Assessment of methods for estimating wild rabbit population abundance in agricultural landscapes

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ABSTRACT

Various methods have been used to estimate rabbit abundance, but comparisons of standard methods are still lacking and thus results remain roughly comparable across studies. Ideally, a method should be applicable over a wide range of situations, such as differing abundances or habitat types. Comparisons of methods are required to evaluate the benefits of each of them, and survey methods should be validated for the conditions in which they will be used. In this study we compare the performance of direct methods (kilometric abundance index and distance sampling) in two seasons and at two times of day (dusk and night), for estimating wild rabbit abundances in agricultural landscapes. Estimates based on direct methods were highly correlated and detected similar seasonal population changes. Night counts provided better estimates than did dusk counts and exhibited more precision. Results are discussed within the context of rabbit behaviour and their implications for rabbit population surveys.

Keywords: lagomorphs, *Oryctolagus cuniculus*, distance sampling, kilometric abundance index

Running head: Methods to estimate rabbit abundance

1 INTRODUCTION

2 Estimates of the size of wildlife populations are fundamental to many aspects of conservation biology and
3 wildlife management, e.g. setting conservation priorities or developing management programs (Thomas et
4 al 2006; Newson et al 2008). Calculations of true population sizes are often prohibitively expensive, but
5 several survey methods have been developed to estimate population size or the relative abundance of
6 species (Tellería 1986). The suitability of a method can depend on a variety of factors including the
7 specific management questions being addressed, the degree of precision required, and the costs involved
8 (Thomas et al 2006). A single best method for estimating animal abundance is unlikely to apply in all
9 circumstances; therefore, sampling methods have to be individually designed for or adapted to the
10 particular needs of each population (Langbein et al 1999).

11 European rabbits (*Oryctolagus cuniculus*) are considered a pest in several regions of the world; e.g.,
12 Australia, New Zealand, and Great Britain, because they damage crops and forest stands, among others.
13 Within their native range on the Iberian Peninsula, rabbit populations have suffered a sharp decline in
14 recent decades, and currently (2009) are at low densities throughout the region (Delibes-Mateos et al
15 2009). In some areas, however, local rabbit populations have recovered and reach high densities. Most of
16 those areas are agricultural landscapes that have soft soils where it is easier for rabbits to build warrens
17 (Calvete et al 2004; Williams et al 2007), and where rabbits are an important game species (Delibes-
18 Mateos et al 2008). Accurate estimates of rabbit numbers are useful in predicting the economic costs of
19 rabbit damage and in gauging the effectiveness of methods of population control (Poole 2003).

20 The techniques used to assess rabbit population sizes include indirect methods, in which signs of rabbit
21 activity are used to estimate rabbit abundance, and direct methods, such as trapping or counts of
22 individuals observed. Indirect methods are particularly useful for nocturnal or elusive species such as
23 rabbits (Poole 2003), and they are often the only practical means of quantifying levels of habitat use
24 when direct sampling is difficult. However, few studies have tried to compare the results of indirect vs.
25 direct methods (Palomares 2001; Ballinger and Morgan 2002), and their validity remains questionable. On
26 the other hand, direct methods provide a rapid, simple means of assessing rabbit abundance, which
27 makes sampling over large areas feasible (Williams et al 1995); however, differences in detectability
28 among habitats and species behaviour can undermine the suitability of direct methods.

29 Crude population indices such as the Kilometric Abundance Index (KAI), i.e. the number of individuals
30 observed per kilometre, have been used widely to quantify rabbit abundance and population trends in
31 Spain (Beltrán 1991; Moreno et al 2007; Williams et al 2007) and France (Marchandeu and Gaudin 1994).

1 KAls have been successful in estimating the sizes of other vertebrate populations across a wide range of
2 densities, which allowed comparisons between localities that had similar habitat structure (Acevedo et al
3 2008). Although KAls show a good reproducibility (Marchandean and Gaudin 1994), their use is quite
4 controversial and their validity has been questioned (Engeman 2005). Criticisms involve variation in the
5 detectability of animals spatially and temporally because KAls do not control for habitat permeability
6 (Marchandean et al 2006; Thomas et al 2006). In contrast, distance sampling methods take into account
7 variation in visibility: the number of objects detected is modelled as a function of the perpendicular
8 distance from the transect line (Thomas et al 2006). Distance sampling is used widely to estimate the
9 relative abundances of animal species (Ruelle et al 2003; Newson et al 2008), from whales to terrestrial
10 vertebrates. It has been used to estimate the population densities of other lagomorphs, i.e. hares (Newey
11 et al 2003; Reid and Montgomery 2007) and has been proposed as a practical means of estimating their
12 abundance at the regional scale (Langbein et al 1999). Despite its potential advantages, distance sampling
13 has seldom been applied to rabbits (but see Blanco and Villafuerte 1993; Palomares 2001; Martins et al
14 2003; Moreno et al 2007), and it's accuracy for this species has not been compared with other standard
15 methods of assessing rabbit populations before.

16 Direct methods based on counts of individuals depend on the probability of detection of animals, which is
17 influenced by several factors, such as observer-related, environmental, and species-specific factors
18 (Thomas et al 2006). For instance, animal behaviour can influence significantly the accuracy and precision
19 of density estimates derived from distance sampling (Ward et al 2004; Hounscome et al 2005). Rabbits are
20 crepuscular-nocturnal and their activity follows circadian rhythms; thus, the timing of the census can
21 significantly affect the results (Ballinger and Morgan 2002). To estimate rabbit abundance direct methods
22 based on dusk or night counts are indistinctly used, and their results are confounded in the literature.

23 Night counts have been widely applied to monitor rabbit populations (Marchandean and Gaudin 1994;
24 Martins et al 2003; Marchandean et al 2006) and to estimate population trends (Caley and Morley 2002;
25 Williams et al 2007), and they have shown to be reliable population indices when compared to capture-
26 mark-recapture methods (Ballinger and Morgan 2002). On the other hand, dusk counts have been also
27 used (Blanco and Villafuerte 1993; Palomares 2001; Martins et al 2003; Moreno et al 2007) and even
28 proposed as the best method to estimate rabbit populations in the Mediterranean region (Blanco and
29 Villafuerte 1993). A comparison of the abundance indices obtained before and after dusk might help to
30 improve the accuracy of the population density estimates of rabbits within their native range in Spain.

The objectives of this study were to compare the performances of different estimates of rabbit populations based on direct methods, i.e. distance sampling and KAls, across a range of time periods (dusk vs. night counts) and seasons under a range of agricultural conditions.

MATERIAL AND METHODS

Study area

The study was conducted in an agricultural area within Córdoba province, southern Spain, which has a dry Mediterranean climate and calcareous soils. Traditionally, those agricultural lands have been devoted to olive groves, vineyards, and cereals (García-Montoya 1989). Today, small-game hunting is important in the area and rabbits occur in large numbers.

Sampling methods

Seven transects approx. 10 km-long were established along dirt tracks at random within the study area. Rabbits were counted along transects from a vehicle travelling approx. 10 km/hr. Each survey occurred on three consecutive days, in clear weather conditions, and avoided days when hunting was permitted. Surveys were conducted by a driver and another observer inside the vehicle, one hour before dusk (hereafter, dusk counts), and repeated one hour after sunset with the observer standing upright through a sunroof, scanning the fields with a 100W hand-held spotlight (hereafter, night counts). To avoid observer bias, the same experienced observer (ICB) conducted all of the surveys. Enough time (about 2 h) was allowed between the dusk and night counts to ensure the independence of the counts and minimize the disturbance to the animals (Martins et al 2003). In both cases, the distance from the observer to a rabbit was measured using a Leica rangefinder (LRF 1200 Scan, Solms, Germany; range = 15-1100 m, precision $\pm 1\text{m}/\pm 0.1\%$), and compass bearings were recorded to determine the angle between the line transect and the animal or group of animals observed (clusters). Surveys were performed in October 2007 and June 2008, which coincided with the times of the year of the minimum and maximum annual rabbit abundances in Mediterranean areas, respectively (Moreno et al 2007). For each transect, season, and type of count (dusk or night counts), we calculated a crude index of rabbit abundance, the KAI, by averaging the number of rabbits counted per kilometre. Distance Sampling 5.0 software (Thomas et al 2006) was used to estimate rabbit density. Six commonly used models and adjustment terms were constructed (Thomas et al 2006), including uniform cosine, uniform simple polynomial, half-normal cosine, half-normal hermite polynomial, hazard rate cosine, and hazard rate

1 simple polynomial. The best model was the model that had the lowest value of Akaike's Information
2 Criterion. To calculate rabbit density, a hazard-rate function with a cosine series expansion was fitted to
3 the data, which were truncated at 145 m and sightings within the first 25 m were pooled.
4 To enable comparisons between distance sampling estimates and KAls, and to avoid pseudoreplication,
5 distance-sampling estimates and KAls were obtained on different days within the same locality (Acevedo
6 et al 2008). First, we assessed the relationship between the methods using those independent data sets.
7 Second, because the independence of distance-sampling estimates and KAls was confirmed, we used all of
8 the data to calculate the two abundance indices.
9 To compare the performance of direct methods and assess the effect of time of day and season on the
10 estimates, linear mixed models were used, considering transect as a random factor in all models. Thus 4
11 models were built, considering distance-sampling and KAI estimates and their coefficients of variation as
12 dependent variables respectively. Season, time of day and the interaction term between season and time
13 were considered as fixed-effects independent variables. One additional model was built to assess the
14 relationship between distance sampling and KAI estimates, for independent data sets and all data.
15 Statistical analyses were performed using R 2.8.1 (R Development Core Team 2008).

17 **RESULTS**

18 **General results**

19 During surveys, 3005 rabbits were observed in 1973 clusters. Distance sampling and KAI estimates were
20 significantly higher for night counts than for dusk counts (Fig.1). With both methods, results were higher
21 in June than they were in October. The distance-sampling and KAls did not find a significant interaction
22 between season and time in predicting density estimates (Table 1). Coefficients of variation of distance-
23 sampling estimates ranged between 3.98% and 48.25%, and were significantly lower in the night counts
24 (mean CV night = 11.11%) than in the dusk counts, but no significant seasonal differences were apparent.
25 Coefficients of variation of the KAI estimates ranged between 4.33% and 110.75%, and were significantly
26 lower in the night counts (mean CV night=21.07%) than in the dusk counts, but again no significant
27 seasonal differences were apparent (Fig. 1).

29 **Comparison of methods**

1 The estimates of relative rabbit abundance derived from distance sampling and KAls were significantly
2 and positively correlated when the estimates were based on independent data sets or when all of the data
3 were included (Table 1).

6 **DISCUSSION**

7 In an agricultural area in southern Spain night counts were better than dusk counts in estimating wild
8 rabbit densities. Rabbits are most active at twilight and night (Blanco and Villafuerte 1993), but there is
9 no consensus on when to conduct rabbit counts in Spain. Some have relied on dusk counts (Blanco and
10 Villafuerte 1993; Moreno et al 2007) while others used night counts (Gortázar 1997; Williams et al 2007),
11 making their results roughly comparable. In a study in SW Spain, Villafuerte et al. (1993) concluded that
12 dusk was the best time to conduct rabbit censuses because activity at that time of day was the least
13 dependent on environmental factors. In contrast we found that night counts performed in clear weather
14 conditions consistently registered larger numbers of rabbits than censuses performed at dusk, and were
15 less variable both across seasons and successive counts. This can be explained because their night counts
16 refer to midnight, when rabbits are less active above ground than they are earlier at night (Ballinger and
17 Morgan 2002). In addition, the proportion of animals above ground in our study appeared to be the same
18 at both times of year, as suggested by the lack of interaction between season and time in predicting
19 density estimates. Similarly, Ballinger et al. (2002) found that time of year had a minor effect on the
20 emergence rates of rabbits from burrows. However a seasonal variation has been reported in
21 Mediterranean environments (Martins et al 2003). They hypothesized that in these areas, foraging
22 activities might be extended throughout the daylight hours during the post-breeding period (Jul to Sep),
23 coinciding with the depletion of food resources and a seasonal increase in the size of populations. In
24 contrast, longer nights in winter make daylight emergence unnecessary and, therefore, higher numbers of
25 rabbits are expected to be seen at night in winter and the breeding season (Martins et al 2003). However,
26 other factors shaping local activity patterns, such as antipredatory strategies (Blanco and Villafuerte
27 1993) or disturbance (Poole 2003), might be masking this seasonal variation in our study. For instance,
28 human disturbance and hunting activity during the day, coupled with the occurrence of few nocturnal
29 carnivores in our study area, may be determining the consistent trend observed.

30 Distance sampling and KAls produced similar estimates of rabbit densities and detected seasonal changes
31 similarly. In addition, the two methods indicated high precision (low CV) in the night counts, which

1 indicates strong reproducibility (Marchandean and Gaudin 1994). Thus, both methods were equally suited
2 to estimate rabbit population trends in our study area and the choice of a method would depend on the
3 particular aims of the survey, as well as on the economic and logistic constraints. If a rough estimate of
4 abundance is required or the objective is to monitor changes, KAls might suffice. Distance sampling is a
5 reliable means of comparing localities that differ in habitat structure, but it requires considerable
6 sampling effort and the underlying assumptions must be met (Acevedo et al 2008).

7 Not all sampling designs, however, can meet the assumptions of the distance sampling method, which
8 assumes that all animals on (or near) the transect line are always detected. Often, that assumption is
9 problematic for surveys of cryptic and mobile species, or where habitat structure prevents the animals
10 from being seen, even if they are present (e.g., in burrows) (Hounsborne et al 2005). Thus, rabbit
11 emergence behaviour is critical in spotlight counting because only rabbits that have emerged from
12 burrows can be detected (Marchandean et al 2006). Indeed, just after dark, about 60% of the population
13 of rabbits are aboveground simultaneously (Ballinger and Morgan 2002; Poole 2003). If it is suspected that
14 a proportion of the population is not available for sampling on the line transect, as is the case, an
15 independent method such as radio tracking should be incorporated into the design of the survey, which
16 can improve the accuracy of estimates. In any case, to maximize the number of animals that can be
17 detected in surveys of species that use warrens, data on behaviour and local activity patterns in the study
18 area should be obtained.

19 The estimates derived from KAls in our study areas were similar to those obtained in other Mediterranean
20 areas before the outbreak of rabbit haemorrhagic disease (7 rabbits/km, (Moreno et al 2007); 8
21 rabbits/km, (Beltrán 1991), but were much lower than those found in places where rabbits were
22 introduced, e.g., Australia (25 rabbits/km, (Ballinger and Morgan 2002) and New Zealand (125 rabbits/km,
23 (Fletcher et al 1999). Although the European rabbit is a well-known colonizer where it has been
24 introduced, rabbit populations have declined dramatically within the species' native range (Lees and Bell
25 2008). In our study area, rabbit populations were at medium-to-high densities and appeared to be
26 recovering, at least in sites that had favourable habitat and rabbit management strategies (Williams et al
27 2007).

28 29 **Implications for rabbit surveys**

30 In our study, rabbit behaviour had a significant effect on abundance estimates and we suggest that a pilot
31 study should be conducted before the survey to identify local patterns of rabbit activity. In our study,

night counts performed better and showed higher precision than dusk counts. In agricultural landscapes like ours, both distance sampling or kilometeric abundance indices can be used, depending on the aims of study: KAls are appropriate when relative abundance or population trends are required, and distance sampling should be used to estimate densities.

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Fig. 1 Population estimates and coefficients of variation in rabbit populations in southern Spain derived using Distance-sampling (a) and Kilometric Abundance Index (b) and based on dusk and night counts at two times of the year (October and June). “*” $p<0.05$; “***” $p<0.01$; “****” $p<0.001$).

1

A. Direct methods estimates						
	Dependent variable: distance Random factor: Transect			Dependent variable: KAI Random factor: Transect		
	F	df	p-value	F	df	p-value
Intercept	295.657	1,18	0.000	145.171	1,18	0.000
Season	26.982	1,18	0.001	14.274	1,18	0.001
Time	32.197	1,18	0.000	16.893	1,18	0.001
Season*Time	0.215	1,18	0.648	0.844	1,18	0.370
B. Coefficients of variation						
	Dependent variable: CV distance Random factor: Transect			Dependent variable: CV KAI Random factor: Transect		
	F	df	p-value	F	df	p-value
Intercept	46.713	1,18	0.000	49.056	1,18	0.000
Season	2.843	1,18	0.109	1.209	1,18	0.286
Time	11.354	1,18	0.003	6.956	1,18	0.017
Season*Time	0.197	1,18	0.662	0.396	1,18	0.537
C. Comparison between methods						
	Dependent variable: distance Random factor: Transect Independent data			Dependent variable: distance Random factor: Transect All data		
	F	df	p-value	F	df	p-value
Intercept	209.110	1,26	0.000	601.092	1,26	0.000
KAI	37.581	1,26	0.000	190.748	1,26	0.000

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Table 1. Linear mixed models results for the direct methods estimates (A), coefficients of variation (B) and the comparison between methods (C).