listed in Annex II to Directive 92/43/EEC (Habitats Directive), and iii) species of the orders Falconiformes or Strigiformes listed in Annex I to Directive 2009/147/EC (Birds Directive). Dark grey background denotes the species considered in the EU regulation and in our analysis (i.e. target species). Light grey background indicates the species considered in our analyses but not affected by the EU Regulation 142/2011 within the study area (i.e. non-target species). White background denotes species considered in the EU regulation but not in our analyses because they are vagrant and/or scarce in the study area, scarce and/or infrequent scavengers or just have not been recorded scavenging (see Appendix S4). Abundance, breeding seasons and parameters are detailed for the scavenging species finally considered in our analyses (i.e. target and non-target species; grey background). See main text for further details.

Other species included in Annex VI of EU Regulation 142/2011 but not present in the study area were: (i) birds directly listed in Annex VI of EU Regulation 142/2011 (i.e. imperial eagle *Aquila heliaca*, Spanish imperial eagle *Aquila adalberti*, white-tailed eagle *Haliaeetus albicilla*), (ii) Falconiformes and Strigiformes listed in Annex I to Directive 2009/147/EC (i.e. *Elanus caeruleus, Circus cyaneus, Circus macrourus, Accipiter gentilis arrigonii, Accipiter nisus granti, Accipiter brevipes, Buteo rufinus, Aquila pomarina, Aquila clanga, Hieraaetus fasciatus, Falco naumanni, Falco vespertinus, Falco columbarius, Falco eleonorae, Falco biarmicus , Falco cherrug, Falco rusticolus, Nyctea scandiaca, Surnia ulula, Glaucidium passerinum, Strix nebulosa, Strix uralensis, Asio flammeus, Aegolius funereus*), and (iii) mammals of the order Carnivora listed in the Annex II of the Habitats Directive 92/43/EEC (i.e. *Lynx lynx, Lynx pardinus, Halichoerus grypus, Monachus monachus, Phoca vitulina*).

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

Species	Listed in	Population size / Breeding parameters	References
Golden eagle *Aquila chrysaetos*	EU Regulation 142/2011	35 breeding pairs Productivity: 0.77 Brood: March-September	Del Moral 2009a
Bearded vulture *Gypaetus barbatus*		14 individuals	FCQ pers. comm.
Griffon vulture *Gyps fulvus*		194 breeding pairs 600-640 individuals Productivity: 0.67 Brood: March-September	Del Moral 2009b; Mateo-Tomás & Olea 2011
Black kite *Milvus migrans*		100-150 breeding pairs 208-313 individuals Productivity: 0.61 Brood: May-August	Palomino 2006; García *et al.* 2014
Red kite *Milvus milvus*		100-120 individuals Wintering: October-March	Molina 2015
Egyptian vulture *Neophron percnopterus*		73 breeding pairs Productivity: 0.88 Brood: April-September	Del Moral 2009c; Mateo-Tomás et al. 2010
Brown bear *Ursus arctos*	Directive 92/43/EEC Annexes II & IV	257-262 individuals 27 females with cubs in 2015 and 29 in 2016 Productivity: 1.9 Cubs: April-December	Nawaz et al. 2008; Eberhardt & Breiwick 2010; Palomero et al. 2011; Principado de Asturias et al. 2016, 2017; Tosoni et al. 2017
Iberian wolf *Canis lupus signatus*	Directive 92/43/EEC Annex V north Duero River	38 wolf packs, 217-405 individuals Mean pack size: 4.8 individuals (January-May), 8 individuals (June-December) Population not linked to packs: 16-25%	Llaneza et al. 2012; Hernández-Palacios & González-Quirós 2017 López-Bao et al. 2018
Cinereous vulture *Aegypius monachus*	EU Regulation 142/2011	Vagrant	Mateo-Tomás et al. 2015, 2017
Eagle owl *Bubo bubo*	Directive 2009/147/EEC	Scarce presence (<5 breeding pairs) and infrequent scavenger (<0.01% of monitored carcasses in Spain)	
Marsh harrier *Circus aeruginosus*			
Osprey *Pandion haliaetus*		Not recorded as scavenger	
Short-toed snake eagle *Circaetus gallicus*			
Montagu's harrier *Circus pygargus*			
Peregrine falcon *Falco peregrinus*			
Booted eagle *Hieraaetus pennatus*			
European honey buzzard *Pernis apivorus*			
Eurasian otter *Lutra lutra*	Directive 92/43/EEC		
European Mink *Mustela lutreola*			

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Appendix S2. Scavenger feeding zones (SFZs)

Previous studies have referred the feeding zones for feeding scavengers designated under EU Regulation 142/2011 as PAFs (i.e. "protection areas for the feeding of necrophagous species of European interest"; Morales-Reyes et al. 2016). Nonetheless, since the Annex VI of this regulation refer to the term "feeding zone", we will use SFZs (i.e. scavenger feeding zones). This will also avoid further confusion with "predictable anthropogenic food subsidies", a term closely related to scavengers and referred to as PAFS in the scientific literature (Oro et al. 2013; Tauler-Ametller et al. 2017).

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Appendix S3. Additional information on scavengers and livestock in the study area

Importance of Spain and Asturias for conserving European populations of obligate scavengers and apex predators

Spain, accounts for >90% of the population of the European vultures (BirdLife International 2017), and ~16% of the global population of the endangered Egyptian vulture; BirdLife International 2017). The country also holds the third largest population of red kite (*Milvus milvus*) in Europe (BirdLife International 2017). Moreover, Spain hosts important populations of apex predators in Western Europe (Chapron et al. 2014). The NW Iberian wolf population, shared between Spain and Portugal, is the largest wolf population in Western Europe, and the third largest wolf population in Europe (Chapron et al. 2014). The Spanish golden eagle population is the second largest European population of the species (i.e. 16% of the European breeding pairs; BirdLife International 2017). Brown bears are distributed in two populations in Spain, the Cantabrian Mountains and the Pyrenees (Chapron et al. 2014; González et al. 2016).

Asturias hosts breeding populations of griffon (*Gyps fulvus*) and Egyptian (*Neophron percnopterus*) vultures (i.e. ~194 and ~73 breeding pairs, respectively; Appendix S1). A recovery program for the bearded vulture (*Gypaetus barbatus*) is underway since 2002 in the Picos de Europa National Park, with at least 14 individuals foraging within the study area (FCQ, pers. comm.). The study area holds ca. 70% (~257-262 individuals) of the Cantabrian brown bear population, and 38 wolf packs (~217-405 individuals; ~13% of the Iberian wolf population; Appendix S1; see Appendix S4 for population estimates).

Livestock censuses in Asturias

Livestock practices are dominated by cattle (*Bos taurus*) breeding, with an official census of ~413,000 heads in 2016 (SADEI 2017); of which 72% (~298,000 heads) are reared extensively. Although a traditional and marginal practice in NW Spain (López-Bao et al. 2013), the census of free-ranging horses (*Equus caballus*) is increasing in the last years, from ~33,300 heads in 2013 to ~38,000 in 2016 (SADEI 2017). Transhumant sheep (*Ovies aries*) and goats (*Capra aegragus* *hircus*), previously abundant in the alpine summer pastures of the Cantabrian Mountains, are sharply decreasing (i.e. from ~90,000 heads in 1990 to ~35,000 in 2007; Olea & Mateo-Tomás, 2009). Stand sheep and goats show the same decreasing trend (Mateo-Tomás & Olea, 2010), with official censuses of ~47,000 sheep and ~31,000 goats in 2016 (versus ~100,000 and ~45,000 heads in 2000, respectively; SADEI 2017).

Livestock carrion availability in Asturias

We obtained data of the number of extensive livestock (i.e. cattle, horses, sheep and goats) per municipality, and their average mortality rates, from the Government of Asturias, nearby areas (i.e. Governments of Cantabria, Galicia and Castilla-León) and previous literature (Mateo-Tomás & Olea 2015). Table S3 shows official data on mean weight and annual mortality rate per livestock species and age class.

Table S3. Annual average mortality rate of extensive livestock obtained from official databases of the Regional Government of Asturias (2016). The average weight per species and age class has been adjusted for common local breeds, as provided by the veterinary authorities of Asturias.

Species	Age	Mean weight (kg)	Annual mortality (%)
Cow	< 6 months	100	9.1
(*Bos taurus*)	6-12 months	200	1.3
	12-24 months	300	1.0
	>24 months	700	1.0
Sheep	< 4 months	8	5.9
(*Ovis aries*)	4-12 months	15	5.9
	Females >12 months	40	5.9
	Males > 12 months	75	5.9
Goat	< 4 months	8	5.4
(*Capra aegragus*	4-12 months	15	5.4
hircus)	Females >12 months	40	5.4
	Males > 12 months	75	5.4
Horse	< 6 months	100	9.1
(Equus caballus)	6-12 months	200	1.3
	12-24 months	300	1.0
	>24 months	600	1.0

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Appendix S4. Study species, abundances and carrion consumption rates

In a first step, we considered 19 vertebrate species included in Annex VI of the EU Regulation 142/2011 and present in Asturias (Table S1). Then, we excluded from our calculations those species with sporadic or scarce presence in the study area, that are also infrequent scavengers (i.e. scavenging at <0.01% out of 249 carcasses monitored across Spain; Mateo-Tomás et al. 2017; Table S1). We also excluded species present in the study area but not recorded scavenging there or elsewhere (Mateo-Tomás et al. 2015, 2017; Table S1).

We finally considered seven vertebrate scavengers affected by EU Regulation 142/2011 within the study area for subsequent analyses (i.e. griffon, Egyptian and bearded vultures, golden eagle, red and black kites and brown bear; Table S1). These species are referred hereafter as target species. Although wolves in Asturias are listed in Annex V of the EU Habitats Directive, and therefore their populations in Asturias are not affected by the EU regulation 142/2011, we also considered the species in our calculations (i.e. hereafter referred as non-target species). The rationale behind this decision was that: i) wolves are important facultative scavengers within the study area and elsewhere (Cuesta et al. 1991; Mech & Boitani 2010; Llaneza & López-Bao 2015; Mateo-Tomás et al. 2015, 2017), and therefore ii) the implementation of sanitary policies preventing carcass abandonment in the field could impact the species trophic ecology having an impact on human-wildlife conflicts (López-Bao et al. 2013; Llaneza & López-Bao 2015), and on the whole scavenger community (e.g. retaliatory illegal use of poison against this predator in the study area severely affects vultures; Mateo-Tomás et al. 2012).

To perform our calculations, we used the abundance estimates retrieved from official censuses of each study species in the study area (see references in Table S1). For Cantabrian brown bears, we estimated the abundance of brown bears in Asturias based on the last official estimate of females with cubs (FWC) provided by the Regional Government of Asturias: 27 FWC in 2015 and 29 FWC in 2016 (Principado de Asturias et al. 2016, 2017). Since female bears breed each other year (Palomero et al. 2011), we considered 56 unique FWC in Asturias. We considered a proportion of adult females in the Cantabrian brown bear population similar to that estimated for other protected bear populations (i.e. 0.274-0.279; Nawaz et al. 2008; Eberhardt & Breiwick 2010), and used also to estimate abundances in other threatened European brown bear populations (i.e. Apennines, central Italy; Tosoni et al. 2017). We considered also a proportion of 0.22 non-breeding females from the total of adult females in the population, as calculated for the Italian brown bear population of the Apennines (Tosoni et al. 2017). Therefore, considering 56 FWC and 72 adult females in our population, we estimated a total abundance of 257-262 bears of all ages in our study area.

To estimate the abundance of wolves in Asturias, we considered the estimate of wolf packs from the Regional Government of Asturias for 2016, i.e. 38 wolf packs (Hernández-Palacios and González-Quirós 2017). Considering a mean pack size of 4.8 individuals in January-May, and 8 individuals in June-December (i.e. between 7 and 9, including pups of the year; Llaneza et al. 2012), we estimated the number of wolves belonging to packs across the year. Next, we calculated the total number of wolves by adding between 16 and 25% of individuals as floaters in the population (López-Bao et al. 2018). Although this range of floaters were calculated for the breeding period, we also used it for the wintertime; figures that were similar to those estimated elsewhere (e.g. 7-20% of non-resident wolves in North America in winter; Mech and Boitani 2010). By combining the estimates for pack members and floaters, the total estimate of wolves in Asturias ranged between 217 and 405 individuals, depending on the season.

Carrion consumption

To estimate the total SFRs (see below), first, it is needed to estimate how much carrion an individual of each species would eat daily. We used the individual Daily Food Intake (i.e. the quantity of food, in grams, that an individual should ingest daily to keep its basic metabolic functions) as follow (Crocker et al. 2002; Mateo-Tomás et al. 2017):

$$Daily\ Food\ Intake\ (DFI) = \frac{Daily\ Energy\ Expenditure\ (kJ)}{Food\ Energy\ \left(\frac{kJ}{g}\right) * (1 - Moisture) * Assimilation\ Efficiency} \quad \text{eq. (1)}$$

Daily Energy Expenditure is strongly correlated with body weight (Hudson et al. 2013):

$$Log\ (Daily\ Energy\ Expenditure) = Log\ a\ +\ b\ *\ (log\ Body\ weight)\quad \text{eq.}\,(2)$$

where *Log a* and *b* are parameters separately obtained at Order level (see Hudson et al. 2013; Table S4.1). Mean body weights for the selected scavengers were obtained from official databases (i.e. PanTHERIA, HBW Alive; Del Hoyo et al. 2015; Jones et al. 2009) and adjusted with data from the study area when possible (Table S4.1). Energy and moisture content for mammal carrion were set as 22.6 kJ/g and 68.8%, respectively (Crocker et al. 2002). We considered different assimilation efficiencies for mammals and several bird groups (i.e. range: 76 - 84%, Crocker et al. 2002; Table S4.1).

We assumed that vulture species (obligate scavengers) and kites fulfilled their daily food intake consuming carrion exclusively (i.e. the 100 % of their DFI consists of carrion); whereas for the remaining facultative scavengers (i.e. those consuming carrion opportunistically), the carrion consumption rate was adjusted when possible.

For Cantabrian brown bears, although they can hunt wild ungulates occasionally (Blanco et al. 2011; Palomero et al. 2011), or even livestock, we assumed that the total vertebrate content found in its diet corresponded to carrion. Thus, we considered that the fraction of carrion consumed varied from 3 to 9.3% of their DFI along the year (Naves et al. 2006). For wolves, we considered that carrion consumption accounted for ~20% of the species' DFI, according to available estimates of carrion consumption rates in NW Spain (Palacios et al. 2014).

This same assumption should be done for other facultative scavengers, especially for apex predators such as the golden eagle. However, due to the lack of specific studies on the topic, it was not possible to precisely distinguish vertebrate remains consumed as live prey from those consumed as carrion, so we assumed that they fulfilled all their feeding requirements with carrion. While we acknowledge that this decision leads to an overestimation, these assumptions had little effect on the estimates of the total feeding requirements for scavengers in the study area (i.e. <6

% change when scavenging by golden eagle ranged between 0 and 100% of its DFI, as evaluated through sensitive analysis; Fig. S4).

The percentage of carrion consumed by scavengers not considered in our calculations was estimated using eq. (1) as in Mateo-Tomás et al. (2017; see Table S4.2).

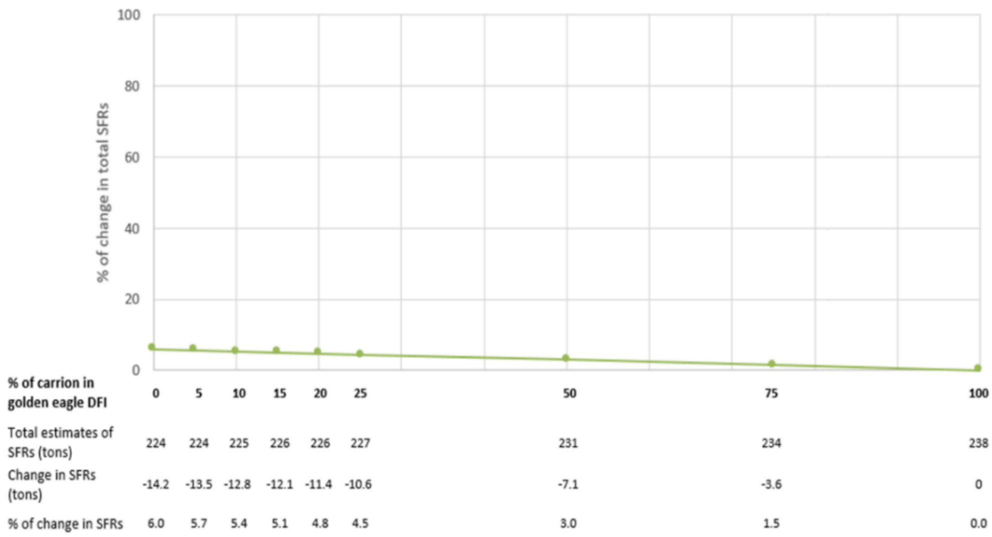
Table S4.1. Mean body weights, parameters and assimilation efficiencies used to estimate daily food intake (DFI) for vertebrate scavengers (see Table S1 and main text). Parameters *a* and *b* were obtained from Hudson et al. (2013) at the lowest taxonomic level available (i.e. species>genus>family>order). See Mateo-Tomás et al. (2017) for further details on the use of these parameters.

Species	Body weight (grams)	a/b parameters	Assimilation efficiency (%)
Aquila chrysaetos	4562.5	7.796 / 0. 692	83
Gypaetus barbatus	5850	7.796 / 0.772	83
Gyps fulvus	8000	7.796 / 0.772	83
Milvus migrans	855	7.796 / 0.692	83
Milvus milvus	1134.5	7.796 / 0.692	83
Neophron percnopterus	1875	7.796 / 0.692	83
Ursus arctos	99450	6.563 / 0.706	85
Canis lupus	30500	6.563 / 0.706	85

Table S4.2. Estimates of the percentage of carrion (from livestock and hunting remains) consumed in the study area by facultative scavengers not considered in our calculations, calculated by using eq.(1) (Mateo-Tomás et al. 2017 and authors, unpubl. data).

Species	**% of carrion consumed**	**Cumulative % of carrion consumed**
Red fox *Vulpes vulpes*	10.1	10.1
Wild boar *Sus scrofa*	10.0	20.1
Domestic dog *Canis familiaris*	9.2	29.3
Raven *Corvus corax*	3.8	33.1
Carrion crow *Corvus corone*	1.3	34.4
Magpie *Pica pica*	0.4	34.8
Common buzzard *Buteo buteo*	0.3	35.1
Stone and pine martens *Martes* spp	0.3	35.4
Common genet *Genetta genetta*	<0.1	35.4
Mice *Apodemus* spp.	<0.1	35.4
Domestic cat *Felis silvestris catus*	<0.1	35.5

Figure S4. Sensitivity analysis showing how the estimates of the scavengers feeding requirements in Asturias (i.e. SFRs) would change when varying the percentage of carrion in golden eagle daily food intake (i.e. DFI).



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Appendix S5. Regulations enforced in Spain and sub-national levels after the transposition of the European regulation EU 142/2011 on feeding scavengers

SPAIN

Real Decreto 1632/2011, de 14 de noviembre, por el que se regula la alimentación de determinadas especies de fauna silvestre con subproductos animales no destinados a consumo humano.

Date of document: 14th November 2011

Date of publication: 25th November 2011 in the Spanish official journal (Boletín Oficial del Estado, num. 284)

Date of effect: 26th November 2011

Andalucía

Orden de 2 de mayo de 2012, conjunta de las Consejerías de Agricultura y Pesca y Medio Ambiente, por la que se desarrollan las normas de control de subproductos animales no destinados al consumo humano y de sanidad animal, en la práctica cinegética de caza mayor de Andalucía.

Date of document: 2nd May 2012

Date of publication: 21st May 2012 in the official journal of the region (Boletín Oficial de la Junta de Andalucía, num.98 p. 13)

Date of effect: 1st June 2012

Orden de 30 de julio de 2012, por la que se establecen y desarrollan las normas para el proceso de retirada de cadáveres de animales de las explotaciones ganaderas y la autorización y Registro de los Establecimientos que operen con subproductos animales no destinados al consumo humano en Andalucía.

Date of document: 30th July 2012

Date of publication: 13th August 2012 in the official journal of the region (Boletín Oficial de la Junta de Andalucía, num.158 p. 10)

Date of effect: 14th August 2012

Aragón

DECRETO 170/2013, de 22 de octubre, del Gobierno de Aragón, por el que se delimitan las zonas de protección para la alimentación de especies necrófagas de interés comunitario en Aragón y se regula la alimentación de dichas especies en estas zonas con subproductos animales no destinados al consumo humano procedentes de explotaciones ganaderas.

Date of document: 22nd October 2013

Date of publication: 4th November 2013 in the official journal of the region (Boletín Oficial de Aragón, num.217)
Date of effect: 5th November 2013

Asturias

Resolución de 25 de mayo de 2017, de la Consejería de Desarrollo Rural y Recursos Naturales, por la que se declaran zonas de protección para la alimentación de especies necrófagas de interés comunitario en el Principado de Asturias y se establecen requisitos específicos para el uso de subproductos no destinados a consumo humano en estas zonas.
Date of document: 25th May 2017
Date of publication: 6th June 2017 in the official journal of the region (Boletín Oficial del Principado de Asturias, num.129)
Date of effect: 26th June 2017

Baleares

Esborrany de l'Avantprojecte de decret _/20__, d__ d____ de 20__, pel qual es regula a les Illes Balears l'ús de determinats subproductes animals no destinats al consum humà per a l'alimentació d'espècies necròfagues d'interès comunitari
Drafted regulation available at http://www.caib.es/sites/proteccioespecies/ca/portada-46282/. Last accessed 14th February 2018

Canarias

ORDEN de 17 de abril de 2014, por la que se delimitan las islas de Fuerteventura, Lanzarote y La Graciosa como zonas de protección para la alimentación de especies necrófagas de interés comunitario en la Comunidad Autónoma de Canarias.
Date of document: 17th April 2014
Date of publication: 28th April 2014 in the official journal of the region (Boletín Oficial de Canarias, num.81)
Date of effect: 18th May 2014

Cantabria

Orden MED/2/2017, de 20 de febrero, por la que se regula las zonas de protección autorizadas para la alimentación de la fauna silvestre necrófaga con cadáveres de animales pertenecientes a explotaciones ganaderas, en la Comunidad Autónoma de Cantabria.
This regulation ammends Orden GAN/30/2012, de 4 de mayo.
Date of document: 20th February 2017

Date of publication: 1st March 2017 in the official journal of the region (Boletín Oficial de Cantabria, num.42)
Date of effect: 2nd March 2017

Castilla-La Mancha
Decreto 120/2012, de 26/07/2012, por el que se crea la red de alimentación de especies necrófagas de Castilla-La Mancha y se regula la utilización de subproductos animales no destinados a consumo humano para la alimentación de determinadas especies de fauna silvestre en el ámbito territorial de Castilla-La Mancha.
Date of document: 26th July 2012
Date of publication: 1st August 2012 in the official journal of the region (Diario Oficial de Castilla-La Mancha, num.150)
Date of effect: 2nd August 2012

Castilla y León
DECRETO 17/2013, de 16 de mayo, por el que se desarrolla en Castilla y León el uso de determinados subproductos animales no destinados al consumo humano para la alimentación de especies necrófagas de interés comunitario.
Date of document: 16th May 2013
Date of publication: 29th May 2013 in the official journal of the region (Boletín Oficial de Castilla y León, num.101)
Date of effect: 30th May 2013

Cataluña
ORDEN AAM/387/2012, de 23 de noviembre, relativa a la alimentación de especies necrófagas de interés comunitario.
Date of document: 23th November 2012
Date of publication: 29th November 2012 in the official journal of the region (Diari Oficial de la Generalitat de Catalunya, num.6264)
Date of effect: 30th May 2013

Comunidad Valenciana
RESOLUCIÓN de 28 de noviembre de 2014, de la directora general de Medio Natural, por la que se delimitan las zonas de protección para la alimentación de aves necrófagas.
Date of document: 28th November 2014

Date of publication: 5th January 2015 in the official journal of the region (Diari Oficial de la Comunitat Valenciana, num.7436)
Date of effect: 25th January 2015
This regulation ammends RESOLUCIÓN de 18 de junio de 2012.

Extremadura

DECRETO 38/2015, de 17 de marzo, por el que se regula la alimentación de determinadas especies de fauna silvestre con subproductos animales no destinados a consumo humano en la Comunidad Autónoma de Extremadura.
Date of document: 17th March 2015
Date of publication: 23rd March 2015 in the official journal of the region (Diario Oficial de Extremadura, num.56)
Date of effect: 24th March 2015

Galicia

No regulation enforced or drafted.

La Rioja

Decreto 25/2014, de 13 de junio, por el que se establecen en la Comunidad Autónoma de La Rioja las condiciones para la alimentación, dentro de las zonas de protección, de determinadas especies de fauna silvestre necrófaga con subproductos animales no destinados a consumo humano procedentes de explotaciones ganaderas y se regula el procedimiento de autorización.
Date of document: 13th June 2014
Date of publication: 18th June 2014 in the official journal of the region (Diario Oficial de La Rioja, num.75)
Date of effect: 19th June 2014
This regulation ammends Resolución nº 489, de fecha 22 de mayo de 2012.

Navarra

Orden Foral 46/2014, de 25 de febrero, del Consejero de Desarrollo Rural, Medio Ambiente y Administración Local, por la que se regula el aporte de alimento para determinadas especies de la fauna silvestre con subproductos animales no destinados al consumo humano, el funcionamiento de los muladares de la Comunidad Foral de Navarra, se establece la zona de protección para la alimentación de especies necrófagas de interés comunitario y se dictan normas para su funcionamiento.
Date of document: 25th February 2014

Date of publication: 7th March 2014 in the official journal of the region (Boletín Oficial de Navarra)
Date of effect: 8th March 2014

Madrid

No regulation enforced or drafted.

Murcia

Proyecto de decreto, por el que se regula la alimentación de determinadas especies de fauna silvestre con subproductos animales no destinados al consumo humano procedentes de explotaciones ganaderas en zonas de protección de la comunidad autónoma de la Región de Murcia.
Drafted regulation available at http://transparencia.carm.es/-/proyecto-de-decreto-por-el-que-se-regula-la-alimentacion-de-determinadas-especies-de-fauna-silvestre-con-subproductos-animales-no-destinados-a-consu-1
Last accessed 14th February 2018

País Vasco

Orden Foral 229/2015, de 22 de mayo, por la que se aprueba el Plan Conjunto de Gestión de las aves necrófagas de interés comunitario de la Comunidad Autónoma del País Vasco, redactado conjuntamente por la Administración General del País Vasco y las Diputaciones Forales de Álava-Araba, Bizkaia y Gipuzkoa.
Date of document: 22nd May 2015
Date of publication: 1st July 2015 in the official journal of the region (Boletín Oficial del Territorio Histórico de Álava, num. 77)
Date of effect: 2nd July 2015
DECRETO FORAL de la Diputación Foral de Bizkaia 83/2015, de 15 de junio, por el que se aprueba el plan conjunto de gestión de las aves necrófagas de interés comunitario de la Comunidad Autónoma del País Vasco.
Date of document: 15th June 2015
Date of publication: 24th June 2015 in the official journal of the region (Boletín Oficial de Bizkaia, num. 119)
Date of effect: 25th June 2015

Appendix S6. Criteria selection and design of scenarios for SFRs and SFZs

Estimates of scavenger feeding requirements (SFRs)

To estimate annual SFRs (kg) under the benchmark scenario, we considered the estimated abundance of each target species in Asturias (number of individuals) and multiplied it by each species DFI (Fig. 1; Appendix S1). Breeding parameters (i.e. breeding success, offspring size) and seasons (i.e. breeding vs. non-breeding period) were considered in order to improve estimates (Appendix S1).

SFRs estimates from the benchmark scenario were compared with those obtained from the following scenarios: a “basic” scenario (i) accounting only for the estimated abundances of target species equally distributed along the year and without considering breeding parameters (Fig. 1; Appendix S1); a “Natura 2000” scenario (ii) considering the SFRs estimates from benchmark scenarios of the target species breeding only within the Natura 2000 Network instead of all Asturias; a “Natura 2000 + conservation areas” scenario (iii), adding to scenario (ii) the SFRs estimates of the target species breeding within areas officially designated for the recovery or conservation of threatened target species (i.e. Egyptian vulture, golden eagle and brown bear in Asturias); a “non-target species (wolf)” scenario (iv), in which we added the SFRs estimated for wolves, including breeding parameters, to the SFRs from the benchmark scenario (Fig. 1). According to their large foraging areas, avian scavengers are expected to forage in Asturias even when they breed outside. We considered therefore a fifth “nearby species” scenario (v) where we combined the SFRs estimates from the benchmark scenario with the feeding needs of target species breeding outside the study area, but expected to forage inside (i.e. those whose home ranges –as defined in Table S6– overlapped our study area; Fig. 1).

Spatial distribution of scavenger feeding zones (SFZs)

The benchmark scenario for the spatial distribution of SFZs (km^2) considered circular home ranges (HRs) around the breeding sites (i.e. nests, colonies or dens) or roosts (i.e. for wintering red kites) of the target species to cover not only their breeding sites, but also their foraging areas

(Fig. 1; Appendix S6). Because the large foraging areas of some target species (e.g. >46,000 km^2 for griffon and >179,000 km^2 for Egyptian vultures; Morales-Reyes et al. 2016), this benchmark scenario covered the entire study area (i.e. all Asturias designated as SFZ).

The area designated as SFZ resulting from the benchmark scenario was compared with those obtained from the following scenarios: (i) a "basic" scenario (Fig. 1) accounting only for the breeding (not foraging) distribution of target species, calculated as the minimum convex polygon –MCP– of all their breeding or wintering sites. The SFZs basic scenario (i.e. Basic MCP -Minimum Convex Polygon-; Fig. 1) accounted only for the breeding distribution of the target species, calculated as the MCP of all their breeding or wintering known locations (Table S6). When the exact locations of the breeding sites were unknown, i.e. for brown bears, we assumed as breeding location the centroid of the MCP calculated from all the existing locations of observations of females with cubs of the year (i.e. a breeding group) made from March to December. The locations were obtained by an established consortium among multiple regional environmental authorities and NGOs (Principado de Asturias et al. 2016, 2017). The breeding group centroids were then used to build the MCP for the species total breeding area. Wintering roosts were only considered for red kites (see Table S6), since the species does not breed in the study area and wintering locations are periodically monitored (Palomino 2006; García et al. 2014).

We considered also a "Natura 2000" scenario (ii) that included as SFZs all the sites within the Natura 2000 Network designated to preserve target species. A "Natura 2000 + conservation areas" scenario (iii) designated as SFZs the already mentioned Natura 2000 sites together with the areas officially designated for the recovery or conservation of threatened target species (Table 1; Fig. 1). We finally added to the benchmark scenario the HRs of wolves (i.e. "non-target species (wolf)" scenario) (iv), and of the nearby populations of target species when overlapping with our study area (i.e. "nearby species" scenario; see above) (v).

Table S6. Area (km^2) of the Minimum Convex Polygons (MCP) and home ranges (HR) considered for each scavenger species included in the analyses. See Table S1 for color code.

Species	Minimum convex polygon (MCP) km^2	Home range		References
		radius around breeding/roosting sites (km)	Total (km^2)	
Golden eagle *Aquila chrysaetos*	4668.8	20[a]	7117.13	Soutullo et al. 2006; Del Moral 2009a
Griffon vulture *Gyps fulvus*	1594.5	52	9361.13	Del Moral 2009b; Mateo-Tomás & Olea 2011; Morales-Reyes et al. 2016
Bearded vulture *Gypaetus barbatus*	1369.4	--	--	GPS-tracking by FCQ, pers. comm. 2016.
Black kite *Milvus migrans*	8213.1	9	10290.28	Palomino 2006; García *et al.* 2014
Red kite[b] *Milvus milvus*	1279.5	11	2469.32	Sergio et al. 2005; Tanferna et al. 2013; Molina 2015
Egyptian vulture *Neophron percnopterus*	6822.5	25	10381.27	Del Moral 2009c; Mateo-Tomás & Olea 2015; Morales-Reyes et al. 2016
Brown bear *Ursus arctos*	4344.0	61 ± 68 km^2	4344.03	Huber & Roth 1993; Palomero 1993; Mertzanis et al. 2005; Ambarlı & Bilgin 2012; Gavrilov et al. 2015; B. Lortkipanidze pers. comm.
Iberian wolf *Canis lupus signatus*	8500.6	122 ± 94 km^2	6554.18	Llaneza 2016

[a]Note that this value is a maximum radius based on GPS-tracked juveniles to include both the movements of adults (mostly smaller than those of juveniles) and juveniles (frequently observed feeding on carrion in the study area and elsewhere in Spain; Soutullo et al. 2008; authors, unpubl. data); [b]Red kite is a wintering species in the study area, so only wintering roosts and distances around them were considered in these calculations.

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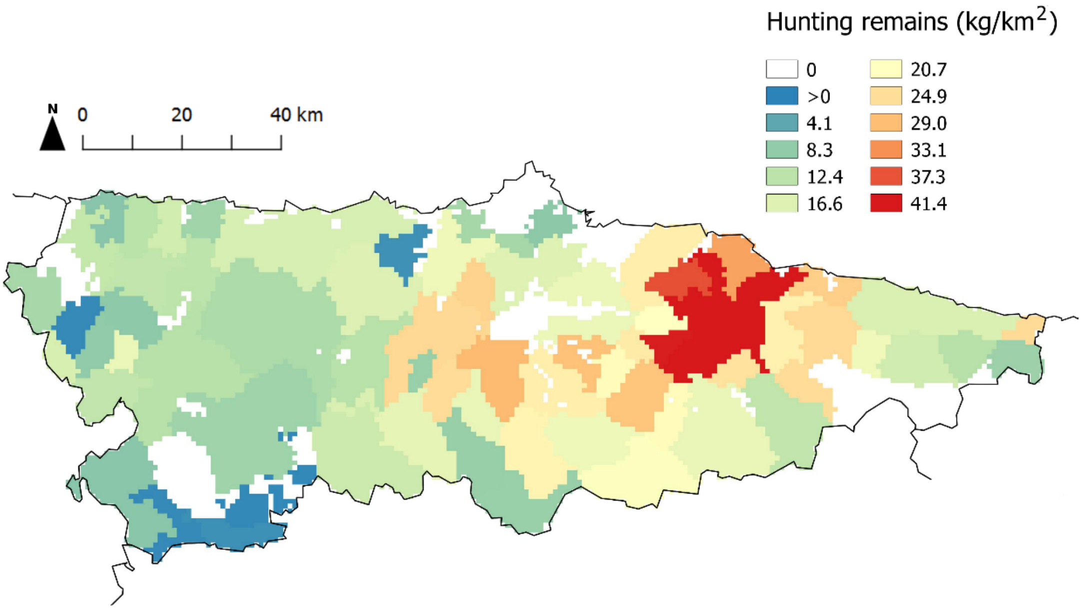
Appendix S7. Spatiotemporal distribution of hunting activity and remains

Table S7. Annual distribution of hunting episodes (N) of wild ungulates in Asturias (dark grey) according to official databases of the Regional Government of Asturias in 2015. The percentage of individuals hunted per species and month is shown. The mean weight of hunting remains abandoned in the field per hunted individual of each species is provided in brackets. Note that, since the number of animals hunted per hunting event in the study area is lower than 20 (i.e. mostly <10 individuals per event; Mateo-Tomás & Olea 2010), the new Spanish regulation on hunting remains (Royal Decree 50/2018), enforced on 1st July 2018, does not of apply to this region. Blank cells indicate no hunting activities.

Game species (mean weight remains/individual)	**N**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Chamois (7 kg) *Rupicapra rupicapra*	209	<1%	13%		11%	11%	11%	<1%	10%	10%	10%	21%	
European roe deer (7 kg) *Capreolus capreolus*	835				27%	27%	27%			9%	9%		
Fallow deer (30 kg) *Dama dama*	90	33%									33%	33%	
Red deer (50 kg) *Cervus elaphus*	536	10%	10%							31%	31%	10%	10%
Wild boar (10 kg) *Sus scrofa*	9947	21%	5%							18%	18%	18%	20%

Figure S7. Spatial distribution of the estimated quantity (kg) of carrion from hunting remains yearly available per km^2 within hunting preserves in Asturias. Zero values correspond to areas where hunting is not allowed (i.e. urban areas and National Park of Picos de Europa).



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