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Surveying carnivores at large spatial scales: a comparison of four broad-applied methods

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Abstract Reliable methods to estimate species richness are very important to managers and conservationists because they provide key data to make the right decisions in conservation programmes. In the case of carnivore mammals, traditional methods, such as direct count censuses, are not useful since these animals are usually scarce, elusive and nocturnal. Difficulties in carnivore sampling are compounded when monitoring programmes are developed at large spatial scales, where high economic costs and field efforts are necessary to achieve reliable richness or abundance estimates. These problems have highlighted the need to find more effective carnivore survey methods, especially in regions with high rates of landscape change, such as the Mediterranean basin. The present study, performed in a typical Mediterranean area, was the first in Europe to test simultaneously the relative efficiencies of four broad-applied sampling methods to detect carnivore species at large spatial scales. Sign surveys based on scat detection, scent stations, camera-trapping and live-trapping were investigated. We compared efficiencies using biological parameters and by considering both the logistic and economic costs of each method. Overall, scent stations and sign surveys were the most efficient methods both in economic and logistic terms. In addition, the use of scent stations may be necessary to detect

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species rarely detected by scats. Detailed and extensive training programmes for conducting sign surveys and scent stations may overcome perceived problems thus enhancing the widespread use of both methods. Our results are applicable not only to other Mediterranean areas, but also to other habitats and regions of the world. More research into the suitability of these and other methods in relation to different landscapes, seasons and species is required.

Introduction

Managers and conservationists need reliable methods to estimate species richness in communities and/or population size of target species in order to make the right decisions in conservation practices (Caughley and Sinclair 1994; Sadlier et al. 2004). This fact has been emphasised by an accelerated lost of biodiversity in recent decades which has reinforced the urgent need for monitoring programmes and the necessity of studies relating habitat and species occurrence and abundance worldwide.

Carnivores are a group where worldwide conservation or management problems have been identified (Ginsberg and Macdonald 1990; Zielinski and Kucera 1995; Gese 2001; Wilson and Delahay 2001). Their position in the top of the food webs and their large potential impact on different human activities (game, agriculture, etc..., Saunders et al. 1995; Reynolds. and Tapper 1996; Moore et al. 1999) make this group especially significant in conservation and management actions. However, because carnivores are usually scarce, elusive and nocturnal, they are very difficult to count by traditional methods such as transects based on direct observation (e.g. spotlight or line-transects, Heydon et al. 2000; Sharp et al. 2001) or capture-re-capture estimates based on trapping records (Tuyttens et al. 1999). These problems are especially relevant when the study needs to consider large spatial scales (Zielinski and Kucera 1995; Zielinski and Stauffer 1996; Webbon et al. 2004), where high economic costs and field efforts are necessary to achieve a reliable estimate (Smallwood and Fitzhugh 1995; Sadlier et al. 2004). However, conservation biology is largely related to large spatial scales problem (Edwards et al. 1994) and we need robust, efficient and low cost sampling methods to survey species at these scales. Several authors, mainly in the USA (Linhart and Knowlton 1975; Smallwood and Fitzhugh 1995; Zielinski and Kucera 1995; Zielinski and Stauffer 1996), but also in the United Kingdom (Tuyttens et al. 2001; Wilson and Delahay 2001; Sadlier et al. 2004; Webbon et al. 2004), have emphasised the use of alternative sampling methods to obtain density estimates or, at least, relative abundance indexes of different carnivore species at large spatial scales. These methods were also proposed under the assumption of their usefulness in detecting species under a variety of density ranges (Sadlier et al. 2004).

The most classical method to detect the presence of carnivores and estimate relative abundance is the use of field signs (scats, footprints, dens). Under the so-called 'sign surveys' (Clevenger 1993) include many different survey methodologies, from snow tracking (Pullianen 1981; Zielinski and Kucera 1995) to scat counting along paths (Cavallini 1994; Virgós et al. 2000; Virgós 2001; Webbon et al. 2004), den enumeration (Cresswell et al. 1989; Wilson et al. 1997) or spoor counts

(Smallwood and Fitzhugh 1995; Staender 1998). Most of these methods have not been tested in relation to true population density, but recent research has indicated a close fit between sign abundance and density for several carnivore species (Staender 1998; Sharp et al. 2001; Tuyttens et al. 2001; Sadlier et al. 2004; Webbon et al. 2004), despite early criticisms about accuracy (Kruuk et al. 1986; Norton 1990). As a consequence, several researchers recommended the use of sign surveys as the main element in national monitoring programmes or large-scale studies (Macdonald et al. 1998; Toms et al. 1999; Baker et al. 2002; Sadlier et al. 2004; Webbon et al. 2004; but see Birks et al. 2004).

Scent station and track plate methodologies, are derived from sign surveys and are routinely used in the USA to estimate population trends or as an index of relative abundance of different species (Roughton and Sweeny 1982; Conner et al. 1983; Sargeant et al. 1998). Overall, evidence has indicated good correlation between abundance indexes derived from this method and population densities (Sargeant et al. 1998). Silveira et al. (2003) found this the best method to detect species richness and relative abundance in a tropical area. However, contrary to its large use in North America and some regions of south America (Travaini et al. 2003; Silveira et al. 2003), the use of scent stations or similar methodologies has been limited elsewhere (but see Travaini et al. 1996).

Both sign surveys and scent station methods showed good efficiencies in carnivore detection rates and low economic costs, but their use may be limited because they require people with good skills in tracking or identification (Burnham et al. 1980; Smallwood and Fitzhugh 1995, Birks et al. 2004). Macdonald et al. (1998) and Sadlier et al. (2004) recognised this problem but they suggested that a well-designed training programme may overcome most of the problems with scat or track differentiation.

Another traditional method to obtain an index of abundance in carnivores is through trapping records (Brand and Keith 1979; Tapper 1992). Few studies, however, have controlled bag numbers by trapping effort which may invalidate the abundance estimates (McDonald and Harris 1999). Nevertheless, the method may be useful when trapping effort is taken into account, as in some of the carnivore survey protocols in Spain (Guzmán et al. 2003), and also in the some surveys with small carnivores in United Kingdom (Birks and Kitchener 1999; McDonald and Harris 1999) or with badgers (Tuyttens et al. 1999). Data from these studies may be recorded as number of trapped individuals by trap/nights (McDonald and Harris 1999), or in small-scale studies as an estimate of density from capture-recapture records (Otis et al. 1978). The latter method, is not useful at a large-scale because capture rates are very low (Tuyttens et al. 1999; Baker et al. 2001), and hence estimates show large confidence intervals which preclude a reasonable density estimation (Rexstad and Burnham 1991). In addition, large areas could be sampled only with a high cost and effort, which can rarely may be achieved by national conservation agencies or researchers.

Finally, more recent sampling methods have included camera-trapping, using a similar approach to traditional trapping, but substituting traps or other capture devices with a 35-mm camera system (Mace et al. 1994; Zielinski and Kucera 1995; Karanth and Nichols 1998). The method has been applied with apparent success for several species, although the relationship with true density has not been tested so far.

Unfortunately, the number of studies and the number of species and environmental conditions where efficiency of the methods in terms of species detection, time

constraints and economic costs has been tested remains very low (Bull et al. 1992; Zielinski and Kucera 1995; Foresman and Pearson 1998; Silveira et al. 2003). Results are partially contradictory, which may reflect different species response to methods and/or changes in the efficiency of methods under different environmental conditions (e.g. tropics vs. large woods in the USA, Foresman and Pearson 1998; Silveira et al. 2003). All authors agree that more research about the performance of different methods in other regions, species or conditions is needed.

In Europe, comparison of different methods to estimate abundance of carnivores is restricted to the UK, and to a small diversity of species, mainly badgers and red foxes (reviewed in Wilson and Delahay 2001; Sadlier et al. 2004). Data are absent from continental Europe, and specifically the Mediterranean region, despite the large diversity of habitats, species and land use regimes in this area. Moreover, the Mediterranean region has considerable conservation value for carnivores because most of the species reach the highest densities in this area. However, despite the high conserved status of this region as compared to UK or central Europe, most of the countries involved (Spain, Portugal, Greece) have accelerated their economic development as a consequence of EU funding, which has had a strong impact on nature conservation (de Juana 2004; Díaz et al. 1997). Monitoring of carnivores in this region is thus very important, and must be prioritised in order to guarantee conservation in a progressively changing landscape. This requires more research on the suitability of different sampling methods in this region.

The aim here is to test the performance of four broadly applied methods to detect carnivore species at large spatial scales: sign surveys based on scat detection, scent stations, camera-trapping and live-trapping, in a typical Mediterranean landscape. We compared these methods with the view that large-scale surveys must optimise precision and repeatability of the results, yet have low cost and resource demands. The usefulness of the different methods were considered by comparing their suitability to detect the different species and then estimate carnivore community composition (species richness), and latency to first detection (sensu Foresman and Pearson 1998) of particular species and by considering both logistics and costs of each method.

Methods

Study area

The present study was conducted in Sierra Harana (Subbetic mountains, Granada province, SE Spain, Fig. 1.) during the winter season of 2004. The study area encompassed 5,000 ha and comprised dense forest formations (old Allepo pine *Pinus halepensis* reforestations but also some Holm oak *Quercus ilex* forest) which covered 38% of the total area, dense scrub formations (16.2%), scattered scrub formations (22.6%) and a mixture of soil-stone-pasture and scrublands (18%). The scrublands were mainly composed of Small-flowered gorse (*Ulex parviflorus*), Rosemary (*Rosmarinus officinalis*) and Prickly juniper (*Juniperus oxycedrus*). In addition to natural vegetative formations, 10% of the area was cultivated (mainly olive orchards but also cereal croplands).

Annual mean temperature and rainfall for the study area was 14°C and 620 mm respectively, i.e. a typical continental Mediterranean climate. The human population

density inside the study area was very low and restricted to some dispersed cottages. Road density was also low, averaging 0.128 km/km^2. Six carnivore species (Red fox *Vulpes vulpes*, Eurasian badger *Meles meles*, Stone marten *Martes foina*, Weasel *Mustela nivalis*, wildcat *Felis silvestris* and Genet *Genetta genetta*) were present in the study area (Barea-Azcón et al. 2005). These from the typical carnivore community in most of Mediterranean Spain. Weasels have been excluded from this study because of their small size compared to the other five, medium-sized carnivores.

Sampling protocol

We selected a sample unit of 2.5 km^2 (hereafter plots). This area was recommended by Zielinski and Kucera (1995) to survey medium-sized carnivore communities because it assures that the species with the largest home range will have the least chance of being overlooked in a survey area. A total of eight plots in this mountain area were sampled. These plots covered about the 30% of the mountain range and held all the representative habitats of the study area. Plots were sampled at short time periods to avoid or mitigate fluctuations in the composition of the carnivore community among them. To coincide with a low resource availability season in southern Spain, which may enhance visitation to bait devices, we selected the period between December and January. This period also coincided with the mating season of many species (Macdonald and Barrett 1993) increasing the probability of attraction by scent bait. Each time, we simultaneously sampled two plots with camera traps, scent stations and box-traps to mimic a representative sampling protocol for a large-scale survey. We also performed a sign survey transect in each plot. The distribution of survey routes and devices in each sampling plot is depicted in the Fig. 2.
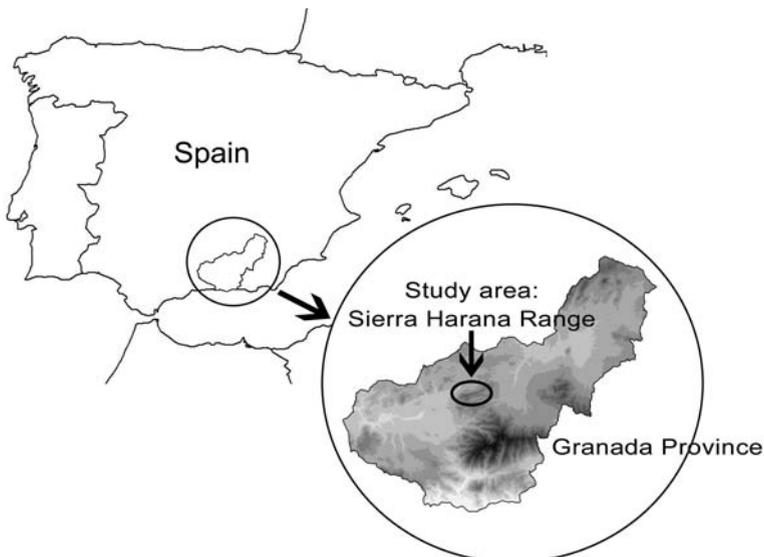
Fig. 1 Location of the study area within Iberian Peninsula and Granada province (SE Spain)
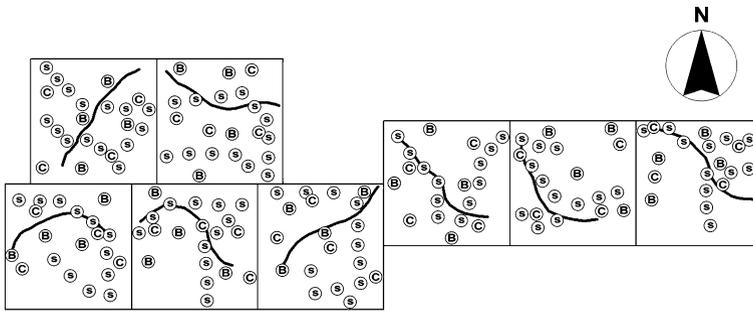
Fig. 2 Sample units and placement of each kind of device. B: box traps; C: camera traps; S: scent station; *Black line*: sing survey transect

Sign surveys

One sign survey transect measuring 3 km was carried out in every plot, following a common procedure for sampling carnivores in large scale surveys (Clevenger 1993; Wilson and Delahay 2001; Virgós et al. 2000; Virgós 2001). Each transect was divided into 250 m intervals (12 segments) following previous protocols (Clevenger 1993; Virgós et al. 2000; Lozano et al. 2003). At every station we searched for faeces of the studied species and we recorded the presence/absence of each species in every segment. Faeces of the different species were identified according to shape, size, odour and location. When signs showed an ambiguous identity they were not used. We did not consider footprints because their presence or absence is dependent on substrate, which invalidates between-plot comparisons.

Scent stations lines

Twelve scent stations were placed in every plot for two weeks (168 scent stations/ night) following the protocols recommended by Zielinski and Kucera (1995). Each scent station consisted of a 0.9-m diameter circle of thin and smoothed earth with a centrally placed cork bark (0.5 m above the ground) impregnated with a synthetic attractant (Conner et al. 1983) (an specific carnivore lure; Armería Alvarez, s.l.). Scent stations were placed along unpaved roads at 400 m intervals and all habitat types and sections of each plot were included. All the stations were checked every 3.5 days. At each check, we noted the visit of different carnivore species from tracks and faeces, and we removed the signs once recorded and repaired the bait. There can be no confusion between the tracks of the five carnivore species inhabiting the study area, but when signs were unclear, they were not recorded.

Camera trapping with a live bait

We placed four automatic line-triggered (Canon Prima) camera systems in each plot for two weeks (56 traps/night). The devices were distributed within the main habitat types. The cameras were placed inside a wooden-made protective structure, to allow it to operate in rain. Despite the fact that the sampling occurred during the coldest season of the year, there were no snowfalls during this period. The cameras worked correctly even during the coldest days. Cameras were baited with a live pigeon

similar to the method used to detect carnivores in other Spanish regions (Guzmán et al. 2003). Each camera was revisited every 3.5 days. Cameras were triggered by the pressure caused by the animal weight over a plate system connected to the camera. We followed the sampling protocols of Zielinski and Kucera (1995).

Box-traps with a live bait

Four box traps ($0.5 \times 0.8 \times 1.3$ m) were placed in every plot for two weeks (56 traps/ night). As for the other devices, the box traps were placed within as many habitat types of the plot as possible whilst trying to cover the different sections of each sampled plot. The box traps were baited with live pigeons in a similar way to previous trapping campaigns for carnivores. Each box-trap was checked every morning in order to minimise possible injuries in captured individuals. All the traps were covered with scrub branches to avoid the capture of raptors.

Cost evaluation

We also estimated the economic costs of every method tested. This evaluation was made based on the average Spanish prices i.e. 200€ per set of camera equip (including camera system, pigeon, pigeon box and food and water supply for pigeon) 2€ per scent station (including earth, synthetic attractive and cork bark) 100€ per box-trap equip (including box trap, pigeon and pigeon food and water), 35€ per day car rental for a 4×4 vehicle and fuel and 60€ per day for the services of a qualified technical expert. We also have included the costs associated with the technical formation of surveyors. Sign surveys and scent station monitoring require the training in track and scat identification which is a very important element of monitoring efficiency (Davison et al. 2002; Sadlier et al. 2004). Training was performed by an expert surveyor during 10 days and with a cost of 120€ per day. One day of training includes the cost of the trainer (60€) and the cost of the technician (60€). For camera and box-trapping using live bait, training was focused in placement selection of the different devices, handling and safety of catched carnivores and pigeons used as a bait. Training was performed by an expert with the same cost of 120€ per day during 5 days (also including the cost of the trainer and of the technician).

Data analyses

We compared differences in the number of species (response variable) detected by different methods by using one-way ANOVA with the different methods sampled as the fixed factor. Prior to analysis we checked for normality and homoscedasticity of variables. The relative efficiency of the different methods in detecting each species (number of plots where a species is detected/total number of plots where a species was recorded) was evaluated by means of a χ^2 test applied to a 2×4 contingency table. Differences between methods in the latency to first detection (LTD) were analysed by means of Friedman ANOVA by ranks because data did not fit normality assumptions. In this analysis, species were used combined as replicates and the three methods tested (camera trapping, scent station lines and box-trapping) as the fixed factor. Sign surveys were not included because the survey was conducted only on one day.

   In all statistical tests we used two-tailed probabilities and the typical $P < 0.05$ as a criterion of significance. Statistica 99 software was used for all statistical analyses.

Results

Number of species detected in the sampled plots

The number of species detected (species richness) differs significantly among the four methods considered (ANOVA: $F_{3\ 28}$ = 5.97, P < 0.01). Post-hoc Duncan tests (not shown) revealed that differences were largely due to the higher values of sign surveys and scent stations as compared to camera-trapping and box-trapping (Fig. 3). Sign surveys and scent stations were not statistically different, nor were differences detected in richness values when camera-trapping and box trapping methods (all $P's$ > 0.5) were compared. The highest richness values were found for sign surveys (that also showed narrow variability values), followed by scent stations and box trapping, with the lowest recorded values for camera-trapping (Fig. 3). A relatively large variability was observed in both scent station lines and box trapping methods (Fig. 3).

The largest values of richness were recorded in sign surveys in three of the sampled plots, while scent stations yielded the highest values in two cases. Camera-trapping and box-trapping did not yield the highest richness values in any of the sampled plots. The largest values of species richness were recorded for sign surveys in three of the sampled plots, while scent stations yielded the highest values in one plot. In other two plots the highest value of richness was recorded both for sign surveys and scent stations. In the remainder two plots, the largest value of species richness was obtained in one case both for scent stations and box-trapping and in another case both for sign surveys and camera trapping (Table 1).

We also tested the relative efficiency of each method in each plot. First, we recorded the total species richness in each plot by summing the records of individual species by each method (Table 2). This information was needed to evaluate the values of efficiency rate computed. We detected a significant difference between them (ANOVA: $F_{3\ 28}$ = 4.02, P = 0.02). Post-hoc Duncan tests (not shown) indicated that, as in the case of species richness, the differences were due to higher efficiencies recorded in sign surveys and scent stations than in camera-trapping and box trapping (0.03 < P > 0.01, Fig. 4). Sign surveys and scent stations did not differ in efficiency (P = 0.95) and the same was observed between camera-trapping and box-trapping (P = 0.88). In contrast to the number of species recorded, the largest mean values of relative efficiencies were found in scent station lines followed by sign surveys, but the latter showed a lower variability (Fig. 4). Camera-trapping and box-trapping yielded the lowest values of relative efficiency (Fig. 4) as we also observed for number of species recorded. Despite the large mean values for the scent station method, we observed that both sign surveys and scent stations yielded the largest efficiency scores in two plots each (Table 2). In the additional four plots we observed a more complicated pattern than in the case of species richness. The largest value was recorded both for sign surveys and scent stations in one plot, while in another plot the largest values were observed in box-trapping and scent station lines. In the two remaining plots, the highest values were shown both by camera-trapping and scent stations in one plot and for all sampling methods in the other (Table 2).

Efficiency in species detection

We tested the relative efficiency of the different methods in detecting each particular species in each sampled plot. Three species were relatively rare in our study area
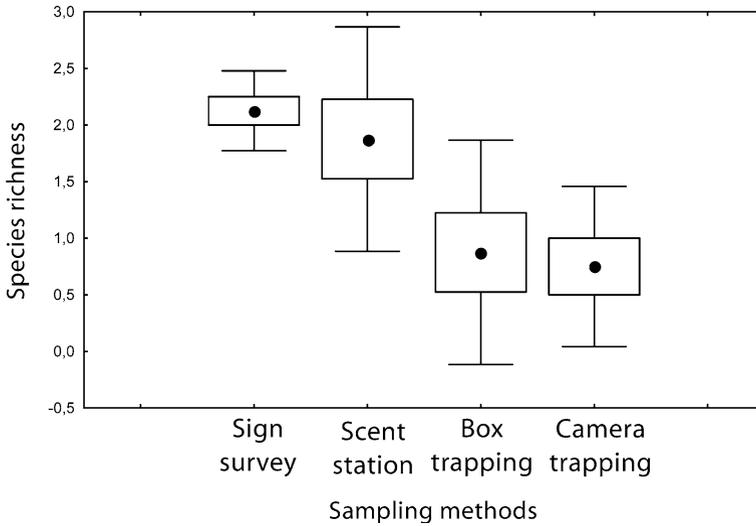
Fig. 3 Means (*black points*), standard errors (*boxes*) and standard deviations (*whiskers*) of species richness for each one of the sampling methods tested

(badger, wildcat and genet), with these species being present in only two or three plots. Red foxes and stone martens were recorded in all plots (Table 3). This information is needed to interpret efficiency data because occupancy patterns affected our computed efficiency rate index.

For detection of Red foxes, we observed a significant difference between sampling methods ($\chi^2 = 13.5$, 3 df, $P < 0.01$). The best method was sign surveys, with a very low efficiency for the remainder methods (Table 3). In the case of stone martens, we also found a significant difference between the methods ($\chi^2 = 9.5$, 3 df., $P = 0.02$). The highest score in efficiency rate was found for scent station methodology, although the value for sign surveys was also very high (Table 3). It was not possible to calculate the chi-square statistic for differences between methods for the other species due to their low occupancy rates. In badgers, both sign surveys and scent stations yielded the highest values. In the case of wildcats, both sign surveys and scent stations had low efficiency for detecting the species, with a relatively larger value both for camera-trapping and box-trapping. For genets, the most efficient

Table 1 Number of species detected (richness) for the different sampled methods in each plot

Plots	Sign surveys	Scent stations	Box-trapping	Camera-trapping	Total richness
1	3	3	0	1	4
2	2	3	3	0	3
3	2	1	1	2	4
4	2	1	0	0	2
5	2	3	0	0	3
6	2	1	1	1	3
7	2	2	1	1	3
8	2	1	1	1	2
Total richness	4	5	4	3	

Table 2 Richness and relative efficiency (number of species detected by a single method/number of species recorded in each plot by combining all sampling methods) of the different methods in each sampled plot

Plots	Sign surveys	Scent stations	Box-trapping	Camera-trapping	Richness
1	0.75	0.75	0	0.25	4
2	0.66	1	1	0	3
3	0.5	0.25	0.25	0.5	4
4	1	0.5	0	0	2
5	0.66	1	0	0	3
6	0.66	0.33	0.33	0.33	3
7	0.33	0.66	0.33	0.66	3
8	0.5	0.5	0.5	0.5	2
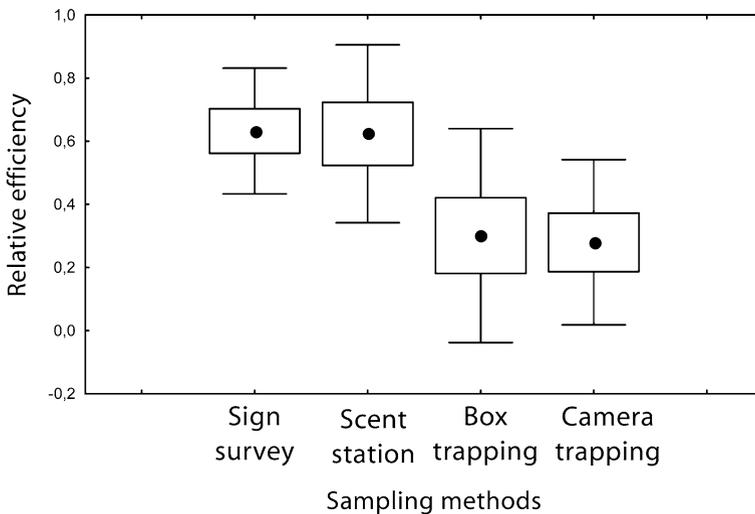
Fig. 4 Means (*black points*), standard errors (*boxes*) and standard deviations (*whiskers*) of the values of relative efficiency for each one of the sampling methods tested

method was scent station lines, followed by box-trapping; this species was not detected by sign surveys or camera trapping (Table 3). It is important to note that the values of 0.66 for efficiency in the case of wildcats and genets were influenced by low occupancy patterns (only three plots).

Latency to first detection

The LTD did not differ significantly among the three methods tested (Friedman ANOVA by ranks: $\chi^2 = 0.73$; 2 df., $P = 0.69$). Though values did not significantly differ between methods, it is clear that for a same method there was a large difference in the time elapsed until the first detection between species (Table 4).

For all species combined, camera-trapping yielded the lowest first detection time (mean value: 6.5 ± 1.14 days), followed by scent-station lines (6.67 ± 1.75 days) and box trapping (8.5 ± 0.79 days). For the Red fox, box trapping yielded the lowest latency time, while scent stations showed the largest values (Table 4). In contrast, for

Table 3 Efficiency value (between brackets) for each species (number of plots where a species was detected/total number of plots where a species was recorded)

Species	Sign surveys	Scent stations	Box-trapping	Camera-trapping
Vulpes vulpes	8/8 (1.0)	2/8 (0.25)	2/8 (0.25)	2/8 (0.25)
Martes foina	6/8 (0.75)	8/8 (1)	2/8 (0.25)	2/8 (0.25)
Meles meles	2/2 (1)	2/2 (1)	0/2 (0)	0/2 (0)
Felis silvestris	1/3 (0.33)	1/3 (0.33)	2/3 (0.66)	2/3 (0.66)
Genetta genetta	0/3 (0)	2/3 (0.66)	1/3 (0.33)	0/3 (0)
Mean efficiency	0.62	0.65	0.3	0.23

We also give the original rate to indicate the current value of occupancy rate (number of plots with the presence of a particular species) for each species

stone martens the lowest LTDs was obtained with scent station lines and the highest with box-trapping, and an identical result was observed for wildcats (Table 4). The genet showed high LTDs and it was not recorded in camera-trapping devices. The lowest LTD was observed with box-trapping methodology and the largest with scent stations. Badgers were not detected by camera-trapping or box-trapping, yielding a relatively larger value for scent station lines (Table 4). We did not perform statistical tests for each species because of the low sample sizes obtained.

Although, these LTDs can be used as a comparative tool between the three methods, they are minimum estimates because in some of the sampled plots we did not detect some of the species despite the fact that they were present (see above).

Economic evaluation for each method

Taking into account that we managed two plots simultaneously, we can estimate the cost for the camera trapping method amounted to 4,680€, including two technical experts, eight camera sets and four visits per two plots (one for collocation, two for revision and the last for revision and removal) and training. For the scent station method we estimated a total price of 3,872€, including two technical experts 24 scent stations per pair of plots and the maintenance costs (four visits per two plots) and training. For box trapping, we estimated a total amount of 3,880€, including the equipment and its maintenance (as for to the other two methods, we employed two technical experts and four visit days per each pair of plots) and training. Only two technical experts were needed for the sign surveys transect and one car per day. In one day it was possible to complete four plots, thus the total cost for this method was 1,510€ to complete the survey of eight plots and considering the 10-day period of training.

Table 4 Mean LTD values (in days) for the five studied species in each one sampled method considered (except, sign surveys, see Methods)

Species	Scent stations	Box-trapping	Camera-trapping
Vulpes vulpes	10.5	7	9.5
Martes foina	3.94	7	5
Meles meles	8.75	Not recorded	Not recorded
Felis silvestris	3.5	7.5	4.5
Genetta genetta	10.5	9	Not recorded

Because we only tested four methods, correlations can not be computed, but we showed the correlation values of the costs of the different methods with the species richness (Table 1) and the mean efficiency for species detection (Table 3) to illustrate this topic. Species richness and computed costs were highly negatively correlated ($r_s = -0.63$), and a stronger negative correlation was found between economic costs and mean efficiency in species detection ($r_s = -0.80$).

Summary of results

We ranked the methods according to the three indices of suitability used: species richness, mean efficiency in species detection and economic costs (Table 5). Scent stations were ranked as the superior method for the four mentioned sampling methods, whereas sign surveys was ranked highest for economic costs. Overall, scent stations and sign surveys were the preferred methods on this basis.

Discussion

The data in this study are the first to simultaneously test the relative efficiencies of several commonly used sampling methods to detect carnivore species in Europe. We compared efficiencies not only by biological parameters but also by economic costs, a key point in any management practice on a large spatial scale. Carnivores are elusive and show relatively low densities as compared to other vertebrate groups (Zielinski and Kucera 1995; Gros et al. 1996; Gese 2001). Several census methods have been proposed but we know little about their relative efficiencies (Zielinski and Kucera 1995; Gros et al. 1996; Foresman and Pearson 1998; Staender 1998; Silveira et al. 2003). However, managers need this information to plan any monitoring programme (Zielinski and Kucera 1995; Gros et al. 1996; Sadlier et al. 2004). In Spain and other European countries, several methods have been used to monitor abundance and population trends, but our results indicated that only a combination of several of these methods allowed us to obtain a true representation of the carnivore community in a location or region. Despite this fact, the different methods showed different suitabilities or efficiencies that may be used when planning monitoring programmes on a large spatial scale.

Overall, scent stations and sign surveys were clearly superior to methods based on attraction of species to a live prey. The number of species detected and the relative efficiencies were clearly lower for camera-trapping and box-trapping (using a pigeon as bait) than for scent stations and sign surveys. These bait methods have been used

Table 5 Ranking of the four tested sampling methods based on the following variables: number of species detection (richness), mean efficiency in species detection and economic costs

Sampling methods	Species richness	Mean efficiency	Economic costs
Sign surveys	2	2	1
Scent stations	1	1	2
Box trapping	3	3	3
Camera trapping	4	4	4

commonly in several carnivore projects in Spain (Guzmán et al. 2003). The use of live pigeons or other potential prey was only justified from our data for wildcats, as this was the only case where this method was superior to sign and scent stations surveys. This method has been mainly used to detect the highly threatened Iberian lynx (*Lynx pardinus*), where it has been shown to be superior to others (Garrote, com. pers.). In wildcats, we suggest that only this method gives confidence for detecting this species in a sampling plot, at least in areas of low density. For the rest of the species we investigated, a combination of sign surveys and scent stations was the preferred methodology both for sampling efficiency and economics. The inclusion of the latter factor is very important when large-scale surveys are planned because money and time are usually the main constraints (see Zielinski and Kucera 1995; Foresman and Pearson 1998). Sign surveys and scent stations are cheaper than camera and box-trapping (even if a lure instead a life prey was used as attractant). An eight-plot survey using both scent stations and sign surveys could be covered by two people in less than one month, and for a cost of 2,300€, which is a lower cost than either camera or box trapping. In addition, where a live prey is used as bait, ethic considerations also need to be considered. Any method that allows the estimation of abundance or presence of the species without intrusions is clearly preferred (i.e. non-invasive methods, Bekoff and Jamieson 1996).

Recent studies have recommended a broader use of sign surveys as a fast and accurate method for monitoring programmes (Gros et al. 1996; Sadlier et al. 2004; Webbon et al. 2004; but see Silveira et al. 2003). More information is available about the suitability of scent stations for undertaking large-scale surveys (Linhart and Knowlton 1975; Conner et al. 1983; Sargeant et al. 1998; Travaini et al. 1996), especially in the USA, but its use in Europe is less well documented (but see Travaini et al. 1996). Our results, advocate a more wide use of scent stations to monitor carnivore populations in Europe. This method was the only one able to detect the five species in our study area as a whole, although it failed to detect some species in particular plots. However, scent stations may be not preferred to camera-trapping when surveyors are not well-trained on track identification (Silveira et al. 2003), but this may be overcome by training programmes before any large-scale survey project (Sadlier et al. 2004; Webbon et al. 2004). In addition, the use of scent stations may be necessary to detect species rarely located by searching for scats on tracks or paths, as was the case for the genets and to a lesser extent the badgers (Virgós et al. 2000; Virgós 2001). In our study area, genets were not detected in sign surveys, but they were detected relatively well using a commercial lure in scent station lines. Other researchers have indicated that genets can be effectively monitored using commercial lures in combination with remote cameras (Torre 2003), but they are also well detected using scent stations, which are much cheaper than camera-trapping. Hence, we advocate using a combination of commercial lures and scent stations to detect genets.

Badgers were also attracted effectively to commercial lures attached to scent lines, a result that confirms previous results in an other area of southern Spain (Travaini et al. 1996), although they were also detected well in the sign surveys. We were able to detect latrines by following paths and tracks as was found in the United Kingdom, where latrine surveys following linear structures in the landscape is known to be a powerful monitoring technique (Tuyttens et al. 2001; Hutchings et al. 2002; Sadlier et al. 2004). The detection of latrines on paths and tracks in Mediterranean environments is more difficult as Mediterranean badgers have a different marking

behaviour, and tend to lay faeces in latrines around the sett rather than at the edge of territories or signalling profitable patches (Pigozzi 1990; Revilla and Palomares 2002; own unpubl. data). However, an ongoing study about the usefulness of latrine surveys in different Mediterranean habitats has shown that they may be located in relatively large numbers on narrow paths and tracks (Mangas et al., in prep.), and is in agreement with our results in this area. Sign surveys may also be useful for badgers, although a combination with scent stations will increase the confidence of the results in large-scale surveys. More research in other low density areas may be useful to ascertain which method is superior for surveying badgers on a large spatial scale.

In the case of stone martens, scent stations were the best method, although sign surveys were also effective. In contrast, for red foxes, sign surveys were the most efficient method, as in a recent, detailed study in the United Kingdom, where it was shown that faecal counts were related to fox density (Baker et al. 2002; Webbon et al. 2004; but see Beltrán et al. 1991). Although our study was not aimed to test relationships between true density and indirect counts, it supports the suitability and low-cost of red fox monitoring on large spatial scales using faeces recorded in tracks and paths. Because the red fox is one of the first target species in predator control and game management in most of Europe (Tapper 1992; Harris and Saunders 1993; Reynolds and Tapper 1996; Virgós and Travaini 2005) the combined data from these studies represents good news for managers that use this easy and efficient way to quickly monitor red foxes. This then allows decisions to be taken based on real data rather than subjective ratings of abundance or trends.

In the case of wildcats, more research is needed on the use of other alternative commercial lures; cat urine may be a good candidate as shown for Iberian lynx sampling (Guzmán et al. 2003). Sign surveys have been used for wildcats (Lozano et al. 2003) reliant on the large marking behaviour of this species in paths and tracks (Corbett 1979). Our results did not support the suitability of sign surveys for this species, although it is important to note that the area showed a low wildcat density (0.17 ind/km^2, Ballesteros-Duperón et al., in prep.), and it may require higher effort to detect the species, for example by using a repeated sign survey on the same paths. More research is needed in areas of different wildcat density.

Several researchers have criticised the use of scat searching as a key sampling method to record carnivore presence or abundance on a large scale (Kruuk et al. 1986; Messenger et al. 2000; Birks et al. 2004). Scat surveys may be invalidated by a combination of non-random sampling, errors in species identification and seasonal or habitat-related differences in detectability or decay rates (Birks et al. 2004). Davison et al. (2002) have shown that even expert scat surveyors may mis-identify a large proportion of faeces, especially in low density areas (Messenger et al. 2000). As in the case of footprints in scent stations, the wide use of sign surveys based on scats needs well-designed training programmes (see also Sadlier et al. 2004). Trial pre-survey projects may also be needed where scat identification are compared with molecular tagging (Davison et al. 2002). Despite the problems derived from scat identification, the method remains attractive for large-scale surveys due to the low cost and faster sampling of large areas. More research is needed about the implications of non-random sampling or about the effects of seasonal changes in detectability or density effects on probability of false negative recordings (see Andelt and Andelt 1984; Walsh and White 1999).

Conservation implications

Carnivore monitoring and conservation requires suitable and efficient sampling protocols. Our results clearly show that large-scale surveys can be undertaken without the use of sophisticated and costly devices in Mediterranean landscapes. Our results could be also applied in other habitats and regions of the world.

We have demonstrated that scent stations and sign surveys based on scat detection are good methods to detect carnivore species and then evaluating species richness. Managers and conservationists are thus advantaged in that these two sampling methods are the cheapest among all the methods compared here. The negative relationship between the efficiency and the economic cost is good news for managers, since it encourages monitoring programs to be carried out on a large spatial scale. Unlike the monitoring of many other animal taxa, survey programs of carnivores (which normally have low population densities) are usually planned over large areas. Consequently, the results from this study are key to many conservation activities.

Unfortunately there have been few attempts to estimate the efficiency of different methods at different environmental situations and for different taxa (Zielinski and Kucera 1995; Foresman and Pearson 1998; Silveira et al. 2003). We advocate a strong research effort in this area, but other key research topic for the future is to address the reasons behind detection differences between methods (e.g. behaviour of different species to the same lure, behaviour differences to the same trap). Efforts should be made to test the relative efficiencies and accuracy of each method when applied to a known population size of each species (see Smith et al. 1994).

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