CHAPTER 1

Non-biological factors affecting track censuses: implications for sampling design and reliability

Factores no biológicos afectan los censos de rastros: implicaciones para el diseño muestral y fiabilidad

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ABSTRACT

Track census is a widely used method for rapid faunal assessments, which assumes that differences in track count numbers mainly reflect differences in species abundance due to some biological factors. However, some methodological and climatic variables might affect results of track censuses. Here, we tested the effect of climatic variables, such as maximum temperature, humidity, wind speed or days since last rain, and methodological factors, such as censusing day period, distance from transect to vegetation edge, substrate condition or observer on the number of tracks of mammal carnivores and some of their potential prey detected in sandy substrates. We sampled 2 x 2 km squares located within the scrubland area of Doñana National Park (southwestern Spain) for carnivore and several potential prey tracks. Our results showed differences in the number of tracks detected between observers and a significant interaction between observers and the day period when censuses were carried out. Moreover, the variables increasing the quality of the substrate (higher environmental humidity, lower wind speed and days since last rain) led to a greater detection of carnivore tracks, but depending on the size of the species sampled other variables, such as distance from transects to the vegetation border, also affected results. We recommend restricting sampling to certain fixed weather conditions when planning to monitor relative animal abundance from track censuses. When not possible, climatic or methodological variables should be included as covariates in analyses that try to test for the biological factors affecting wildlife abundance, taking into account that these variables, which affect the number of tracks detected could vary between years.

RESUMEN

Los censos de rastros constituyen un método ampliamente utilizado en estudios de fauna y asumen que las diferencias en el número de rastros detectados reflejan diferencias en la abundancia de las especies debido a factores biológicos. Sin embargo, algunas variables metodológicas y/o climáticas pueden afectar los resultados de dichos censos de rastros. En este estudio analizamos el efecto potencial de variables climáticas tales como la temperatura máxima, la humedad, la velocidad del viento o los días transcurridos desde la última lluvia, así como de variables metodológicas como el periodo del día en el que se realiza el censo, la distancia desde el transecto al borde de la vegetación, las condiciones del sustrato o el observador, en el número de rastros de diferentes especies de mamíferos carnívoros así como de algunas de sus potenciales presas detectados en censos de rastros en sustratos arenosos.

Censamos rastros de carnívoros y de diferentes presas potenciales en cuadrículas de 2 x 2 km^2 localizadas dentro del área de matorral del Parque Nacional de Doñana (situado en el suroeste de España). Nuestros resultados mostraron diferencias en el número de rastros detectados en los censos dependiendo del observador, así como una interacción significativa entre el observador y el período del día en el que se realizó el censo. Además, las variables que incrementaban la calidad del sustrato (una mayor humedad ambiental y una menor velocidad del viento, así como un número bajo de días transcurridos desde la última lluvia), permitieron una mayor detección de rastros de carnívoros. No obstante, dependiendo del tamaño de la especie, otras variables como la distancia del transecto al borde de la vegetación también afectaron los resultados. Recomendamos restringir los censos a ciertas condiciones climáticas determinadas cuando se planteen realizar

monitoreos de la abundancia relativa de especies basándose en datos obtenidos por censos de rastros. En los casos en los que no sea posible, las variables climáticas y/o metodológicas se deben incluir como covariables en los análisis que tengan como objetivo analizar los factores biológicos que determinan la abundancia de las especies, teniendo en cuenta que esas variables que pueden afectar los resultados de censos, además pueden variar entre distintos años.

INTRODUCTION

Determining occurrence and estimating population abundance of species is fundamental for their conservation, research and management (Caughley and Sinclair 1994; Silveira et al. 2003; Sadlier et al. 2004). This is particularly difficult and poses many practical problems on a large spatial scale and in long-term monitoring for cryptic species with nocturnal and solitary habits, large home ranges, low-density populations and an elusive nature, such as most mammalian carnivore species and their prey.

Few methods are suitable for monitoring elusive, low-density species (Mills et al. 2000) in spite of the amount of available monitoring methods (Williams et al. 2002; Liebenberg 2010), but indirect sampling methods such as track counts on suitable natural substrates (e.g. snow, mud or sand) have been traditionally used to overcome these problems (e.g. Stephenson 1986; Smallwood and Fitzhugh 1995; Zaumyslova 2000; Gusset and Burgener 2005; Datta 2008; Funston et al. 2010).

The broad application of natural sign surveys such as track counts has firmly established their use as a tool for wildlife detection. Track surveys do not rely upon special technology or equipment, can be relatively straightforward and quick to conduct, and can easily incorporate multispecies and large geographic area objectives. Moreover, track counts do not require a behavioural response to attractants or other survey equipment, thus there are potentially fewer species-specific limitations and biases inherent to track surveys (Long et al. 2008). Nevertheless, field-based species identification may be ambiguous or unfeasible so additional efforts and highly skilled and experienced trackers are needed to validate the identification of species or individuals. This weakness related to species identification combined with the limited availability of appropriate tracking mediums or conditions, the ephemeral and weather-dependent character of tracks and the inconsistent survey designs and quality control procedures, have resulted in a growing criticism of track surveys and the need to improve survey efforts to meet more rigorous standards.

Although strong relationships between kilometric abundance indices (KAI), obtained by spotlight counts, and population size have been previously reported (e.g. Newsome et al. 1989; Short et al. 1997; Garel 2010), it is important to highlight that track censuses can only be taken as indices of presence, relative abundance or density estimators (Anderson 2001) and that such indices are rated closely to true animal abundance across habitat types, observers, and other factors (see Gibbs 200). Herein, the number of tracks of certain species encountered on a transect will depend on biological factors, such as their abundance, food density and distribution, vegetation structure and intra- or interspecific interference, including humans (e.g. Odonoghue et al. 1997; Shapira et al. 2008; Bayne et al. 2008; Blaum et al. 2009) but there are other classes of variables that affect the index (Buckland et al. 1993). These variables are related to the observer, including the observer's training and experience, eyesight and fatigue level, the environment (i.e. climatic conditions and local habitats) and aspects of the species itself, such as their body size (Anderson 2001; Mackenzie and Kendall 2002). Among the variables associated with the environment, such as wind speed, temperature, humidity, cloud cover, time of sunrise or days from the last rain or snow, many have been previously suggested as potential influences on the results of track sampling (Norton 1990; Hayward et al. 2002; Long et al. 2008). These non-biological factors constitute an important source of error, as they affect the probability of detection and therefore the count. If they are not considered when designing a monitoring program they can increase variance or uncertainty for the estimates of relative abundance indices (Thompson et al. 1989).

Despite the potential influence that the above-mentioned factors may have on track counts, specific studies on the subject are scarce (Jennelle et al. 2002; Karanth et al. 2003, but see Stander 1998; Balme et al. 2009; Zielinski and Schlexer 2009). Nevertheless, there is a growing suggestion to include measures of precision and estimates of the detection probability when using indices values (usually raw counts) purporting to measure relative abundance (e.g. Anderson 2001; Rosenstock et al. 2002; Engeman 2003).

Here, we studied how methodological and climatic factors affected the number of tracks detected in surveys carried out on sand-based substrates. Specifically, we examined whether some climatic variables such as maximum temperature, average relative humidity, maximum wind speed or days since last rain and methodological factors such as censusing day period, distance from transect to vegetation edge, substrate condition or observer may affect the number of tracks detected for a set of seven mammalian carnivores and some of their potential prey on sandy substrates in South-western Spain and how, depending on the size of the animals surveyed, different factors could affect the detection probability.

METHODS

Study area

The study was carried out in Doñana National Park in southwestern Spain (37º9´N, 6º26´W). This is a 550 km^2 flat sandy area at sea level bordered to the south and west by the Atlantic Ocean and to the east by the Guadalquivir River mouth. The climate is Mediterranean subhumid (i.e. characterised by mild wet winters and hot dry summers), with an average annual rainfall of 500-600 mm. There are three main environmental units in the park: marshland, dunes and Mediterranean scrubland (Fig. 1). Track censuses were restricted to the scrubland area, which is mainly characterised by heterogeneous patches of xerophytic species such as *Halimium* sp. and *Cistus* sp., and hygrophytic ones such as *Erica* sp., with some patches of *Juniperus phoenicea* and *Pistacia lentiscus* shrubs. Interspersed with the scrubland there are scattered cork oak trees (*Quercus suber*) and wild olive trees (*Olea europea*), and a few patches of pine *Pinus pinea* and eucalyptus *Eucalyptus* sp. plantations. The Mediterranean scrubland represents approximately half of the National Park surface area.

Carnivore species in our study area are the red fox (*Vulpes vulpes*), the Eurasian badger (*Meles meles*), the Egyptian mongoose (*Herpestes ichneumon*), the common genet (*Genetta genetta*), the polecat (*Mustela putorius*) the Iberian lynx (*Lynx pardinus*), the European otter (*Lutra lutra*), wild and domestic cat (*Felis* sp.), and domestic dog (*Canis familiaris).* Polecats and otters were excluded from our study because of their low abundance.

Potential target prey species for hunting or consumption as carrion by the carnivore community and sampled in our study were small mammals (i.e. Garden dormouse (*Eliomys quercinus),* Southern Water Vole *(Arvicola sapidus),* bush rat

(Rattus rattus), Long-tailed Field Mouse *(Apodemus sylvaticus)* and other mice *(Mus* spp.*),* but the most common are *A. sylvaticus* (Kufner and Moreno 1989)), European rabbits (*Oryctolagus cuniculus)*, red partridges (*Alectoris rufa*), domestic cows *(Bos Taurus)* and horses (*Equus caballus*) and wild ungulates such as the fallow deer (*Dama dama)*, the red deer (*Cervus elaphus)* and the wild boar (*Sus scrofa*).

Track sampling

Under a wider project that aims to study biological and anthropic factors affecting wild and domestic carnivore abundance and distribution within Doñana National Park, during the wet seasons of 2007-08 and 2008-09 (from

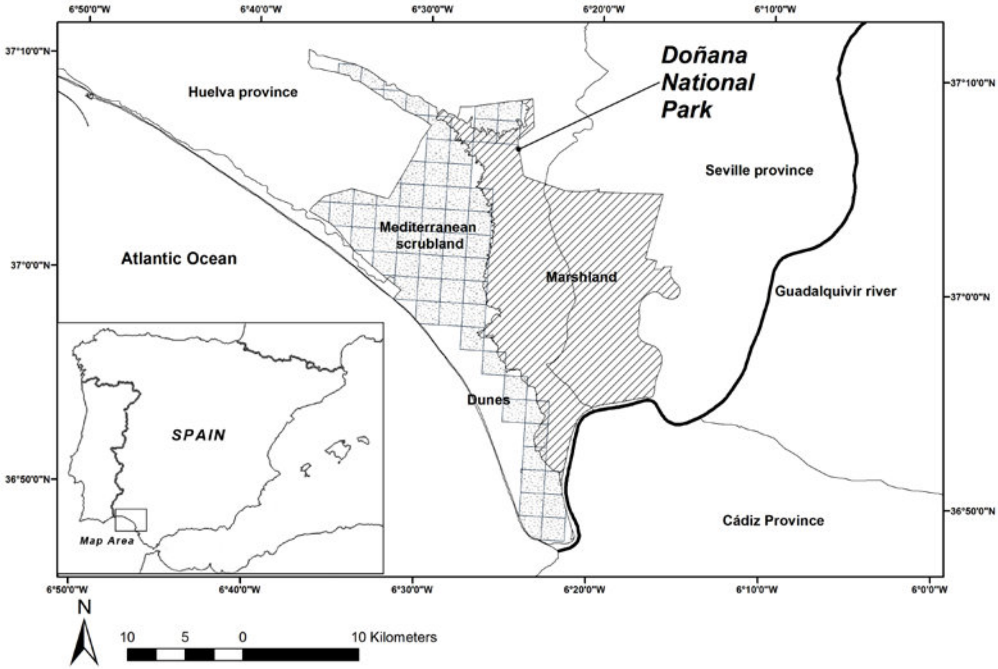

Figure 1. Map of the study area showing Doñana National Park in the southwestern Spain and the 2x2 km^2, where carnivore and prey track censuses were carried out

November 2007 to May 2008 and from October 2008 to April 2009) three and two observers sampled 59 and 57, respectively, 2 x 2 km squares all with at least 40% of their surface located within the scrubland area of the park (Fig.1). Marshland area was not sampled as its clay soils make it unsuitable for track censuses. The squares with ≥40% area of open dune were excluded for the present study since vegetation is clearly different from the rest of the scrubland area, which would add an extra source of variability to data. The three observers of the first year were a fieldworker with 15 years of experience and two without previous experience, but that were trained for two months by the experienced fieldworker. During the second year, the experienced observer and one of the others carried out the surveys.

We sampled for carnivore tracks in each square by slowly walking zigzag (ca. 1.5 km/h) in at least 3 km-long sandy paths (in car tracks or firebreaks). Once a continuous track, that crossed side to side across the pathway, was detected, we georeferenced it using a GPS. We noted location as a grid reference, date, and the methodological variables, censusing day time (we established three block schedules; early morning (from 8 a.m. to 12 a.m.), afternoon (from 12 a.m. to 3 p.m.) and evening (from 5 p.m. to sunset), start time and end time for each census, and the observer who carried out the census. In order to homogenize the number of tracks detected per grid and maximize the probability of detection for each carnivore species, we re-sampled the same path (leaving at least 7 days between samplings) a second time in a few squares until completing 3 km if during the first sampling there was not enough available path within the square to achieve this distance. Thus, we had more censuses than total number of 2x2 km squares. We always carried out surveys at least 3 days after any rainfall.

We concentrated prey sampling within on month to avoid strong intermonthly variations in abundance for some species (e.g. see Kufner 1986; Palomares et al. 2001 for small mammals and European rabbits, respectively). Thus, we carried out the sampling of prey tracks in April 2009 along transects in every 2x2 km square sampled for carnivore tracks. These transects for prey species were walked as they were for carnivore tracks, were 25 m in length and approximately 1.7 m wide (i.e. the area of a four-wheel-drive car) and were located in the middle of the census path and separated by at least 300 m. We recorded the location as a grid reference, date, observer, and the following methodological variables: distance from nearest border of census transect to the closest vegetation border (not recorded for carnivore track censuses as they were carried out by zigzag walking), pathway where transects were established (firebreaks or car tracks) and quality of the substrate for detecting tracks based on the presence of grass (we established two categories; good (when grassy groundcover was less than 10% in any part of the 25 m transect) and fair (when grassy groundcover in any part of the 25 m transect was between 11-30%). We considered unsuitable for prey counts transects in which grassy groundcover was more than 30% in some part of the transect.

The climatic variables result from an average of the maximum temperature (calculated as the average of the maximum temperature measured on the census day and the maximum temperature measured two consecutive days before the census day), relative humidity, maximum wind speed, and the number of days since last rain. The data was obtained from a station located inside Doñana National Park (Control RM1 Meteorological Station; Latitude: 37º 1’18”, Longitude: 6º 33’ 17” http://icts.ebd.csic.es).

Data analyses

In order to avoid linearity assumptions, we preliminary explored the shape of the response for each landscape variable before fitting them into the final equations (Austin, 2002). With this aim we fit Generalised Additive Models (GAMs) (Hastie and Tibshirani, 1990) using carnivore Kilometric Abundance Indexes and the number of prey tracks as response variables and fitting smoothing splines with 3 degrees of freedom to model every climatic and methodological continuous effect. The smoothed variables were then turned into suitable parametric terms guided by visual inspection of the partial residual plots (Crawley, 2005). The postulated models were then fit to the track-census dataset using general linear models (GLM) with the log link, negative binomial error structure and linear and non-linear responses to fixed effects in accordance with the GAM results. We analyzed the effect of methodological variables observer (*observer*) and censusing day time (*day_time*), and climatic variables maximum temperature (*max_temp*), average relative humidity (*humidity*), maximum wind speed on census day (*wind_speed*), and days since last rain (*last_rain*) on the carnivore Kilometric Abundance Index (KAI)). We also included in the models the interactions between *observer* and *day_time*, as the number of samplings carried out by each observer in each daily time period was different. Correlations between predictors were always low ($r < 0.6$) so we fitted full models (i.e. models including all the methodological and climatic variables). As for some 2x2 km squares we carried out more than one census, our sampling unit was the census and not the square. We examined the effect of the above variables on total carnivore abundance index, small carnivore (from 1-5 kg of body mass) abundance index (including the common genet, wild and domestic cats and the Egyptian mongoose) and medium-sized carnivore (>7 kg of body mass) abundance index (including the red fox, the Eurasian badger, the Iberian lynx and the domestic dog).

We followed a backward regression-model selection procedure excluding variables contributing least to the model (i.e. variables with $P > 0.3$) before models were refitted. Only variables with $P \leq 0.05$ were interpreted as statistically significant. Overdispersion was not a problem (ϕ was close to 1 (1.14 - 1.21)) for any of the models (Zuur at al. 2009). We analyzed data separately for each study year as the number of observers changed and to maximize the variability between conditions, which could affect the number of tracks detected on sand substrates.

We also performed general linear models (GLM) with negative binomial errors and log link function to analyse the effect of observer, distance from border of census transects to the closest vegetation border (*dist_veg.)*, type of path (*place*) where prey censuses were carried out (firebreaks or car tracks), quality of the substrate (*quality*) and climatic variables *last_rain*, *max_temp*, *humidity* and *wind_speed* on track counts data of prey species. We also included in the models the interactions between *observer* and *quality* and *observer* and *place*. Prey data were grouped as total prey, small prey (small mammals), medium-sized prey (rabbits and partridges) and large prey (cows, horses and ungulates). Correlation between predictors was low ($r < 0.5$), so we fitted full models. Overdispersion was not a problem ($\phi = 1.04 - 1.24$). The sample unit to adjust GLM was the 25 m transects.

To simplify models and their understanding we also followed a backward regression-model selection procedure excluding variables with $P > 0.3$, and then refitted the models.

All statistical analyses were performed using the SAS® 9.2 statistical software (SAS Inst. Inc., Cary, NC), GAM and GLM were fitted using the gam and genmod procedures, respectively.

RESULTS

A total of 471 km were walked and 8,373 carnivore tracks were found during surveys, with the red fox, the Eurasian badger and the Egyptian mongoose being the most recorded species (Table 1). For prey, 5,000 tracks were detected on 11,575 m sampled (Table 2). Prey species more often detected were ungulates (i.e. fallow deer, red deer, wild boar) and rabbits.

For the first year, there were differences in the number of tracks detected among observers for all small and medium carnivores, and the number of tracks decreased when wind speed increased for total carnivores, increased when humidity was higher for small carnivores, and was highest during the afternoon for medium-sized carnivores (Table 3, Fig. 2). A significant interaction was also detected between the censusing day period and the observer, with the three observers finding more medium-sized carnivore tracks in the evening than in the morning or afternoon (Table 3, Fig. 2d).

Table 1. Carnivore kilometric abundance index (tracks / km; KAI) in the scrubland area of Doñana National Park during the wet seasons of 2007-2008 and 2008-2009.

	2007-2008				**2008-2009**			
Species	Positive censuses	Total number of tracks	KAI (mean±SD)	Range	Positive censuses	Total number of tracks	KAI (mean±SD)	Range
Lynx pardinus	19	65	0.4 ± 0.9	0 - 5.4	14	75	0.4 ± 0.9	0 - 5.0
Meles meles	68	599	3.9 ± 5.1	0 - 20.6	53	666	3.7 ± 3.8	0 - 17.3
Herpestes ichneumon	60	631	4.0 ± 4.4	0 - 21.1	48	544	2.8 ± 3.3	0 - 12.5
Vulpes vulpes	76	3,138	17.7 ± 9.1	2.4 - 44.2	61	2,333	11.9 ± 6.5	1.2 - 32.6
Genetta genetta	21	160	0.8 ± 2.3	0 - 15.9	20	66	0.4 ± 0.7	0 - 2.8
Felis sp.	8	25	0.2 ± 0.8	0 - 5.7	17	27	0.1 ± 0.3	0 - 1.3
Canis familiaris	12	23	0.2 ± 0.7	0 - 5.9	11	21	0.1 ± 0.3	0 - 2.0

Number of censuses was 76 and 62 for each study year, respectively.

During the second year, more tracks were detected when humidity increased for total and medium-sized carnivores, and fewer small carnivore tracks were recorded when daily maximum temperature and days since last rain increased (Table 3, Fig. 3).

Most of the variables considered affected the total number of prey tracks detected (Table 4). Thus, the number of tracks for total prey increased when the daily maximum temperature, humidity and days since last rain increased (Fig. 4c), and decreased when wind speed and distance to vegetation edge was highest. Furthermore, the number of total tracks was higher when samplings were carried out in car tracks than in firebreaks (Fig. 4b), one observer detected more tracks than the other (Fig. 4a), and there was a significant interaction between *observer* and *place* (Fig. 4d). Some interesting exceptions to this general pattern were found when data were separated by type of prey (Table 4). For small prey, number of tracks was not affected by wind speed, humidity, maximum daily temperature and days since last rain, and the interaction between *observer* and *place* was not found. For medium-sized prey the number of tracks found was not affected by wind speed, daily maximum temperature and days from the last rain, but in this case quality of the road did affect results, with a higher number of tracks being detected at transects without grass. Finally, the number of large prey tracks was not affected by daily maximum temperature, distance to vegetation, type of path, or observer, and there was no interaction between *observer* and *place*.

DISCUSSION

Track censuses can provide a rapid and cost-effective assessment of relative abundance of a species, but improving their performance and robustness by understanding the factors that potentially affect them is a key step for the design of sound monitoring programmes. Indexes derived from track surveys are partially a function of animal abundance, but are also a function of a long list of methodological and climatic variables and characteristics of the species being surveyed. Our results support the hypothesis that non-biological factors can affect the number of animal tracks detected in surveys, and must be taken into account when planning to study animal abundance, distribution or the biological factors determining them.

The aim of this study is not to establish a standard protocol to carry out track censuses in sandy substrates but to identify how different methodological and climatic variables can affect the number of tracks detected in censuses. Nevertheless, as a rule, our study shows how variables increasing the quality of the substrate (e.g. higher environmental humidity, lower wind speed and few days since last rain) allowed the detection of a greater number of tracks. Previous studies had suggested that these types of variables could influence results, but no quantitative data had been provided (but see Hayward et al. 2002; Bayne et al. 2008). For instance, to determine the presence of mountain lions *Felis concolor californica,* through track surveys, Van Dyke et al. (1986) and Smallwood and Fitzhugh (1995) recommended excluding desert areas or windy conditions. Other authors (Zielinski and Kucera 1995; Bayne et al. 2005) have made recommendations for snow tracking to detect the presence of a wide diversity of species such as American

Table 2. Total number of tracks detected and the mean index of abundance (tracks / 25 m) for each group of potential prey species along 463 25 m transects.

Species group	No of tracks	Mean ± SD	Range
Small mammals	233	0.5 ± 1.4	0 - 13
Rabbits	2,132	4.6 ± 9.4	0 - 115
Partridges	260	0.6 ± 1.3	0 - 11
Cows/horses	210	0.4 ± 1.6	0 - 18
Ungulates	2,165	4.7 ± 9.4	0 - 33

martens (*Martes americana*), Canada lynx (*Lynx canadensis*), wolverines (*Gulo gulo*), coyotes (*Canis lastrans*), red foxes (*Vulpes vulpes*), bobcats (*Lynx rufus*), grey wolves (*Canis lupus*) or mountain lions (*Puma concolor*) among others. Recommendations include avoiding tracking during snowfall and waiting until the second morning after a snowfall, carrying out tracking early in the morning during periods of melting and freezing and not tracking on south-facing slopes.

Moreover, in Europe and other arid regions of Australia, India, South America or South Africa where track surveys occurring in dust, mud or sand are more broadly employed, many authors have also tried to standardize survey design and

Table 3. Results of GLM analysis to test for the effect of several methodological and climatic variables on abundance indeces of total, small and medium-sized carnivores in Doñana National Park. Standard errors have been omitted to simplify the table. Variables with $P > 0.3$ excluded from the models are represented as (-). Least squares means (LS-Means) of the categorical fixed effects *observer* and *day time* are shown. Non-est. means that the model could not calculate the parameter because of little data. (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns not significant).

Effects	**2007-2008**			**2008-2009**		
	Total carnivores	Small carnivores	Medium-sized carnivores	Total carnivores	Small carnivores	Medium-sized carnivores
Intercept	3.7238 ***	0.5065	3.2957***	2.4779**	2.0154	1.4906
wind_speed	-0.1329*	-	-0.1316	0.1071	-0.1751	-0.0711
humidity	-	0.0269**	-	0.0194**	-	0.0261**
max_temp	-	-	-	-0.0376	-0.0937**	-0.0095
last_rain	-	-	-	-0.0160	-0.048**	-0.0023
day_time						
early morning	24.5214	-	15.1443**	16.5645	-	15.1596
afternoon	28.3601	-	22.8087**	20.3801	-	16.6357
evening	35.5493	-	27.8652**	29.2495	-	23.1351
observer						
1	20.7509***	3.4544***	16.1252**	-	3.5478	20.0273
2	27.8207***	2.4517***	25.1415**	-	2.4450	16.1825
3	38.8229***	11.5468***	28.3257**	-		
*observer*day_time*	ns	-	***	-	-	-

effort by suspending searches of tracks for ≥ 24 hours after precipitation or periods of high winds (≥ 24 km/h) and also by using only early morning observations for analysis (e.g. Stander et al. 1998; Sargeant et al. 2005; Evans et al. 2009; Funston et al. 2010).

There was some exception to the general rule stated. A positive correlation was found between number of tracks recorded and days since last rain for large prey species. Their large size rendered their tracks easily recognizable in poor substrate conditions.

Table 4. Results of GLMM analysis to test for the effect of several methodological and climatic variables on abundance indeces of total, small and medium-sized and large prey in Doñana National Park. Standard errors have been omitted to simplify the table. Variables with $P > 0.3$ excluded from the models are represented as (-). Least squares means (LS-Means) of the categorical fixed effects *place, quality* and *observer* are shown. Non-est. means that the model could not calculate the parameter because of little data. (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$).

Effects	Total prey	Small prey	Medium-sized prey	Large prey
Intercept	2.4520***	-2.7311***	0.7317*	2.4978***
wind_speed	-0.0005**	-	-0.0004	-0.0006**
humidity	0.0001***	-	0.0001**	0.0001**
max_temp	0.0002**	-	0.0002	-
last_rain	0.0439***	-	-	0.0622***
distance_veg	-0.0666***	-0.1018*	-0.1234***	-
place				
firebreak	2.4818**	-1.0304**	1.2910*	-
car track	2.8317**	-2.3403**	1.7615*	-
quality				
without grass	2.5409	-1.3780	1.8563**	1.5986***
with grass	2.7726	-1.9927	1.1962**	2.3358***
observer				
1	3.1145***	-1.2665**	2.3213***	-
2	2.1989***	-2.1042**	0.7312***	-
*observer*place*	***	-	***	-
*observer*quality*	Non-est.	Non-est.	Non-est.	Non-est.

Other methodological variables also affected results depending on the size of the species sampled. A higher number of prey species tracks were detected when transects ran near a vegetation border or in car tracks. This result could be caused by two different reasons. Vegetation must exert a protective effect against wind and maintain a higher level of moisture on the sand, thereby increasing substrate quality for detecting tracks. Also, medium and small prey may prefer to remain near a vegetation edge to decrease predation risk (Hughes and Ward 1993, but see Moreno et al. 1996).

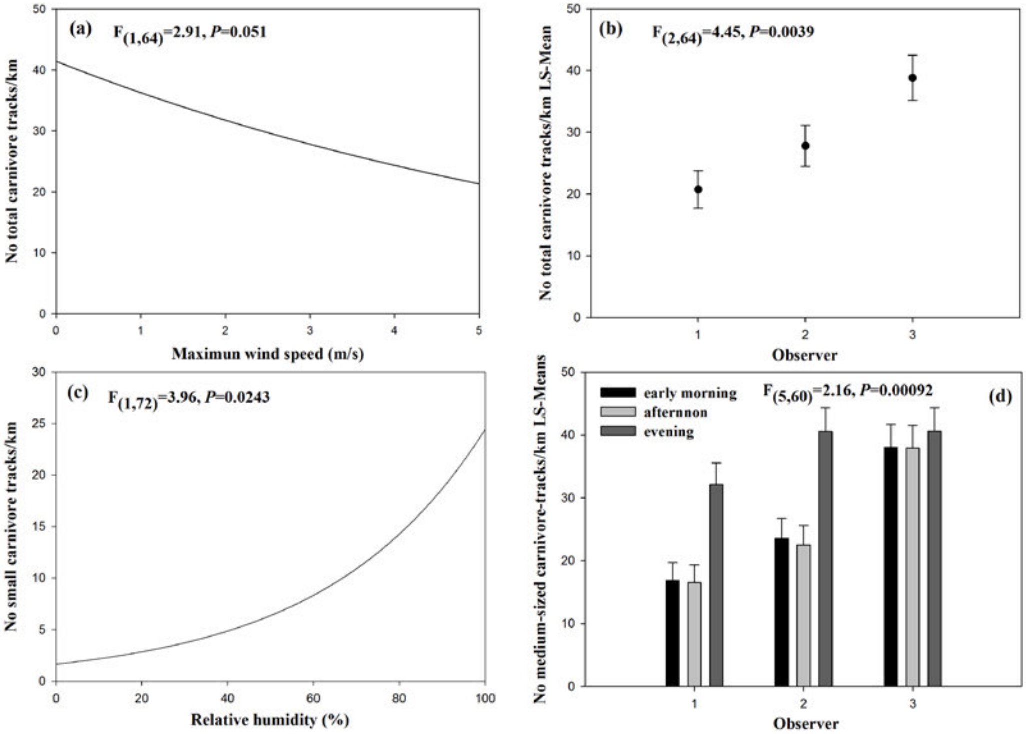

Figure 2. Effects of wind speed on total carnivore tracks per km detected (a), of observer (least square means and their standard errors are represented) on total carnivore tracks per km (b), of relative humidity on small carnivore tracks per km (c), and differences in the number of medium-sized carnivore tracks per km detected by observers in each period of the day given as estimated least square means and their standard errors (d) during the first study year. F values computed as MS_{Model} / MS_{Error} (i.e. Mean $Square_{Model}$/Mean $Square_{Error}$), and their respective p-values are shown.

Nevertheless, it is necessary to note that our results were not consistent among size groups or between years. This could be due to the fact that many of the variables that affect detectability, and therefore the count, exhibit time trends (i.e. vary between years) further confounding the value and interpretation of the index. This is an important issue as it makes track censuses incomparable across different climatic and methodological conditions.

Our results also showed differences in the number of tracks detected amongst observers. Moreover, the differences were more apparent in poor substrate conditions, when the tracks of nocturnal species would have suffered the greatest deterioration due to time, sun or wind, as was suggested by the significant interaction found between observer and the census day time. This result reflects the fact that some observers are able to detect more tracks at one period of the day than others, probably depending on their performance. The effect of the observer in the number of tracks detected could also be partially related to the census speed as differences among observers in their average speed as a function of their experience were detected (data not shown). Quality of data had been previously questioned

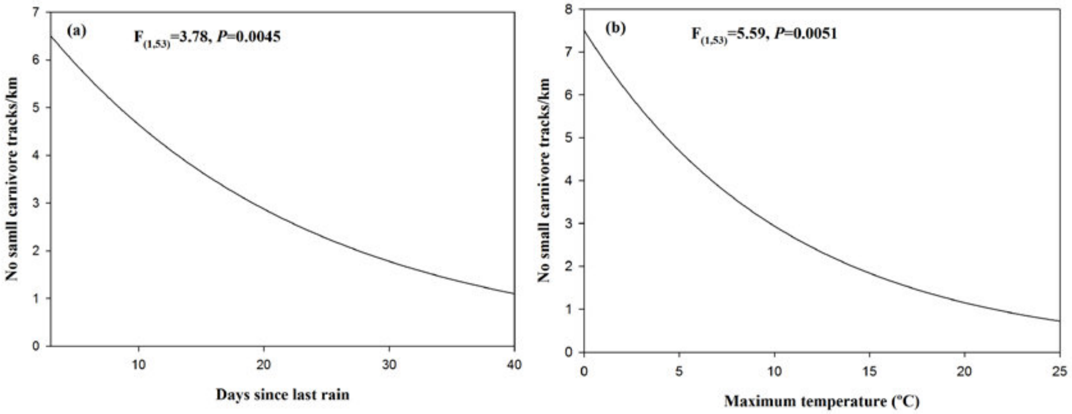

Figure 3. Effects of maximum temperature on small carnivore tracks per km (a), and of days since last rain on small carnivore tracks per km detected (b) for the second study year. F values computed as MS_{Model} / MS_{Error}, and their respective p-values are shown.

depending on skill level of observers (Bider 1968; Smallwood and Fitzhugh 1995; Anderson 2001; Wilson and Delahay 2001; Silveira et al. 2003). For this reason, suggestions have been recently proposed to decrease differences among observers or to evaluate observer skills (Sadlier et al. 2004; Evans 2006, 2009; Zielinski and Schlexer 2009).

Different approaches might be used to reduce the possible influence of methodological and climatic variables on track counts. One would be to limit track censuses to some given weather conditions, which would ensure a constant substrate quality for detecting tracks. Furthermore, to keep constant the time of the

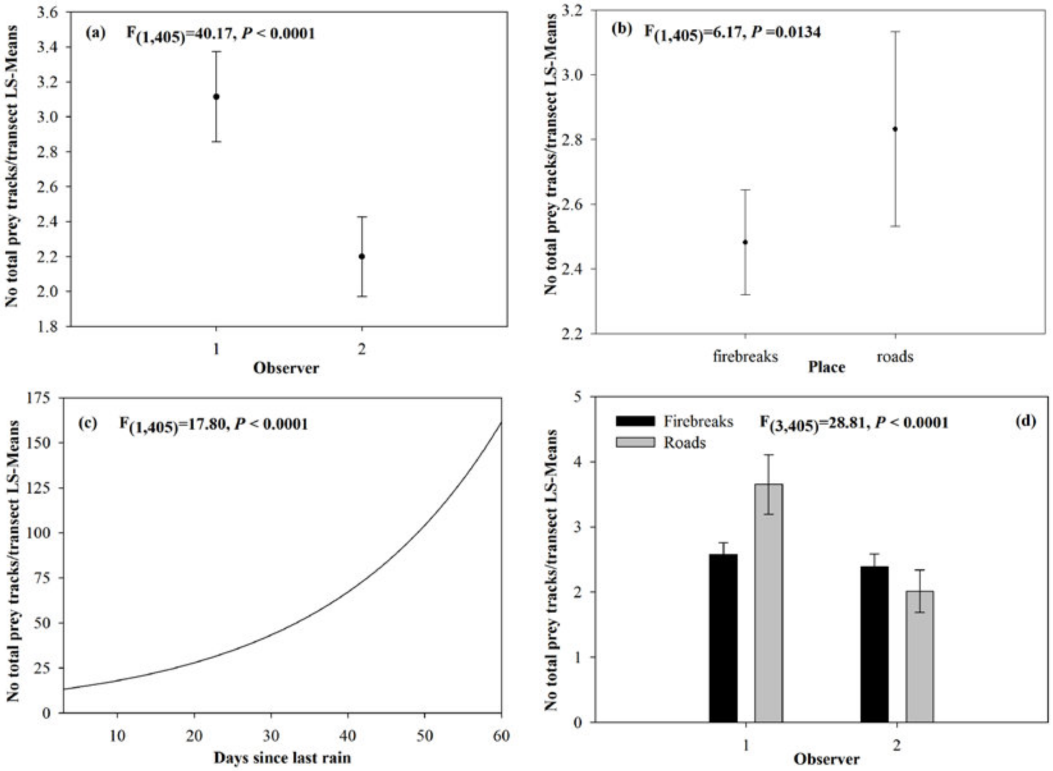

Figure 4. Effects of observer (least square means and their standard errors are represented) on total prey tracks per 25 m transects (a), of censusing place on total prey tracks per km (least square means and their standard errors are represented) (b), of days since last rain on number of large prey tracks (c), and the interaction between observer and type of pathway sampled given as estimated least square means and their standard errors (d). F values computed as MS_{Model} / MS_{Error}, and their respective p-values are shown.

day, days from the last rain or snow, observers involved in the sampling, or distance to vegetation borders will also help to diminish variability in the number of tracks recorded. Some of these suggestions have been approached by maintaining constant substrate quality through the use of artificial substrates and by erasing and resampling newly left tracks on transects for a given fixed number of days (Gruber at al. 2008; Watts et al. 2008; Russell et al. 2009; Zielinski and Schlexer 2009).

Avoiding such potentially confounding effects in data collection should be a fundamental design concept (Engeman 2003). However, it is not always possible to consider these meteorological or methodological issues when carrying out large-scale samplings or when large volumes of data are needed for population estimation procedures. Thus, we also propose that these possible meteorological or methodological variables be recorded and to include them as covariates in any further statistical analysis aiming to test for biological factors affecting relative animal abundance (also see Smallwood and Fitzhugh 1995). Survey design and statistical rigor are important, but we agree with previous authors (e.g. Thompson et al. 1998;Nichols et al. 2000; Anderson 2001; Yoccuz et al. 2001; Mackenzie and Kendall 2002) that estimating relative abundance based on indices alone (e.g., raw counts) is naive, and that the focus of efforts ought to be on estimating detection probabilities as well.

These results could be applied to a variety of research fields, both for testing validity of pre-existing data and improving the suitability and performance of future studies based on track surveys. Although the indices derived from track censuses are only partially a function of animal abundance (Anderson 2001), if the variables associated with the observer, the environment, and characteristics of the species being surveyed are controlled, the reliability of the information extracted from these methods may be improved.

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