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RESEARCH ARTICLE

Shepherds' local knowledge and scientific data on the scavenging ecosystem service: Insights for conservation

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Abstract Integrating indigenous and local knowledge (ILK) and scientific knowledge (SK) in the evaluation of ecosystem services has been recommended by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. We examined the similarities and contradictions between shepherds' ILK and SK on the scavenging service provided by vertebrates in Spain. We conducted 73 face-to-face surveys with shepherds to evaluate their ILK. We collected scientific information on 20 scavenger species by monitoring the consumption of 45 livestock carcasses with camera traps. We found a high consistency between ILK and SK regarding the provision of the scavenging service by vertebrates, which was also consistent over the range of shepherd ages and experience. Our findings support the importance of ILK held by shepherds to better understand and to collect information on the scavenging service, particularly at the species level. The integration of ILK and SK into the management strategies of scavengers can benefit the conservation of globally endangered scavengers and the ecosystem services they provide.

Keywords Camera trapping · Carrion · Experience · Extensive livestock farming systems · Traditional ecological knowledge · Vultures

"The wild beasts are not our problem, the problem is we can't sell our products and the prices are too low […] Even beasts […] have a purpose, even the bad ones like wolves, they have their own role, they eat the corpses of dead animals, they cleanse the landscape" Stefan Dunca, 50 years old, shepherd, in Roué and Molnár (2016, pp. 35)

INTRODUCTION

The advantages of maintaining biodiversity and the associated ecosystem services (i.e., the benefits that people obtain from ecosystems; MA 2005; Díaz et al. 2015) are well known. Despite these positive contributions of biodiversity to society, human threats prominently undermine numerous ecological functions from which present and future humans could benefit (Díaz et al. 2015). For this reason, approaching biodiversity conservation from a socio-ecological perspective has been recently recommended (Ban et al. 2013; Martín-López and Montes 2015; Bennett et al. 2017).

Socio-ecological approaches to biodiversity conservation have begun to incorporate local and experiential knowledge as a relevant source of information to characterize and understand human–nature relations and to inform guidelines for conservation and environmental management (Berkes 2004). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) define indigenous and local knowledge (ILK) as "the cumulative body of knowledge, practices, and beliefs regarding the relationships of living things to their environment" (Díaz et al. 2015). IPBES, together with some international multilateral environmental agreements, such as the Convention on Biological Diversity (CBD), have recognized the role of ILK to provide essential information for conservation practices (Tengö et al. 2017). For instance, ILK has been used to obtain information on species abundance and perceived population trends in both terrestrial and marine environments (e.g., Anadón et al. 2009; Frans and Augé 2016), to evaluate the potential driving factors influencing vegetation dynamics (Sop and Oldeland 2013) or the status of endangered species (Pan et al. 2016), to monitor the

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sustainability of hunted wildlife populations (Parry and Peres 2015), and to detect ecological changes in coastal communities after a disturbance (Aswani and Lauer 2014). Nevertheless, the application of ILK to the conservation of endangered vertebrate species has been scarce.

The functional groups of obligate (i.e., vultures) and large facultative scavengers (e.g., apex predators) are widely threatened worldwide (Estes et al. 2011; Ogada et al. 2012; Buechley and Şekercioğlu 2016). However, these functional groups are essential for the provision of multiple ecosystem services (Moleón et al. 2014; DeVault et al. 2016). Crucially, by removing livestock and wild animal carcasses, scavengers contribute to nutrient cycling (Wilson and Wolkovich 2011; Beasley et al. 2015) and pest and disease regulation (Ogada et al. 2012). The close relationship between humans and scavengers has benefited humanity since the earliest hominins (Moleón et al. 2014) and was strengthened with the domestication of animals around 12 000 years ago (Moleón et al. 2014). Thereafter, scavengers have largely relied on carcasses of livestock (Donázar et al. 2009) and wild ungulates from culling and big game hunting (Mateo-Tomás et al. 2015). In the Mediterranean Basin, traditional livestock farming practices are closely linked to scavenger conservation (Olea and Mateo-Tomás 2009). In fact, Morales-Reyes et al. (2018) demonstrated that experienced shepherds of extensive livestock farming systems have a positive perception of the provision of scavenging services; however, there is no evidence of the association between the ILK held by shepherds and scavenging services. Nonetheless, ILK has been broadly studied in Mediterranean farming systems to assess its contributions to management practices and its trends (e.g., Gómez-Baggethun et al. 2010; Oteros-Rozas et al. 2013). In fact, the Mediterranean area of the Iberian Peninsula is one of the 'hotspots' of European ILK research on extensive farming systems (Hernández-Morcillo et al. 2014). This research has shown that ILK has been eroded through generations with implications in livestock management (e.g., Gómez-Baggethun et al. 2010; Oteros-Rozas et al. 2013). In this sense, to explore ILK about scavenging in the Mediterranean extensive livestock farming systems can contribute with useful insights for livestock management and scavenger conservation.

Our main goal was to assess the similarities and contradictions between ILK and scientific knowledge (SK) regarding the scavenging service provided by vertebrates in extensive livestock farming systems. We explored the correspondence between ILK and SK according to two levels of ecological organization, i.e., species and community. In addition, we investigated if shepherds' ILK was age- or experience-dependent, because both factors may affect their ILK (Gómez-Baggethun et al. 2010; Oteros-Rozas et al. 2013; Iniesta-Arandia et al. 2015). We conducted this study in Spain, home to > 90% of the European vulture population (Margalida et al. 2010) and the largest populations of brown bears (*Ursus arctos*) and gray wolves (*Canis lupus*) in Western Europe (Chapron et al. 2014).

MATERIALS AND METHODS

Study areas

We performed the study in two protected areas within the Cantabrian Mountains in northern temperate Spain, and the Baetic Mountains in southeastern Mediterranean Spain (Fig. 1). These areas hold a high diversity of major vertebrate scavengers, both obligate (i.e., vultures) and facultative scavengers. The four species of Spanish vultures are present in the study areas: griffon vulture (*Gyps fulvus*; the most abundant one), cinereous vulture (*Aegypius monachus*), bearded vulture (*Gypaetus barbatus*), and Egyptian vulture (*Neophron percnopterus*). Other major avian scavengers such as golden eagle (*Aquila chrysaetos*), black kite (*Milvus migrans*), red kite (*M. milvus*), common raven (*Corvus corax*), and common magpie (*Pica pica*) are also present. Among mammalian facultative scavengers, mesocarnivores, such as red fox (*Vulpes vulpes*) and stone marten (*Martes foina*), and omnivores, such as wild boar (*Sus scrofa*), are common in both study areas, and apex predator such as brown bear and gray wolf are also present in the Cantabrian Mountains (Mateo-Tomás et al. 2015; Morales-Reyes et al. 2018).

The study areas represent two of the main traditional extensive livestock farming systems in Spain (i.e., pasture-based farming). Both areas are characterized by the presence of shepherds performing traditional livestock farming practices such as transhumance and the abandonment of livestock carcasses in the field (see Table 1 for details of socio-demographic and farming characteristics), which seem to influence shepherds' levels of ILK (Oteros-Rozas et al. 2013; Morales-Reyes et al. 2018). In similar systems in the Mediterranean Basin, vultures and eagles have been described as prominent in the culture of local communities (Stara et al. 2016) and it has been found that shepherds hold high level of knowledge about these species (Cortés-Avizanda et al. 2018). In fact, in the study areas, the average number of species known by shepherds relative to the total number of species asked about was 67.6% in the Cantabrian Mountains and 73.7% in the Baetic Mountains. Additionally, average number of species seen by shepherds relative to the total number of species asked about was 64.7% in the Cantabrian Mountains and 64.8% in the Baetic Mountains.

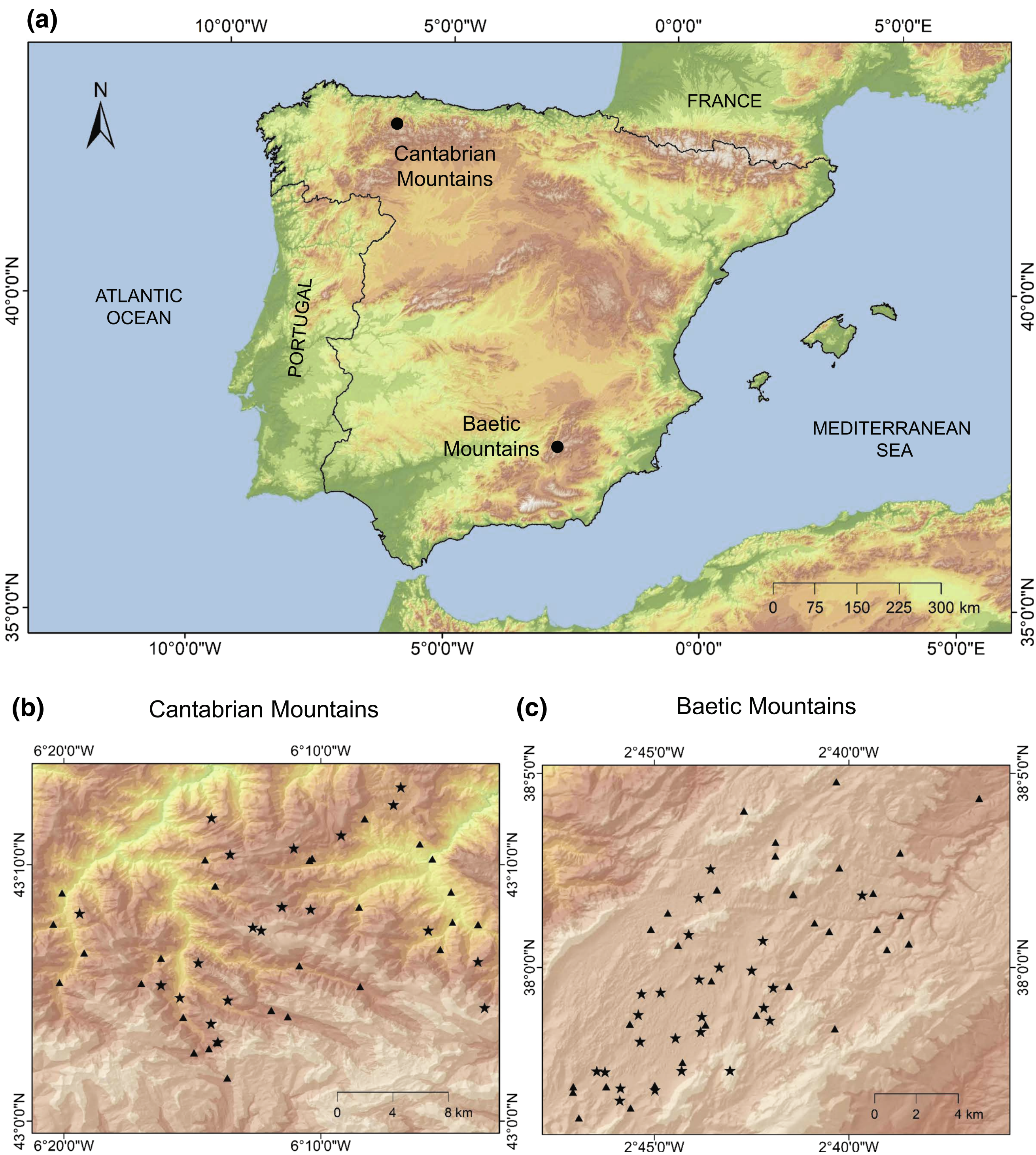

Fig. 1 Map of continental Spain (**a**) showing the two study areas: Cantabrian Mountains (**b**) and Baetic Mountains (**c**). The locations of surveyed shepherds (triangles) and monitored carcass sites (stars) are shown. Maps were generated with ArcGIS 10.1

Indigenous and local knowledge

We collected data through face-to-face surveys with shepherds during 2015 and 2016 (see Fig. 1 for sampling points). We systematically divided the sampling strategy into three main stages. First, for each study area, we randomly selected an initial set of shepherds in extensive livestock systems from the Spanish General Register of Livestock Farms. Second, we obtained the contact details of shepherds from the local sanitary authorities. Third, we

Table 1 Total shepherd population (N), total number of questionnaires conducted (n), margin of error, date of sampling, number of questionnaires conducted according to each category of age ('born') and experience as a shepherd ('experience'), and main socio-demographic and farming characteristics of the shepherds in each study area. Mean (SE) is shown. Total shepherd population (N) refers to farms with > 25 heads of sheep or goats, and > 10 head of cattle or horses

Variable	Cantabrian Mountains	Baetic Mountains
N	246	122
n	40	33
Margin of error (%)	14.2	14.6
Date of sampling	2016	2015
Shepherds' age ('born')		
≤ 1950	13	4
1960	10	18
≥ 1970	17	11
Experience as a shepherd ('experience')		
≤ 20	15	6
21–40	16	12
≥ 41	9	15
Socio-demographic characteristics		
Average age of shepherds (in years)	50.4 (2.2)	47.2 (1.1)
Average experience of shepherds (in years)	29.2 (2.8)	35.6 (2.0)
Gender		
Males (%)	77.5	100
Females (%)	22.5	0
Farming characteristics		
Total number of livestock	88.0 (11.8)	695.2 (60.7)
Number of sheep	2.6 (1.2)	660.0 (58.8)
Number of goats	18.1 (8.8)	29.1 (8.8)
Number of cattle	64.3 (10.4)	5.8 (4.0)
Number of horses	2.9 (1.0)	0.4 (0.2)
Shepherds performing transhumance (%)	20.0	63.6
Shepherds leaving carcasses in field (%)	95.0	100

met with shepherds on or near their farms to conduct the survey. In total, we completed 73 face-to-face questionnaires (40 in Cantabrian Mountains and 33 in Baetic Mountains). The sample size is representative of the total shepherd population of extensive farming systems in each study area (see Morales-Reyes et al. 2018 for details). We adhered to the standard ethical principles required for conducting social surveys (Iphofen 2013). Before being surveyed, respondents were briefed on the nature, scope, and purpose of the research project. Surveys were performed with the free, prior, and informed consent of the respondents. Respondents' confidentiality was guaranteed.

We used the questionnaire to collect information on shepherds' knowledge of the scavenging ecosystem services provided by vertebrates in each study area (see Table S1 for the 20 species considered). We structured the questionnaire into two sections according to different levels of ecological organization. At the species level, we asked shepherds about the frequency of occurrence at carcasses of each scavenger species ('frequency of occurrence at carcasses ILK') and their capacity to provide the 'scavenging service ILK'. At the community level, we asked shepherds about the time needed by scavengers to detect ('detection time ILK') and completely consume ('consumption time ILK') their livestock carcasses. In both sections, questions aimed at assessing the shepherds' knowledge built through observation of scavengers and the shepherds' practical experience gained when leaving livestock carcasses in the field. Table S2 provides a detailed description of four variables and questions.

We also asked shepherds for their age and experience with traditional livestock farming practices. In particular, we recorded their age ('born') and experience as a shepherd ('experience'). In relation to shepherds' age, we established three categories: ≤ 1950 (born in the 1940s–1950s), 1960 (born in the 1960s), and ≥ 1970 (born in the 1970s–1990s). Shepherds' experience was also grouped into three categories: ≤ 20 years, 21–40 years, and ≥ 41 years. We set the categories of 'born' and 'experience' to allow for a balanced distribution of the sample (see Table 1).

Scientific knowledge

We collected scientific information on the scavenging ecosystem services by monitoring the consumption of 45 livestock carcasses (20 in Cantabrian Mountains and 25 in Baetic Mountains) with camera traps equipped with passive infrared sensors (Little Acorn 5210A and Bushnell NatureView Cam HD Max). We used a camera to monitor each carcass. Data on the scavenging function at the species and community levels were collected between 2012 and 2015. We monitored 10 horses, 7 cows, and 3 sheep in the Cantabrian Mountains and 24 sheep and 1 goat in the Baetic Mountains. Thus, monitored carcasses are in general representative of the livestock species and numbers in each study area (see Table 1 for comparison). Carcass sites and surveyed shepherds were randomly distributed within each study area (Morales-Reyes et al. 2018; Fig. 1).

We set cameras to take 1–3 pictures every minute (Baetic Mountains) or they were activated by movement (Cantabrian Mountains). They were active for 24 h (Cantabrian Mountains) or from dawn to dusk (6:30–21:30 h; Baetic Mountains). In the Baetic Mountains, 19 carcasses were completely consumed before dusk and 6 carcasses were consumed after dusk. In this case, we inspected the surroundings of carcass sites the next morning to look for signs of the presence of scavengers (e.g., footprints, feces) and evidence of carrion consumption based on Selva et al. (2005). We detected carrion consumption by wild boar at four of the carcasses placed at night. Dogs (*Canis lupus familiaris*) and red foxes may also have consumed any of those four carcasses but went unnoticed. However, both dogs and foxes were also detected during the day at these carcasses, so there are no biases regarding the frequency of occurrence at carcasses of these species. Carcass monitoring was complete once the carcass was completely consumed, i.e., when only the skeleton, skin, and dehydrated meat remained (Moleón et al. 2015).

We used this scientific information to calculate four variables associated with different levels of ecological organization. At the species level, we calculated the frequency of occurrence at carcasses of each scavenger species (‘frequency of occurrence at carcasses SK’) and the percentage of biomass consumed by each scavenger species (‘biomass consumed SK’) according to Mateo-Tomás et al. (2017; see also Appendix S1). At the community level, we calculated the time needed by scavengers to detect (‘detection time SK’) and completely consume (‘consumption time SK’) the experimental livestock carcasses (see Table S3 for a description of these variables).

Data analyses

We evaluated, separately for each study area, the level of consistency between ILK and SK at each ecological organization level (i.e., species and community). Other studies have tested the overlap between these two knowledge systems by calculating percent agreement and quantity disagreement statistics (Aswani and Lauer 2014) or by performing correlation and multivariate regression statistics (Anadón et al. 2009; Fernández-Llamazares et al. 2017). Here, we used a mixed approach that includes nonparametric comparison tests, correlations, and covariance analyses. We used XLSTAT software (version 2016.04, Addinsoft) and R (R Core Team 2016).

Comparison of ILK and SK at different ecological organization levels

At the species level, we used Spearman’s correlations to test the relationship between the frequency of occurrence at carcasses, as observed by shepherds (‘frequency of occurrence at carcasses ILK’) and as measured by camera traps (‘frequency of occurrence at carcasses SK’), as well as to test the relationship between the consideration of each species as a provider of the scavenging service by shepherds (‘scavenging service ILK’) and the carrion consumed (‘biomass consumed SK’) by each species as indicated by camera traps. At the community level, we used Mann–Whitney U tests ($\alpha = 0.05$) to check whether the time needed by scavengers to detect and completely consume the livestock carcasses observed by shepherds varied from those shown by camera traps.

The influence of age and experience

We analyzed the consistency between the variables of SK and ILK in relation to shepherds’ age (‘born’) and experience (‘experience’) at different ecological organization levels. At the species level, we conducted an analysis of covariance (ANCOVA; $\alpha = 0.05$) to test whether shepherds’ age and experience had an effect on the level of consistency between ILK and SK. We included ‘born’ and ‘experience’ as covariates. At the community level, we used Mann–Whitney U tests ($\alpha = 0.05$) to test whether the detection and consumption times calculated from camera traps differed from those observed by shepherds depending on each category of ‘born’ and ‘experience’.

RESULTS

Consistency between ILK and SK at different ecological organization levels

Overall, we found that shepherds’ ILK was highly consistent with SK at different ecological organization levels. At the species level, we found a high correlation between the frequency of occurrence of scavengers at carcasses as reported by shepherds (‘frequency of occurrence at carcasses ILK’) and calculated from camera traps (‘frequency of occurrence at carcasses SK’) in both study areas (Baetic Mountains: Spearman’s rho = 0.852, $p < 0.001$; Cantabrian Mountains: Spearman’s rho = 0.861, $p < 0.001$; Fig. 2a). In addition, the shepherds’ consideration of each species as providers of the scavenging service (‘scavenging service ILK’) and the carrion biomass consumed by the species measured from camera traps (‘biomass consumed SK’) were highly related in both study areas (Baetic Mountains: Spearman’s rho = 0.762, $p = 0.004$; Cantabrian Mountains: Spearman’s rho = 0.865, $p < 0.001$; Fig. 2b).

At the community level, we found no significant differences between ILK and SK regarding the detection time of livestock carcasses by scavengers (Cantabrian Mountains: $U = 45.0$, $p = 0.2$; Baetic Mountains: $U = 391.5$, $p = 0.7$), although mean detection time observed by shepherds was lower than mean detection time obtained from camera traps (see Fig. 3a). We found significant differences between ILK and SK regarding livestock carcass consumption time, with lower values for ILK compared to SK

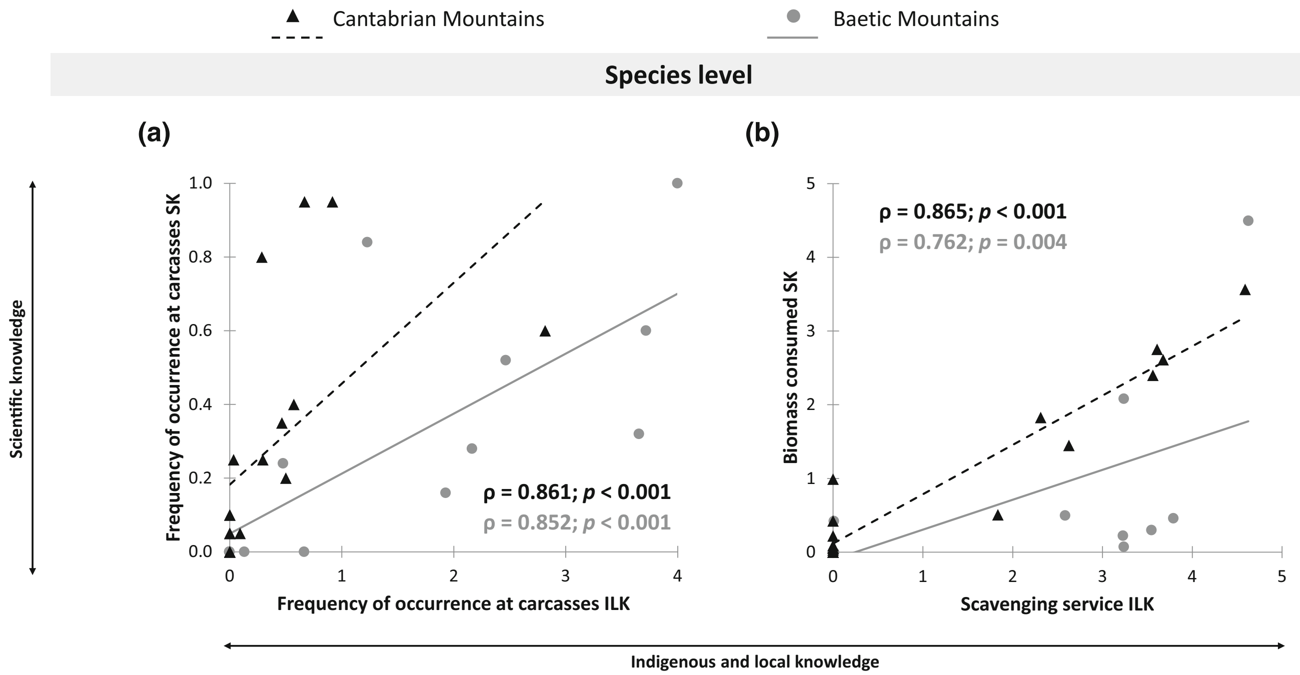

Fig. 2 Relationships between indigenous and local knowledge (horizontal axis) and scientific knowledge (vertical axis) variables at the species level in the Cantabrian Mountains (dashed lines and black triangles) and the Baetic Mountains (solid lines and gray circles). **a** Relationship between the frequencies of occurrence at carcasses of each species as observed by shepherds and as measured from camera traps. **b** Shepherds' consideration of each species as providers of the scavenging service in relation to the carrion biomass consumed by each species at the monitored carcasses. Spearman's rho (ρ) and p values are shown. Statistically significant results are indicated in bold. See Tables S2 and S3 for a description of the variables

(Cantabrian Mountains: $U = 76.0$, $p < 0.001$; Baetic Mountains: $U = 88.0$, $p < 0.001$; Fig. 3b).

The influence of age and experience

At the species level, we found no significant differences in the level of consistency between ILK and SK in relation to shepherds' age or experience ($p > 0.05$; Figs. 4a–d; Tables S4, S5). At the community level, we found no significant differences between SK and ILK across the different categories of age regarding livestock carcass detection time except in the Baetic Mountains, where mean detection time observed by the oldest shepherds (i.e., born $\leq$ 1950) was significantly lower than mean detection time measured from camera traps (see Fig. 3c; Table S6). We did not detect differences between SK and ILK due to shepherds' experience regarding carcass detection time (Fig. 3d; Table S6). However, we found significant differences between SK and ILK across age categories regarding carcass consumption time in all cases (lower for ILK than for SK) except in the Baetic Mountains, where mean consumption time reported by the oldest shepherds was not significantly different from mean consumption time obtained from camera traps (Fig. 3e; Table S6). We also observed significant differences between SK and ILK across experience categories regarding carcass consumption time in all cases except in the Baetic Mountains, where mean consumption time observed by the least experienced shepherds was not significantly different from mean consumption time calculated from camera traps (Fig. 3f; Table S6).

DISCUSSION

Similarities and contradictions between ILK and SK

Our findings show a high consistency between shepherds' ILK and SK regarding the scavenging service provided by vertebrates at the studied ecological levels, particularly at the species level. There is an increasing research trend in conservation science showing that integration of both knowledge systems can benefit species conservation. Among the multiple benefits of ILK and SK integration for biodiversity conservation, former research has highlighted the seasonal complementarity in the observations made by scientists and ILK holders (Knapp et al. 2013), the complementarity in the evaluation of population status and abundance of marine species (Bender et al. 2014) and in assessments of habitat use by mammals (Prado et al. 2014). Nonetheless, former research showing overlap between

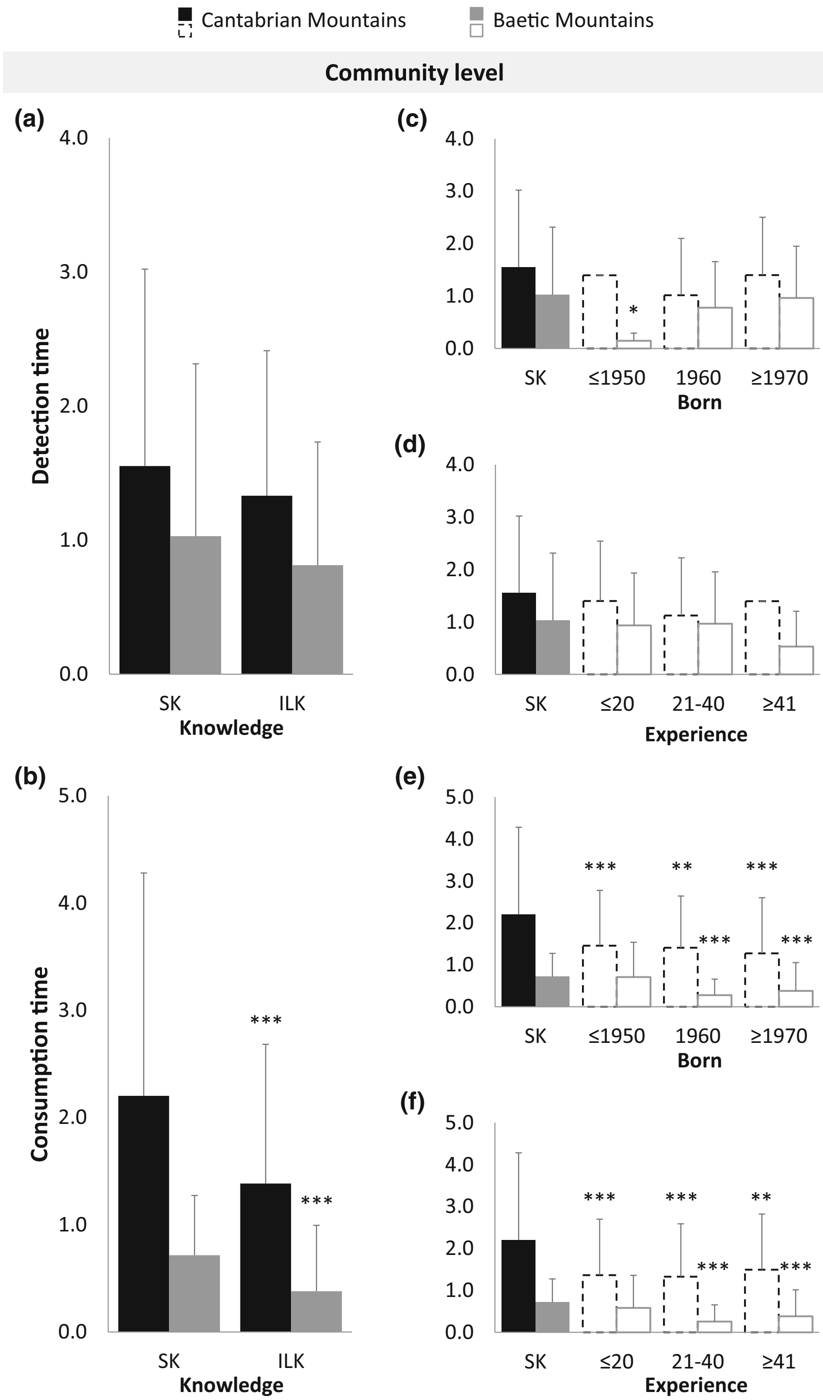

Fig. 3 Detection and consumption times of livestock carcasses by scavengers in the Cantabrian Mountains (in black and dashed lines) and the Baetic Mountains (in gray and solid lines). **a** Detection times measured from camera trap monitoring (scientific knowledge, SK) and reported by shepherds (indigenous and local knowledge, ILK). **b** Consumption times calculated from camera traps and observed by shepherds. **c** Comparison between detection times indicated by camera traps and reported by shepherds for each category of age ('born'). **d** Comparison between detection times measured by camera trap monitoring and observed by shepherds for each category of experience as a shepherd ('experience'). **e** Comparison between consumption times measured by camera traps and observed by shepherds for each category of 'born'. **f** Comparison between consumption times shown by camera trap monitoring and observed by shepherds for each category of 'experience'. Bars indicate the mean value of detection and consumption times (whiskers indicate standard deviation). Asterisks indicate significant differences between SK and ILK (**a**, **b**) and between SK and each category of 'born' (**c**, **e**) and 'experience' (**d**, **f**) within the same study area (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$). Log $(x + 1)$ transformation was applied to improve the graphical representation. See Tables S2 and S3 for a description of the variables and Table S6 for additional details on the statistical analyses

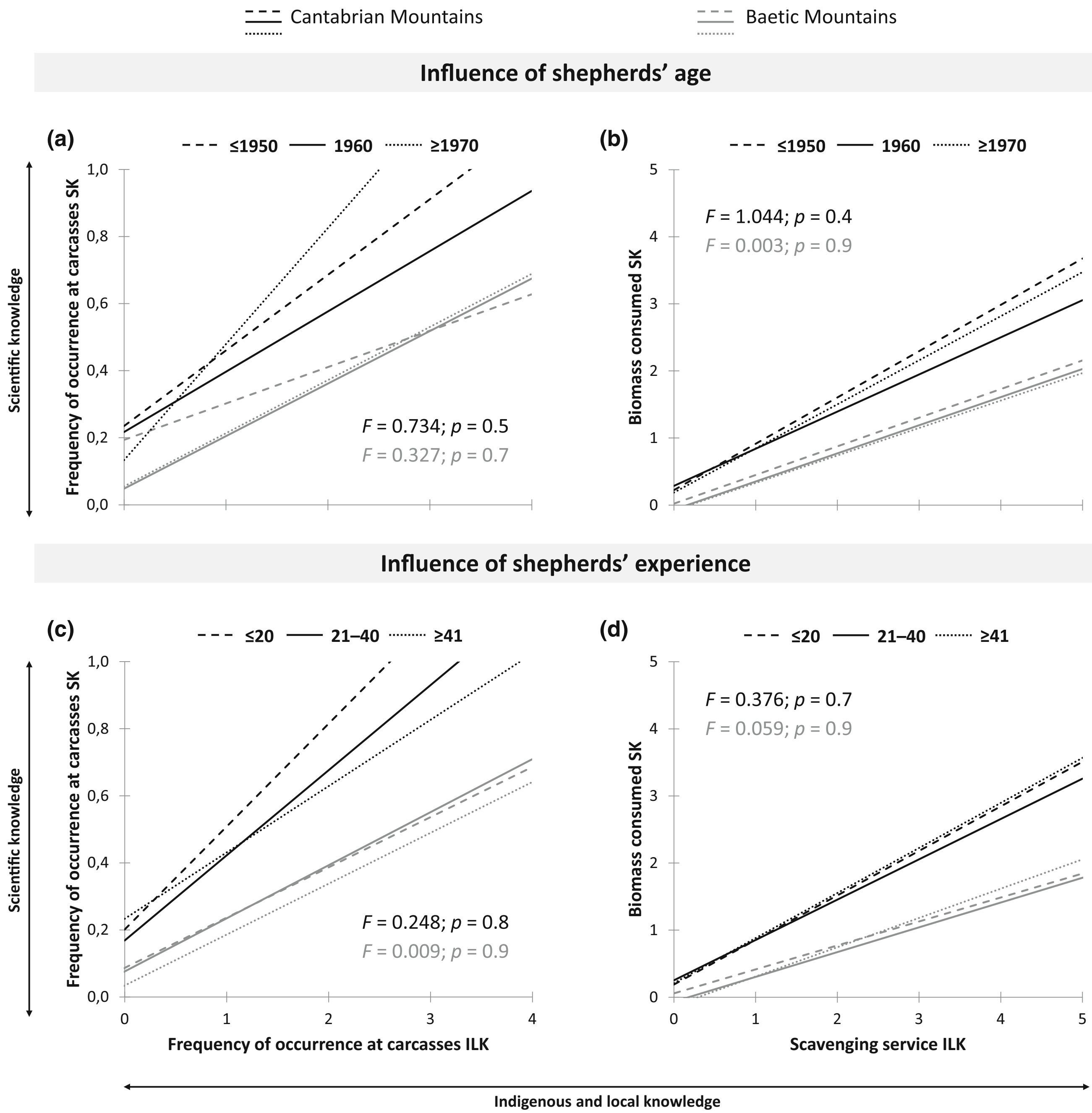

Fig. 4 The influence of shepherds' age (top panels) and experience (bottom panels) on the relationship between indigenous and local knowledge (ILK; horizontal axis) and scientific knowledge (SK; vertical axis) variables at the species level in the Cantabrian Mountains (black lines) and the Baetic Mountains (gray lines). **a** Relationship between the frequencies of occurrence at carcasses of each species as reported by shepherds and as measured from camera traps for each category of age ('born'). **b** Shepherds' consideration of each species as providers of the scavenging service in relation to the carrion biomass consumed by each species at the monitored carcasses for each category of 'born'. **c** Relationship between the frequencies of occurrence at carcasses of each species observed by shepherds and shown by camera trap monitoring for each category of experience as a shepherd ('experience'). **d** Shepherds' consideration of each species as providers of the scavenging service in relation to the carrion biomass consumed by each species at the monitored carcasses for each category of 'experience'. F statistic and p values of the interaction (i.e., ILK–'born' and ILK–'experience') are shown. See Tables S2 and S3 for a description of the variables and Tables S4 and S5 for additional information on regression models

ILK and SK has often overlooked the contradictions that can appear between the two knowledge systems.

The complementarities between ILK and SK found in this research (Figs. 2a, b, 3a) support former research conclusions about the importance of integrating both knowledge systems for species conservation (e.g., Knapp et al. 2013; Bender et al. 2014). Additionally, the discrepancies between both knowledge systems regarding the consumption times of carcasses by scavengers can enhance our understanding of the different temporal scales at which the scavenging service takes place and are perceived by shepherds. Shepherds and scientists may disagree on what they consider to be "total consumption", which can explain why carcass consumption time was generally different (lower) for ILK compared to SK (Fig. 3b). In particular, our findings suggest that shepherds may ignore the consumption of the final scraps, which represent little biomass but it may take hours or even days to be consumed (Selva et al. 2003). Previous research also found that scientists and ILK holders made their observations with different timing and with different intensity (Knapp et al. 2013).

This research also gives insights about the ecological levels at which observations made by shepherds (ILK) overlap with observations made by camera traps (SK). The level of consistency between both knowledge systems is higher at the species level than at the community level (Figs. 2a, b, 3a, b). This result can be explained by the fact that the sighting of species scavenging at carcasses requires less observation effort than the evaluation of the ecological process of scavenging at the community level. While detecting which species are scavenging at carcasses can be made through occasional observations, the understanding of the whole carcass removal process needs more observation time. Further, the SK obtained from camera traps provides a snapshot of the scavenging processes, but ILK held by shepherds provides a longer temporal perspective of the ecological processes.

Trends in ILK according to age and experience

We detected that ILK at the species level was highly consistent with SK at all levels of age and experience. These results contrast with previous research that demonstrated that older shepherds have greater ILK (e.g., Gómez-Baggethun et al. 2010; Oteros-Rozas et al. 2013). However, as Oteros-Rozas et al. (2013) pointed out, the use and transmission of ILK through generations are more relevant than the age of ILK holders. Thus, the continuous experiential connection of shepherds in extensive farming systems with nature and their livestock can explain the homogenous level of ILK across generations (Fig. 4).

Contrary to previous studies (e.g., Turner and Turner 2008; Gómez-Baggethun et al. 2010), we did not find evidence that ILK among shepherds is declining. This could be several reasons for this. First, younger shepherds are more likely to be in contact with other shepherds and external sources of training and information through the use of new technologies, such as the Internet, compared to older shepherds. As previously highlighted, the exchange of information with other members of the community can increase the level of ILK (Iniesta-Arandia et al. 2015). Similarly, such an exchange of information with external training can result in hybridization processes, where ILK is merged with novel forms of knowledge and technologies to create new knowledge able to sustainably manage biodiversity and ecosystem services (Łuczaj et al. 2012; Varga et al. 2016). In contrast, unfortunately, the knowledge acquired through some external sources (e.g., the media) may negatively influence shepherds' perception of scavengers. For instance, increasing the public alarm over attacks on livestock attributed to scavengers negatively affected their conservation (Margalida et al. 2011). Second, many young shepherds (e.g., in the Cantabrian Mountains) rely on a second economic activity to subsist, especially linked in recent years to nature tourism, facilitating the acquisition of knowledge of some species and ecological processes. Third, vultures suffered an important decline during the 1950s and 1960s in Spain (Cramp and Simmons 1980), but vulture populations have shown a notable recovery in the last few decades (e.g., del Moral 2009). In the Cantabrian Mountains, the number of griffon vulture colonies increased from 3 in the 1970s to 120 in the 2000s (Mateo-Tomás and Olea 2011). Populations of large mammal scavengers such as bears and wolves have also increased recently (Chapron et al. 2014). A consequence of this recovery of many scavenger species may be the similar ILK held by older and younger shepherds.

The relevance of ILK for the conservation of scavengers

The association between shepherds' ILK and SK suggests that ILK can be useful for conservation of scavengers. For example, ILK might be used to identify species with a higher mortality risk associated with carcass consumption, such as poisoning (e.g., Mateo-Tomás et al. 2012) or related to the ingestion of veterinary pharmaceuticals (i.e., diclofenac; Margalida et al. 2014; Green et al. 2016). This is especially relevant to globally endangered vultures (Ogada et al. 2012; Buechley and Şekercioğlu 2016), which were also considered by shepherds as the most important providers of scavenging services (Morales-Reyes et al. 2018). In agreement with recent studies (e.g., Anadón et al. 2009; Danielsen et al. 2014), we have pointed out that future research could significantly benefit from shepherds' ILK to collect reliable information on endangered scavenger species in a more rapid and cost-effective way than standard scientific methods (e.g., camera traps), for instance, in data-deficient places (e.g., remote areas). Nevertheless, former research has warned that many potential biases can distort data on ecosystem long-term dynamics, for instance, when inferring population trends only from ILK (see, e.g., Daw 2010).

In scenarios where shepherds have a wide knowledge of the scavenger community and a strong appreciation for scavenging services (Morales-Reyes et al. 2018), shepherds can play a key role for providing useful information regarding scavengers and for the preservation of scavenger species. In this sense, our results are relevant to conservationists managing those cultural landscapes associated with extensive farming systems, as those shepherds with rich ILK who also appreciate the role of scavengers as providers of ecosystem services can act not only as providers of reliable information regarding scavengers, but also can become stewards for conservation. Consistently, recent studies have demonstrated the relevance of ILK in shaping positive perceptions towards scavenger species and their conservation (Morales-Reyes et al. 2018; Cortés-Avizanda et al. 2018). In addition, shepherds' ILK is central to the preservation of traditional livestock farming practices such as transhumance (Oteros-Rozas et al. 2013) and the practice of abandoning livestock carcasses in the field (Morales-Reyes et al. 2018), which play a fundamental role in the conservation of the community of vertebrate scavengers (Olea and Mateo-Tomás 2009). For instance, the application of a restrictive sanitary policy that prohibited the traditional practice of livestock carcass disposal in which scavengers freely remove livestock carcasses led to negative consequences on scavenger conservation (Arrondo et al. 2018). Consequently, ILK could be jeopardized by these policies with negative implications in livestock management and scavenger conservation. Therefore, our findings are also relevant for policy-making which tends to rely on SK and overlook ILK (Molnár and Berkes 2018).

Conservation of scavengers can benefit from the consideration of both knowledge systems. The global scientific understanding (SK) of the scavenging service tempered with the ILK adapted to different local settings can leverage contextually actions and programs for scavengers conservation. In doing so, the Multiple Evidence Base approach suggested by IPBES offers a platform where ILK and SK are considered equally useful to build an enriched understanding of biodiversity and ecosystem services that can provide new insights and innovations for conservation (Tengö et al. 2014).

CONCLUSIONS

This research shows the importance of equally bringing different knowledge systems, i.e., ILK and SK, in a research process for assessing the regulating services of carcass removal provided by vertebrate scavengers, which were perceived by shepherds as the most important services provided by scavengers (Morales-Reyes et al. 2018). Recently, IPBES has called for scientists to engage with ILK and to bring SK and ILK on an equal platform to gain understanding about biodiversity and ecosystem services (Tengö et al. 2014, 2017). In fact, this study aligns with the Multiple Evidence-Based approach proposed for IPBES assessments (Tengö et al. 2014) by bringing together two knowledge systems in order to understand the scavenging service.

By enhancing the understanding of the relationship between shepherds and vertebrate scavengers in traditional livestock farming systems and by engaging with shepherds in a respectful collaboration, conservationists can rely on ILK to obtain information about scavengers and the ecosystem services provided by them, particularly at the species level. However, nowadays, shepherds and their ILK are often overlooked both in European and national policies (Molnár and Berkes 2018). In this sense, it is necessary to highlight the relevant role of ILK and to integrate ILK and SK into management and conservation strategies (Firn et al. 2018) of globally endangered vultures and other large scavengers.

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