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Supplanting ecosystem services provided by scavengers raises greenhouse gas emissions

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Global warming due to human-induced increments in atmospheric concentrations of greenhouse gases (GHG) is one of the most debated topics among environmentalists and politicians worldwide. In this paper we assess a novel source of GHG emissions emerged following a controversial policy decision. After the outbreak of bovine spongiform encephalopathy in Europe, the sanitary regulation required that livestock carcasses were collected from farms and transformed or destroyed in authorised plants, contradicting not only the obligations of member states to conserve scavenger species but also generating unprecedented GHG emission. However, how much of this emission could be prevented in the return to traditional and natural scenario in which scavengers freely remove livestock carcasses is largely unknown. Here we show that, in Spain (home of 95% of European vultures), supplanting the natural removal of dead extensive livestock by scavengers with carcass collection and transport to intermediate and processing plants meant the emission of 77,344 metric tons of CO_2 eq. to the atmosphere per year, in addition to annual payments of ca. $50 million to insurance companies. Thus, replacing the ecosystem services provided by scavengers has not only conservation costs, but also important and unnecessary environmental and economic costs.

Global warming is one of the most debated topics among environmentalists and politicians because of its implications in biodiversity conservation and human welfare[1,2]. Scientific evidence supports a link between this unequivocal and continuing rise in average temperatures over the last 130 years and human-induced increments in atmospheric concentrations of some gases such as carbon dioxide, methane or nitrous oxide (globally called greenhouse gases, GHG)[3,4]. Thus, in 1997 the United Nations Framework Convention on Climate Change (UNFCCC) developed the Kyoto Protocol, committing parties to setting internationally binding emission reduction targets. However, although the initiative is outstanding, policies have been weakly applied, and attempts to improve them have seen little success[5]. In fact, global GHG emissions have accelerated since 2000[6]. The future is even more uncertain as some new human activities may be leading to novel pathways for GHG emissions.

An example of a new source of GHG emerged after the recent mad cow crisis in Europe. On this continent, the outbreak of bovine spongiform encephalopathy (BSE) in 2001 and the detection of the variant (vCJD) and new variant (nvCJD) of Creutzfeldt-Jakob disease in humans led to the passing of sanitary legislation (Regulation EC 1774/2002) that greatly restricted the use of animal by-products not intended for human consumption (ABPs). Under this legislation, carcasses of domestic animals had to be collected from farms and transformed or destroyed in authorised plants, not only contradicting the obligations and efforts of member states to conserve scavenger species[7–9], but also potentially generating an unprecedented source of GHG emissions through carcass transportation, transformation and incineration. Thus, while the European Commission is attempting to reduce GHG emissions by applying an assortment of policies and technologies[10], it is also potentially putting policies in place that increase emissions by replacing an ecological service that has been provided by scavengers for millennia[11].

Moreover, as vultures (specialized or obligate scavengers) in Europe have traditionally relied on domestic livestock carcasses for feeding[12,13], the implementation of the European sanitary legislation – with the associated reduction in food supply and/or the change in its temporal and spatial availability, has had negative impacts on vulture behaviour, ecology and conservation at both the individual and guild levels[14–17].

Although new and encouraging legislation was approved in March 2011 (Regulation EC 142/2011), allowing farmers to abandon extensive livestock carcasses in certain "free areas" in the field and at feeding stations[18], it is far from implementation and an important portion of livestock carcasses is still removed from the field by authorised companies as mandated by the previous regulation. Moreover, some regions lack the specific legislation required to apply the European guidelines at the local scale, and future reversion to more restrictive rules due to new sanitary pressures cannot be ruled out. Thus, modelling the current scenario of GHG emissions linked to the artificial removal of livestock carcasses may help to broaden our understanding of the dimensions of supplanting this ecosystem service provided by scavengers. Mapping ecosystem services, or the consequences of their suppression, has been suggested as an essential step to minimize the anthropogenic footprint through the implementation and improvement of "win-win" strategies –those benefiting both biodiversity conservation and human welfare, as well as the reconciliation of conflicting policies[19,20]. Until now, however, how vertebrate animals might be allied in the fight against climate change, hence benefiting humanity through preventing the release of carbon and nitrogen stored in terrestrial ecosystems to the atmosphere is largely unknown[21], and never has been spatially assessed.

Here, we spatially quantify the GHG emissions associated with one aspect of the application of the European sanitary regulation 1774/2002, namely the transport of carcasses from extensive farms to processing plants (Fig. 1). Briefly, this regulation mandates that livestock carcasses be collected from farms within 24 (cattle) or 48 h (other livestock) after death and moved to processing plants, where they are subjected to different treatments depending on their risk to public and animal health (i.e., if they are ruminant or non-ruminant carcasses). However, due to the long distance at which these plants are located, most livestock collected is first stored, unprocessed, at intermediate plants. At the end, carcasses can be used for industrial purposes (e.g. to produce organic fertilizers) or be transported to incineration plants or approved landfills[22]. Fossil fuel combustion associated with the transport sector is one of the main sources of GHG emissions worldwide[23], and thus our goal is to demonstrate how much of this emission could be prevented in the return to traditional and natural systems in which scavengers freely remove livestock carcasses, or conversely, how much GHG is generated by supplanting this ecological service. We recreated the process of carcass collection and transport and the associated generation of GHG in peninsular Spain, where the majority of European vulture populations is located (ca. 95%)[7,9].

To spatially estimate GHG emission, we divided the entire area into 10 × 10 km grids and, for each, estimated the biomass of carcasses generated per year using the total number of extensive livestock (i.e., cattle, sheep, goat and pig), their weight and annual mortality rates. We calculated the distance covered in the transport of carcasses to intermediate and/or processing plants by twice simulating the displacement (using the main national road network) of a truck from the nearest plant to the centre of each grid (empty and full truck; Fig. 1). We calculated GHG emissions associated with carcass transport according to IPCC[24]. GHG emissions are quantified as metric tons of CO_2 equivalents. As an indicator of the capacity of the environment to provide the supplanted ecosystem service, we used information from the National Biodiversity Inventory to cross the estimated GHG emissions with the distance of each grid centre to the nearest breeding site, and with the richness per grid of obligate scavengers (griffon *Gyps fulvus*, cinereous *Aegypius monachus*, Egyptian *Neophron percnopterus* and bearded vultures *Gypaetus barbatus*).

Results

Supplanting the removal of dead livestock by scavengers through carcass collection and transport to intermediate and processing plants represented trips by 49,808,685 km and the consequent emission of 77,344 metric tons of CO_2 eq. to the atmosphere per year. Our estimates of CO_2 eq. should be considered as a minimum, as GHG

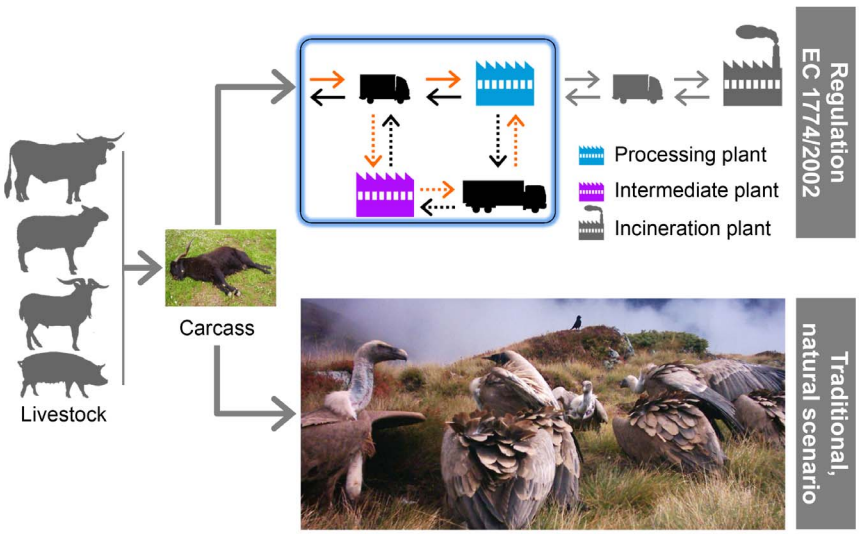

Figure 1 | Schematic representation of the application of the European sanitary regulation 1774/2002 and the natural system of extensive livestock carcass removal. Following this regulation, carcasses are collected from extensive livestock farms and moved to the nearest processing plant within 24–48 h after death. However, as some regions are too far from these processing plants and trucks would thus cover long distances without a full load, some intermediate plants have been established as storage points. From there, carcasses are then moved to processing plants using larger trucks. Carcasses may then be transported to incineration plants. The route done by full and empty trucks is shown by orange and black arrows, respectively. In the traditional, natural scenario, vultures and other scavengers efficiently remove carcasses *in situ*, normally in <24 h[15]. The activities modelled in this article are included in the blue box. Photographs were taken by José A. Donázar (goat) and José A. Sánchez-Zapata (vultures).

emitted during carcass processing and incineration has not been included. This calculation is a challenge, as collected carcasses might follow very different industrial processes subjected to different sources of energy consumption and GHG emissions.

Mountainous and remote areas such as the Pyrenees or western Spain showed the highest levels of GHG emissions (Fig. 2), mainly due to their higher numbers of livestock but also to their location far from intermediate and/or processing plants. Paradoxically, those

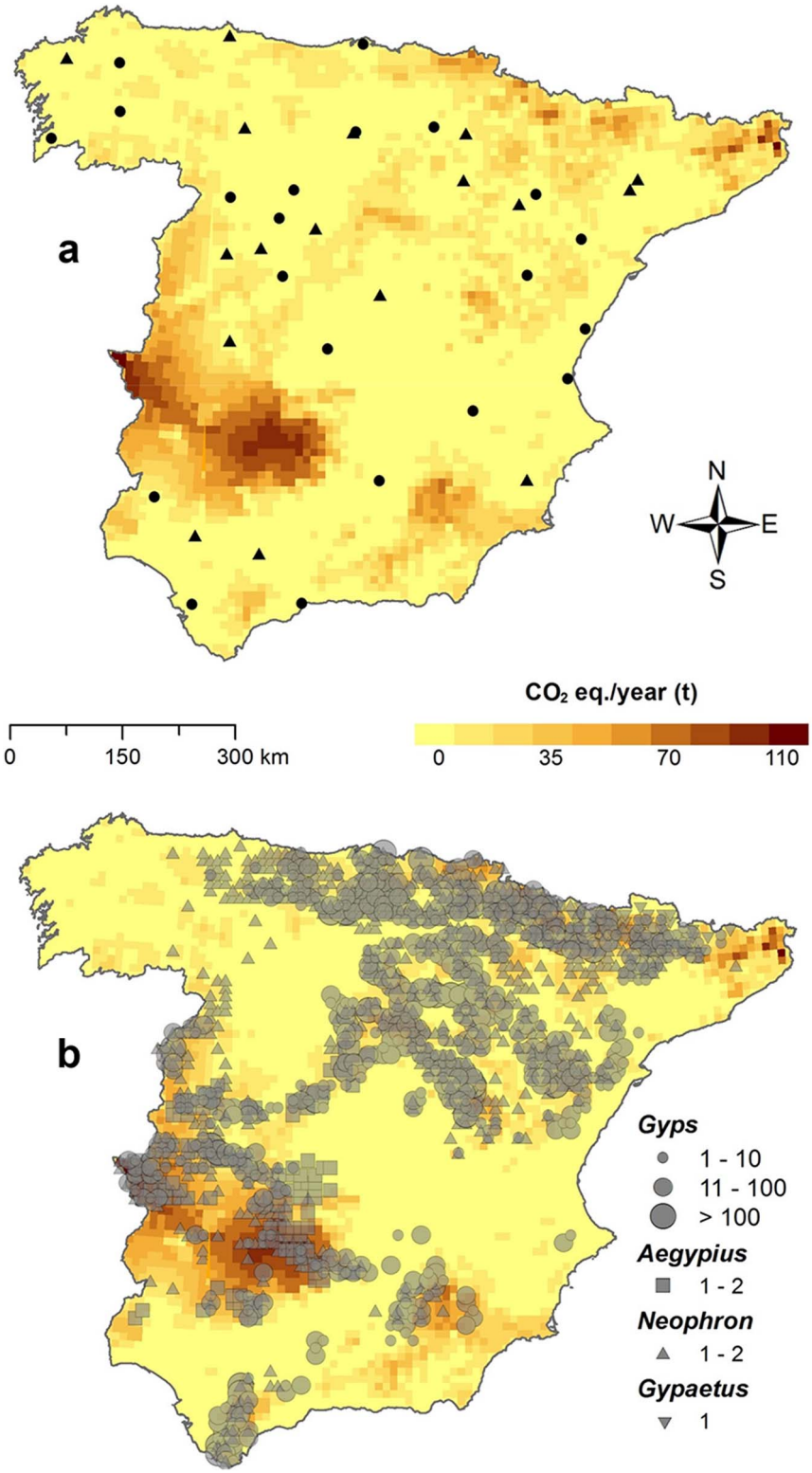

Figure 2 | Estimated CO_2 emissions (in metric tons of CO_2 eq. per 10 × 10 km grid per year) associated with the transport of extensive livestock carcasses from farms to processing plants in continental Spain. The location of intermediate (circles) and processing (triangles) plants is shown in (a), and vulture breeding sites are shown in (b). Legend values represent the number of breeding pairs. Maps were generated with ArcGIS 10.1.

areas are also among the best conserved regions in Europe, showing the highest densities of vultures. Indeed, we found a strong association between CO_2 emissions and the distribution and richness of obligate scavengers (Fig. 3).

Discussion

After the implementation of the European sanitary legislation approved in 2002, many contradictions between biodiversity conservation and sanitary policies arose. The removal of livestock carcasses from the field and their disposal at only a few authorised feeding points proved to have more negative than positive effects for the long-term viability of vulture and other scavenger populations[8,25]. Our findings suggest an additional argument in favour of traditional, more natural systems of livestock carcass removal. In Spain, emissions from the transport sector increased by 43.7% between 1990 and 2012, and currently account for 23.7% of total GHG emissions. According to our results, the emissions associated with the transport of extensive livestock carcasses represented 0.1% of the total national transport emissions in 2012[26]. For comparison, our estimate signifies 25, 15, 8 and 4% of total national emissions arising from rice cultivation, burning of agricultural residuals in the field, the chemical industry and sewage treatment, respectively[27]. It is worth to remark that this estimate corresponds only to one part of livestock carcass treatment, such that emissions would increase with the inclusion of the transformation and incineration of carcasses. Thus, further research is needed to complete the estimation of the total GHG emission linked to whole application of the actual sanitary regulation.

Given that Spain is one of European countries that has to pay more to comply with the Kyoto protocol[28], this is an unnecessary increment in GHG emission that should be considered, mainly when scavengers –and vultures in particular– are highly efficient in removing carcasses from the field[29,30]. Indeed, the removal rate of livestock carcasses by scavengers in Spain (median: 166 min for predictable and 182 min for unpredictable carcasses)[15] is faster than figures depicted in the legislation. Strikingly, regions with the largest amounts of CO_2 emissions are also those supporting the largest vulture populations, suggesting that, in the absence of sanitary constraints, vultures would have removed most of the extensive livestock carcasses from the field without unnecessary environmental costs. In addition, this EC regulation also entails economic costs other than those previously mentioned (i.e., derived from the excess of CO_2). The annual payment made by farmers and regional and national administrations to Spanish insurance companies for the artificial removal and processing of extensive livestock carcasses was ca. $50 million in 2012[31]. Environmental and economic savings associated to natural carcass removal have also been identified in other European countries hosting vultures, such as France, in which livestock carcass management strategies differ. However, due to the restricted geographic distribution of the main scavenger species, the griffon vulture (720 breeding pairs at one reintroduction site in the Grands Causses region, Massif Central, France), figures are substantially lower than those calculated in Spain (8.42–33.11 tons of CO_2 per year, depending on the simulated scenario)[21].

In 2013, no cases of BSE were reported in Spain, and European statistics show that the number of reported cases in farmed cattle is anecdotal[32], so the sanitary risk associated with the natural removal of carcasses could be considered negligible. Therefore, the return to the traditional system in which vultures and other scavengers freely exploit the carcasses of extensive livestock is highly recommended from multiple points of view. Humans and scavengers have coexisted for millennia, and vultures have traditionally provided important ecosystem services such as disease and pest control, nutrient cycling, cultural inspiration and recreational activities[11]. Replacing some of these services, as shown here, not only has conservation costs but also unnecessary environmental and economic costs, which can be saved if we simply let nature do its job.

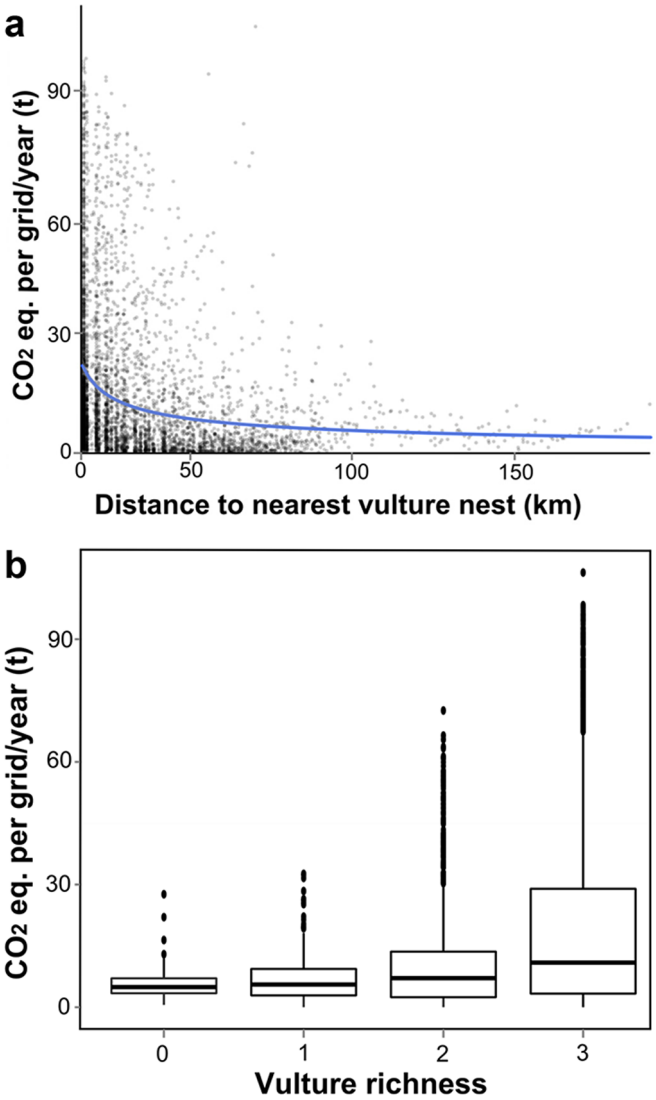

Figure 3 | Relationships between CO_2 emissions and vulture distribution and richness in continental Spain. Metric tons of CO_2 eq. per grid per year were (a) negatively associated with distance to the nearest vulture nest/colony (estimate: 2.80E-07, SE: 1.60E-08; $\chi^2 = 482.71$, $p < 0.0001$) and (b) higher in areas with higher richness of vulture species (Kruskal-Wallis test, $\chi^2_3 = 187.8$, $p < 0.001$).

Methods

Livestock and carcass availability. We obtained the number of head of livestock per municipality in 2012 from the Spanish Ministry of Agriculture, Food and Environment[33]. We included the most important extensive livestock species: cattle, sheep, goat and pig. From the same source, we obtained the average weight of each livestock age class. Numbers, weight, and the annual mortality rate of each type of livestock per age class (Decree 17/2013 of the region of Castilla y León[34]; Supplementary Table 1) were used to calculate the biomass of carcasses generated per year. We generated one map with the biomass of carcasses per municipality per day, as carcass collection should occur within 24–48 h after livestock death. This map was then divided into 10 × 10 km grids using the Universal Transverse Mercator (UTM) system.

Carcass transport. We simulated the movement of carcasses from farms to processing plants directly or indirectly, through intermediate plants, following the scheme shown in the Fig. 1. We estimated the distance travelled by carcasses using the main national paved road network and the network analysis extension in ArcGIS 10.1. As the location of each farm was not available, we considered the center of each 10 × 10 km grid to be the point of origin (i.e., the farm) from which carcasses were moved. From these points, we calculated the distance travelled by trucks to the nearest plant. If this plant was a processing plant, then carcass movement was considered complete. If this plant was an intermediate plant, another truck was used to complete

the transport of the carcasses to processing plants. In our analysis, movements from farms (i.e., grid centers) to intermediate or processing plants were performed daily, using 7.5 t rigid trucks of 230 hp, while movements from intermediate to processing plants occurred weekly and used 24 t articulated trucks of 340 hp. Vehicle types were determined by direct information from companies and regional regulations. We assumed that daily trucks collected all the carcasses generated within a grid cell until they reached their full load (7.5 t). Trucks moving carcasses from intermediate to processing plants were also completely loaded. Typically, more than one truck per week moved from an intermediate plant to a processing plant. All trips were calculated twice, as trucks must make the same trip in both directions. Intermediate and processing plants were geographically located using information provided by the Spanish Ministry of Agriculture, Food and Environment and the Autonomous Communities[35]. Distance calculations were made using the shortest road between origin and destination points (i.e., farms to intermediate or processing plants, and intermediate plants to processing plants), and prioritizing road type from highest to lowest speed (i.e., highways, national roads, autonomic roads, streets, and unpaved roads)[36].

GHG emissions. During the combustion process, most carbon is immediately emitted as CO_2, although other GHG such as N_2O and CH_4 are also produced. Thus, we calculated the emissions of these three gases separately as $E(i) = AD * EF(i)$, where i is the gas type (CO_2, CH_4 or N_2O), AD is activity data and EF is the emission factor, 73.7 t/TJ for CO_2[37] and 0.0039 t/TJ for CH_4 and N_2O[24]. Activity data (AD) was calculated as $FC * FD * LHV$, where FC is fuel consumption, FD is fuel density and LHV is lower heat value. FD (0.845 kg/l) and LHV (0.0424 TJ/t) were obtained from the Spanish Ministry of Agriculture, Food and Environment[33]. FC was calculated by multiplying the distance covered by each truck by the expected average fuel consumption per km expected by each type of truck[24]. We considered that all trucks of the same type consumed the same quantity of fuel per km regardless of their load (0.21 l/km for trucks used to move carcasses from farms to the nearest plant and 0.26 l/km for trucks used to move carcasses from intermediate plants to processing plants)[38]. We assumed that all trucks used oil/diesel fuel and were 11 yrs old, such that motors are thermally stabilized and do not have catalysts. These assumptions are based on the fact that in 2011, ca. 90% of trucks and vans in Spain were diesels, and their average age was 11 yrs old[39]. As fuel combustion is not perfect and a small portion may lead to residuals (ash and soot), we included an "oxidation factor" which expresses the ratio of CO_2 emitted per fuel unit (0.99)[37]. Results are presented as CO_2 equivalents (CO_2 eq.), a quantity that describes, for a given mixture and amount of GHG, the amount of CO_2 that would have the same global warming potential (GWP) when measured over a specified timescale (100 years)[24]. GWP values for CH_4 and N_2O were 34 and 298, respectively, with climate-carbon feedback values and lifetimes taken from[40]. CO_2 eq. is expressed as parts per million by volume and referred to the 10×10 km grid cell where carcasses originated.

Scavenger distribution. We used data available from the Spanish National Biodiversity Inventory[33] to map the distribution of obligate scavengers (i.e., griffon *Gyps fulvus*, cinereous *Aegypius monachus*, Egyptian *Neophron percnopterus* and bearded vultures *Gypaetus barbatus*) across Spain. We focused on the breeding population, which represents approximately two-thirds of the total vulture population. We calculated the distance of each 10×10 km grid center to the nearest breeding site (i.e., nest or colony) of any obligate scavenger. Because of the high daily mobility of these species (griffon vultures: up to 70 km from breeding sites; cinereous vultures: up to 86 km from breeding sites; bearded vultures: up to 45 km from breeding sites; Egyptian vultures: up to 70 km from breeding sites)[12,41], we also calculated their richness (i.e., number of species) in a 100 km buffer around each 10×10 km grid cell. We used Generalized Linear Models ($1/mu^2$ link function and inverse Gaussian error distribution) to explore the relationship between metric tons of CO_2 eq. per grid and distance to the nearest obligate scavenger breeding site. Metric tons of CO_2 eq. in a 100 km buffer around grids with different species richness (from 0 to 4) were compared using a Kruskal-Wallis test. All analyses were performed in R[42]. We used ArcGIS 10.1 to generate maps.

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Author contributions

Z.M.-R., F.B. and J.A.S.-Z. conceived the idea. Z.M.-R., J.M.P.-G., F.B., C.L., R.M.-O. and J.A.S.-Z. collected and analysed the data. Z.M.-R., M.M., M.C. and J.A.S.-Z. wrote the paper. Z.M.-R., J.M.P.-G., M.M., F.B., M.C., C.L., R.M.-O., A.M., J.A.D. and J.A.S.-Z. discussed the results and commented on the manuscript.

Additional information

Supplementary information accompanies this paper at http://www.nature.com/scientificreports

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