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ORIGINAL PAPER

Towards a standardized index of European rabbit abundance in Iberian Mediterranean habitats

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Abstract European rabbits *Oryctolagus cuniculus* are a keystone species in Iberian Mediterranean ecosystems. Studies over the past few decades have revealed drastic declines in many rabbit populations. However, the reliability of methods for estimating rabbit abundance, particularly when at low numbers, is not well understood. Further, better standardization of these methodologies would allow abundance estimates to be more reliably compared between areas and periods. Consequently, we compared several frequently used methods of estimating rabbit abundance and assessed the advantages and disadvantages of each. During the summers of 2008 and 2009, in 11 localities of central-southern Spain we undertook (a) driving transect counts of rabbits, either at dusk or at night, (b) linear transects on foot recording rabbit signs, (c) cleared-plot pellet counts at permanent plots, and (d) standing crop counts, both with and without habitat stratification. Density estimated at night from driving transects using the Distance Sampling method (the reference method against which all other indices were compared), varied from 0 to 2.69 rabbits ha^{-1}. Most pellet-count indices were significantly related to the reference method. In particular, cleared-plot pellet counts in permanent plots corrected for pellet persistence showed the best correlation with the reference method. In contrast, latrine counts were not related to the reference method index, and we recommend against their use. A standard methodology based on cleared-plot pellets counts could be used to monitor rabbit abundance on a large scale, particularly where there is an urgent need for management and conservation of rabbits, and their associated endangered predators.

Keywords Abundance indices · Density estimates · Lagomorphs · *Oryctolagus cuniculus* · Reference method · Standardization

Introduction

European rabbits *Oryctolagus cuniculus* are a key species in Iberian Mediterranean ecosystems (Delibes-Mateos et al. 2007; Valverde 1967), being consumed by more than 40 predator species (Delibes and Hiraldo 1981; Delibes-Mateos et al. 2008a). Rabbits also act in this area as ecosystem engineers, because of their effect in vegetation (creation of open areas, preservation of plant species diversity, increased plant growth by inducing soil fertility), but also because they provide feeding resources (latrines) for many invertebrate species, and nest sites and shelter (burrows) for vertebrates and invertebrates (Delibes-Mateos et al. 2008a; Gálvez et al. 2009). Rabbits are also a popular small game species (Angulo and Villafuerte 2003). Although considered harmful pest species in other parts of the world (Lees and Bell 2008; Thompson and King 1994; Williams et al. 1995), European rabbits are only regarded as an agricultural pest in a few localized areas in Spain (Barrio et al. 2010b; Ríos 2010). Rabbit numbers on the Iberian peninsula have declined over recent decades, due mainly to habitat loss (Delibes-Mateos et al. 2010) and the occurrence of two viral diseases, myxomatosis during the 1950s (Muñoz 1960) and rabbit hemorrhagic disease (RHD) at the end of the 1980s (Villafuerte et al. 1995). Since the RHD outbreak in Doñana National Park (southwestern Spain), rabbit numbers have declined by an estimated 90% (Moreno et al. 2007). Most populations in Spain have continued to decline (Delibes-Mateos et al. 2008b), resulting in significant economic and ecological consequences for Iberian Mediterranean ecosystems (Delibes-Mateos et al. 2008a). Monitoring rabbit populations is currently a major challenge for conservation, making the development of widely applicable and reliable monitoring methods particularly important (Delibes-Mateos et al. 2009). For instance, the Iberian lynx (*Lynx pardinus*) is a critically endangered predator specialist on rabbits (Ferreras et al. *in press*) and it has been calculated that the autumn mean rabbit density required for Iberian lynx residence is 1 rabbit ha^{-1}, while the spring mean rabbit density required for reproduction is 4.6 rabbits ha^{-1} (Palomares et al. 2001). Hence, large and cost-effective spatial monitoring projects to select areas suitable for lynx re-establishment are dependent on reliable and easy-to-perform indices of rabbit abundance (Ferreira and Delibes-Mateos *in press*).

Direct and indirect methods are currently used to estimate rabbit abundances and population trends. Direct methods are based on surveys or counts of the animals, while indirect methods are based on the monitoring of animal signs. One of the most commonly used direct methods is counting individuals along linear transects, which can provide absolute estimates of density (Barrio et al. 2010a; Martins et al. 2003; Palomares 2001; Palomares et al. 2001) by using the Distance Sampling method (Buckland et al. 1993). The accuracy of this method is dependent on several assumptions (e.g., objects on the line or point are detected with certainty, objects do not move, measurements are exact; Thomas et al. 2010) and these may not always be met. A considerable sampling effort is also required to obtain sufficient number o sightings to reliably estimate density in low density populations (Newey et al. 2003). One alternative to the Distance Sampling method is the kilometric abundance index (sightings km^{-1}; Beltrán 1991; Moreno et al. 2007; Williams et al. 2007), which is correlated with population density (Barrio et al. 2010a; Palomares et al. 2001) and provide data for a range of abundances. Rabbit counts have also several drawbacks (see e.g., Martins et al. 2003; Twigg et al. 1998; Villafuerte et al. 1993). Other direct methods used to estimate densities are based on live trapping, mostly by means of capture-recapture (e.g., Ballinger and Morgan 2002; Marchandeau et al. 2006) and the minimum number of individuals known to be alive (MNA, King and Wheeler 1985; Wood 1988).

Indices from rabbit signs are alternatives to direct methods. Indices based on counts of warrens are widely used (Myers et al. 1975) and can be corrected for distances traversed during these counts (Palomares 2001). Pellet counts per unit area can also be used to estimate abundance (Cabezas and Moreno 2007; Delibes-Mateos et al. 2008b; Moreno and Villafuerte 1995), as can latrines per unit of distance (Calvete et al. 2006).

The standing crop count method involves counting pellets during only one visit, enabling a large area to be sampled. Nevertheless, to estimate absolute densities it is necessary to correct for defecation rates and pellet persistence (Putman 1984). The cleared-plot count method involves counting pellets that accumulate over a period of time in plots from which pellets had been previously removed (e.g., Palomares 2001). It is important to identify the period during which pellet accumulation and persistence is highest in order to reduce the zero counts in low density populations and the effect of pellet decay in pellet counts. This method is time consuming and labor intensive and it is necessary to optimize the time of visits (Massei et al. 1998). This method can provide reliable estimates of abundance when animal densities are low (Murray et al. 2002), a situation limiting the accuracy of other methods. Other signs, such as scrapes and tracks, are rarely used to obtain indices of rabbit abundance (but see Twigg et al. 2001).

Studies monitoring the abundance and trends of rabbit populations in the Iberian Peninsula have used most of the methods described above (Calvete et al. 2006; Delibes-Mateos et al. 2008b; Moreno et al. 2007; Williams et al. 2007). Unfortunately, due to the variety of methods used, it is not always possible to compare results (i.e. rabbit abundances) among studies (Delibes-Mateos et al. 2009). Several studies have attempted to standardize methodologies by comparing indices with a reference method, which provides less biased estimates of population size and absolute densities, often using live trapping indices (Ballinger and Morgan 2002; Marchandeau et al. 2006; Wood 1988). However, the high costs in human effort, time and logistical resources prevent the use of live trapping in wide-scale studies, in many localities and in medium/long-term monitoring programs. As a result most studies have been based on rabbit counts (Barrio et al. 2010a; Myers et al. 1975; Palomares 2001; Palomares et al. 2001), though as the same methods are not simultaneously performed in the same study areas, the optimal method for specific conditions and objectives is unclear. Moreover, fewer studies have used a wider approach than using a locality scale. We therefore sought to compare several commonly used methods, and assessed the advantages and disadvantages of each. We propose common and comparable methodologies for assessing rabbit abundances according to the objectives and scale of each study.

Material and methods

Areas and periods of study

Field work was performed in 11 localities of central-southern Spain (Fig. 1), with different rabbit abundances but similar habitat structures and climate. All localities had a Mediterranean climate, characterized by wet, mild winters and warm, dry summers with marked drought periods. Habitats were composed mainly of Mediterranean scrubland, pastures, croplands, 'dehesas' (savanna-like formations that combine pastures with intermittent cereal cultivation in park-like oak woodlands; Blondel and Aronson 1999) and tree plantations. We used the same methods (Table 1, further details below) to estimate rabbit abundance in each locality during the summers (June–August) of 2008 (localities 1–8) and 2009 (localities 9–11). For some indices (density estimates at night, DEN-N; kilometric abundance index at night, KAI-N; cleared-plot pellet counts corrected and uncorrected by persistence, COR and UNC respectively, see below and Table 1) and localities (1–8), data were also collected in the winter–spring (December-May) seasons of 2007–2009 and in summer 2007.

Driving transect counts

Rabbits are active during twilight and at night, with two activity peaks that coincide with sunrise and sunset (Díez et al. 2005). However, rabbit counts at night provide more precise estimates than at dusk (Barrio et al. 2010a). We counted rabbits at dusk (starting one hour before sunset) and at night (starting two hours after sunset) in good weather conditions (no strong winds and no rainfall). Surveys were undertaken at each locality and at each of these periods of the day (dusk and night) for three consecutive days, unless climatic or logistic circumstances prevented so. Transects were travelled in an all-terrain pick-up at a speed of 15 km/h along dirt tracks varying in minimum length (mean ± SE = 14.04 ± 1.61 km) and traversing different habitats with good visibility. Most of the sightings were observed within 100 m, though some observations were exceptionally obtained up to 200 m approximately. One observer stood at the trunk of an all-terrain pick-up observing the 180º area ahead. At night, a 100-W halogen spotlight was used. The distance (m) of each rabbit from the observer was measured using a telemeter, and the angle between the transect line and the line from the observer to the animal was measured using a compass. We calculated an average kilometric abundance index (rabbits seen km^{-1}, KAI-N and KAI-D) at each locality by pooling the data obtained from the three replicates, and we estimated the rabbit density (rabbits ha^{-1}, DEN-N and DEN-D) with the Distance Sampling method (Buckland et al. 1993), using the Fourier series estimator as detection function in TRANSECT software (Burnham et al. 1980).

Linear transects on foot

Four-km transects were walked by two observers traversing areas favorable to rabbits, mainly those ecotones between Mediterranean scrubland and pastureland or cropland (Delibes-Mateos et al. 2008b). The variables assessed along the transect were rabbits (rabbits seen km^{-1}, RAB), latrines (latrines km^{-1}, LATR), scrapes (scrapes km^{-1}, SCR) and warrens (warren entrances km^{-1}, WARR) indices. For the latter index, all entrances (either active, inactive or unknown) were considered, since > 90 % of the entrances observed were active, with little difference in indices using only active entrances or total entrances. A pellet index (pellets m^{-2}, PEL) was obtained from 40 circular plots of 0.5 m^2 each, regularly distributed along the transect (one plot per 100 m). A relative density index (RDI) was obtained as the first axis score from a Principal Component Analysis (PCA, Zar 1984) of four raw variables that were highly correlated (LATR, WARR, RAB and SCR) following Delibes-Mateos et al. (2008b) and Villafuerte et al. (1998).

Local pellet counts in permanent plots

A 30x90 m grid was set in the area with the highest rabbit abundance at each locality, identified from the four-km transect on foot (see above). Every month, we performed cleared-plot pellet counts on the sampling areas, which consisted of 40 plots sited as four parallel lines of 10 plots each (Fernandez-de-Simon et al. *submitted*). The distance between each plot and line was 10 m, resulting in a regular sampling grid. After counting all pellets within the 0.5 m^2 circular plot centered at a wooden stake, we cleared the plot and, approximately one month later, we again counted the pellets in each plot. For each month, we obtained an uncorrected daily pellet accumulation rate (UNC) by calculating the average number of pellets m^{-2} day^{-1} (e.g., Catalán et al. 2008). We also estimated the persistence of rabbit pellets for each month and locality by placing 10 pellets marked with nail polish in each of five plots, (n = 50 marked pellets per locality per month, Fernandez-de-Simon et al. *submitted*). Remaining marked pellets were counted one month later, and daily persistence rates were calculated by assuming a constant daily decay between counts. The daily pellet accumulation rate corrected for persistence (COR) was calculated according to Palomares (2001), using the formula:

$$COR = UNC\ (DPR-1) / (DPR^{nd} - DPR)$$

where DPR = daily persistence rate of pellets, and nd = number of days elapsed since the last count.

We used the data from the month closest to the night counts dates, as the density estimates at night (DEN-N) were used as the reference method (see below). We also measured the standing crop counts (pellets m^{-2}, STA) in this high density area by counting dung pellets within 40 0.5 m^2 circular plots interspersed halfway among the cleared-plots within the same line.

Stratified pellet counts

We walked seven 400-m transects in each locality that contained 40 standing crop counts in regularly distributed 0.5 m^2 circular plots (one plot every 10 m). Transects were stratified among the habitats according to the proportion of the area occupied by each habitat type in each locality. The rabbit abundance index was determined by calculating the average number of pellets m^{-2} (STR, Table 1) for each locality.

Statistical analyses

Density estimates at night (rabbits ha^{-1}, DEN-N) was considered the reference method for estimating rabbit density when comparing the different techniques (Barrio et al. 2010a). The Distance Sampling method has been used previously to estimate rabbit density (Barrio et al. 2010a; Martins et al. 2003; Palomares 2001; Palomares et al. 2001). Linear regression was used to test the ability of the indices of rabbit abundance (independent variables) to predict DEN-N (dependent variable). First, we calculated linear regression using the data from the summers of 2008 and 2009, when all methods were assessed at each locality. All regressions were forced through zero intercept, as the indices should be zero when the rabbit density is zero. The degree of fitting was assessed using the coefficient of determination (r^2). Relationships were considered significant when $P < 0.05$. Afterwards, we tested whether these relationships were maintained for variables KAI-N, UNC and COR during other seasons, years and localities. Thus, a general linear model (GLM) was used separately for each of these three variables to test the effect of locality (1–8, random effect), season (winter–spring and summer, fixed effect), and year (2007 and 2008, random effect) on the slope of the linear regression between the reference method and each index of abundance (dependent variable). Significant effects by season or year would preclude pooling the data in the linear regressions. All analyses were performed using STATISTICA 6.0 (StatSoft 2001).

Results

Density estimates

In summer and in four localities (6, 2, 9 and 8), the low number of sightings precluded reliable estimation of DEN-N. In locality 6, no rabbits were observed during the three nights. Consequently, in these localities, rabbit densities were indirectly estimated from the linear regression between density estimates (dependent variable) and kilometric abundance index (independent variable, Palomares et al. 2001). The mean ± SE rabbit density considering all localities was then 0.85 ± 0.29 rabbits ha^{-1} ($n = 11$, range: 0–2.69 rabbits ha^{-1}, Fig. 2). To calculate the density estimates at dusk (DEN-D) in localities with insufficient sightings (2, 6 and 9), we used the linear regression between density estimates at dusk (dependent variable) and kilometric abundance index at dusk (independent variable).

Comparisons between indices

Of the variables tested, the pellet count indices were the most significantly related to the reference method (Table 2, Fig. 3). Among these, the COR showed the best fit to the reference method ($r^2 = 0.79$, $P \leq 0.001$). Nevertheless, we observed a low difference in r^2 among all indices based on pellet counts (see Table 2 and Fig. 3). RAB, based on rabbit counts during linear transects on foot, was also significantly related to the reference method ($r^2 = 0.68$, $P \leq 0.001$). KAI-N was also significantly associated with the reference method ($r^2 = 0.73$, $P < 0.05$), although this was expected because both KAI-N and DEN-N were derived from the same datasets. KAI-D was also significantly related to the reference method, although with lower r^2 than the same index at night (KAI-N). The variables RDI ($r^2 = 0.5$, $P < 0.05$) and WARR ($r^2 = 0.45$, $P < 0.05$), both based on linear transects on foot, were also significantly related to the reference method. In contrast, SCR, LATR and DEN-D were not significantly associated with the reference method ($P > 0.05$).

With respect to the model during other seasons, all independent factors except year ($P = 0.46$) significantly affected the slope between KAI-N and the reference method (locality, $F_{7,17} = 3.30$, $P = 0.02$, season, $F_{1,17} = 5.78$, $P = 0.03$). Pooling data from different years (2007-2009), we found that KAI-N was significantly related to the reference method both in winter–spring ($r^2 = 0.63$, $P \leq 0.001$, Table 3, Fig. 4) and in summer ($r^2 = 0.78$, $P \leq 0.001$, Table 3, Fig. 4). DEN-N estimates were obtained from these relationships and for each season separately in cases where there were insufficient observations (see above for details). Because no factor was significant for the UNC and COR models ($P > 0.05$), we pooled the data among seasons, years and localities for each variable. Both UNC ($r^2 = 0.45$, $P \leq 0.001$) and COR ($r^2 = 0.4$, $P \leq 0.001$) were significantly related to DEN-N (Table 3, Fig. 4).

Discussion

Using DEN-N as a reference standard, we evaluated the applicability of most rabbits abundance indices used previously, as described in the literature. We found that most pellet-count indices may reliably estimate abundances, whereas other indices, such as scrape and latrine indices and density estimates at dusk were not related to abundance on a regional scale. Among the pellet-count indices, cleared-plot pellet counts corrected and uncorrected by persistence were similarly related to the reference method, as previously demonstrated (Palomares 2001; Wood 1988). Estimating these indices in the zone of highest relative abundance within a locality may minimize the number of zero counts in areas of low rabbit density. In yearly monitoring of Mediterranean habitats it is advisable to obtain pellet-count indices during early summer, at the start of the dry season, thereby reducing the biases associated with differences in rabbit pellet persistence due to the effects of rainfall (Fernandez-de-Simon et al. *submitted;* Iborra and Lumaret 1997). Standing crop counts in summer were also related to density, resulting in only a slightly lower fit than COR. Therefore, if two visits are not possible owing to logistical constraints, standing crop counts may be a valid option for estimating rabbit abundance. Long-term monitoring of rabbit populations may be accomplished by repeated cleared-plot pellet counts over time, because they were found to be related to density during both summer and winter–spring periods. Pellet counts, however, are affected by other factors, such as the non-random distribution of pellets over the area due to heterogeneity in the environment (that may be corrected undertaking stratified transects) or the variation in defecation rates between populations or even between individuals (Putman 1984).

Of the driving transect indices, KAIs were related to the reference method for the seasons tested, although the relationships with DEN-N differed between seasons. Caution must be taken with KAIs because they do not control for habitat variation in rabbit detectability (Marchandeau et al. 2006). Furthermore, sight counts may underestimate rabbit abundance (Poole et al. 2003; Twigg et al. 1998), since the proportion of rabbits seen in a population are inversely related to rabbit density due to social interactions (Twigg et al. 1998). In the Iberian Peninsula, however, the densities reached are much lower than those of Australia (Barrio 2010), and at such densities the activity levels are relatively high during the spotlight counts (Twigg et al. 1998).These factors probably affects the slope of the regressions and make relationships obtained for each locality and season more reliable. KAI-D was related to the reference method, albeit with a lower fit than KAI-N, as found by Barrio et al. (2010a). DEN-D was not related to the reference method, although the transects were identical and performed on the same days. This may be related to an avoidance of dusk-time hours to prevent higher predation risk (hunting and diurnal raptors, Fernández de Simón et al. 2009) or to an avoidance of dirt tracks during the day to prevent human disturbance (similarly as the roe deer *Capreolus capreolus*; Ward et al. 2004). Driving transect counts may be affected by environmental factors such as visibility, wind speed and rainfall, which may affect to rabbit activity (Martins et al. 2003; Twigg et al. 1998; Villafuerte et al. 1993). Similarly, numbers of predators and hunting pressure should be considered when conducting the se surveys as rabbits may shift their activity to reduce the predation risk (Fernández de Simón et al. 2009). All these factors make advisable to conduct replicates and to complement these estimates with alternative indices to increase the results reliability.

The lack of significant relationships of LATR and SCR with the reference method may be due to the strong behavioral component of latrine (Monclús and de Miguel 2003) and scrape (Burggraaf-van Nierop and van der Meijden 1984) abundance, which may not be linked to rabbit abundance. Biases concerning latrine counts may also derive from subjective criteria for latrines (Delibes-Mateos et al. 2008b). Although these indices may locally result in reproducible variations in densities, we do not recommend their use in regional monitoring programs if they are not complemented by additional rabbit data (e.g., RDI). Despite LATR being recently adopted as a standardized methodology for monitoring rabbits in Portugal (Ferreira and Delibes-Mateos *in press*), our findings indicate this method is not reliable for monitoring abundance on large spatial and temporal scales, being preferable other pellet-count indices.

Recommendations

Overall, DEN-N may be used to provide reliable estimate of rabbit abundance when sufficient resources are available and when terrain, habitat and weather conditions permit. In other circumstances (wide-scale monitoring programs, many localities surveyed, long-term monitoring), pellet-count indices (except LATR) may be the most reliable for obtaining estimates of abundance when rabbit numbers are low to moderate. In summer and depending on the scale, the best indices for estimating rabbit abundance on small-, intermediate- and large-scales are the cleared-plot pellet counts corrected by persistence, the standing crop pellet index collected along a transect and the standing crop index at stratified transects, respectively. However, other indices obtained from linear transects on foot (rabbit, relative density and warren indices) may also be appropriate. Using an abundance index without knowing its relationship to estimated densities throughout the range of abundances likely to be encountered may compromise the reliability of the results. It would also make it difficult to compare these results with those of other studies. Therefore, standardization of abundance indices allows the most appropriate method to be selected, depending on the characteristics and objectives of the study. This can be performed using the methods described in this study, though the standardization with techniques such as density estimates from night counts may not always be possible. In this situation, equations provided here may be useful for monitoring studies and projects carried out in the same study area. Further research is also encouraged to standardize the abundance and density indices in other study areas or with other reference methods (e.g., live-trapping). Here, we concluded that COR may be optimal for monitoring rabbits on a large-scale and may be implemented as standardized methods for rabbit conservation programs, as well as for management issues (e.g., hunting, agriculture, etc.). Administrators, researchers and other personnel monitoring rabbits should promote the use of these methods for uniform monitoring and should abandon less reliable methods such as LATR. Effective monitoring to manage and conserve rabbit populations and their endangered predators is only possible when standardized and comparable monitoring methods are used.

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Table 1 Variables obtained with the different methods. The reference method (DEN-N) is highlighted in italics

	Driving transect counts
DEN-N	*Density estimates at night (rabbits ha^{-1})*
KAI-N	Kilometric abundance index at night (rabbits km^{-1})
DEN-D	Density estimates at dusk (rabbits ha^{-1})
KAI-D	Kilometric abundance index at dusk (rabbits km^{-1})

	Linear transects on foot
LATR	Latrine index (latrines km^{-1})
WARR	Warren index (warren entrances km^{-1})
RAB	Rabbits seen index (rabbits km^{-1})
SCR	Scrapes index (scrapes km^{-1})
PEL	Standing crop pellet index (pellets m^{-2}) collected along the transect
RDI	Relative density index (PCA from LATR, WARR, RAB and SCR)

	Local pellet counts in permanent plots
COR	Cleared-plot pellet counts corrected by persistence (pellets m^{-2} day^{-1})
UNC	Uncorrected cleared-plot pellet counts (pellets m^{-2} day^{-1})
STA	Standing crop counts (pellets m^{-2}) in the high-density area

	Stratified pellet counts
STR	Standing crop counts (pellets m^{-2}) at stratified transects

Table 2 Significant linear regressions ($P < 0.05$) between the reference method of rabbit density estimated at night from driving transect spotlight counts (DEN-N, dependent variable), and several rabbit abundance indices in decreasing order of coefficient of determination (r^2). Data were collected during summer surveys of 11 localities in central-southern Spain, and are shown graphically in Fig. 3. Codes of variables are shown in Table 1

Independent variable	r^2	Degrees of freedom	*F*	*P*	Equation
COR	0.79	1,10	38.27	≤ 0.001	$y=0.708x$
PEL	0.77	1,9	30.87	≤ 0.001	$y=0.018x$
UNC	0.73	1,10	27.5	≤ 0.001	$y=0.759x$
KAI-N	0.73	1,7	18.64	0.003	$y=0.154x$
STR	0.71	1,9	22.28	≤ 0.001	$y=0.026x$
STA	0.7	1,10	23.29	≤ 0.001	$y=0.004x$
RAB	0.68	1,10	21.55	≤ 0.001	$y=0.153x$
KAI-D	0.5	1,9	9.04	0.02	$y=0.115x$
RDI	0.5	1,10	9.82	0.01	$y=0.798x$
WARR	0.45	1,10	8.11	0.02	$y=0.025x$

Table 3 Significant linear regressions (*P* < 0.05) between the reference method of rabbit density estimated at night from driving transect spotlight counts (DEN-N, dependent variable), and several rabbit abundance indices in decreasing order of coefficient of determination (r^2). Data were collected during surveys in different seasons (winter–spring and summer) at 11 localities in central-southern Spain, and are shown graphically in Fig. 4. Significant regressions pooling the data from different seasons (pooled) are also exhibited. See Table 1 for codes of variables

Season	Independent variable	r^2	Degrees of freedom	*F*	*P*	Equation
Winter-spring	KAI-N	0.63	1,17	28.5	≤ 0.001	*y=0.103x*
Summer	KAI-N	0.78	1,14	49.11	≤ 0.001	*y=0.161x*
Pooled	UNC	0.45	1,41	33.85	≤ 0.001	*y=0.625x*
	COR	0.4	1,40	26.67	≤ 0.001	*y=0.515x*

Figure captions

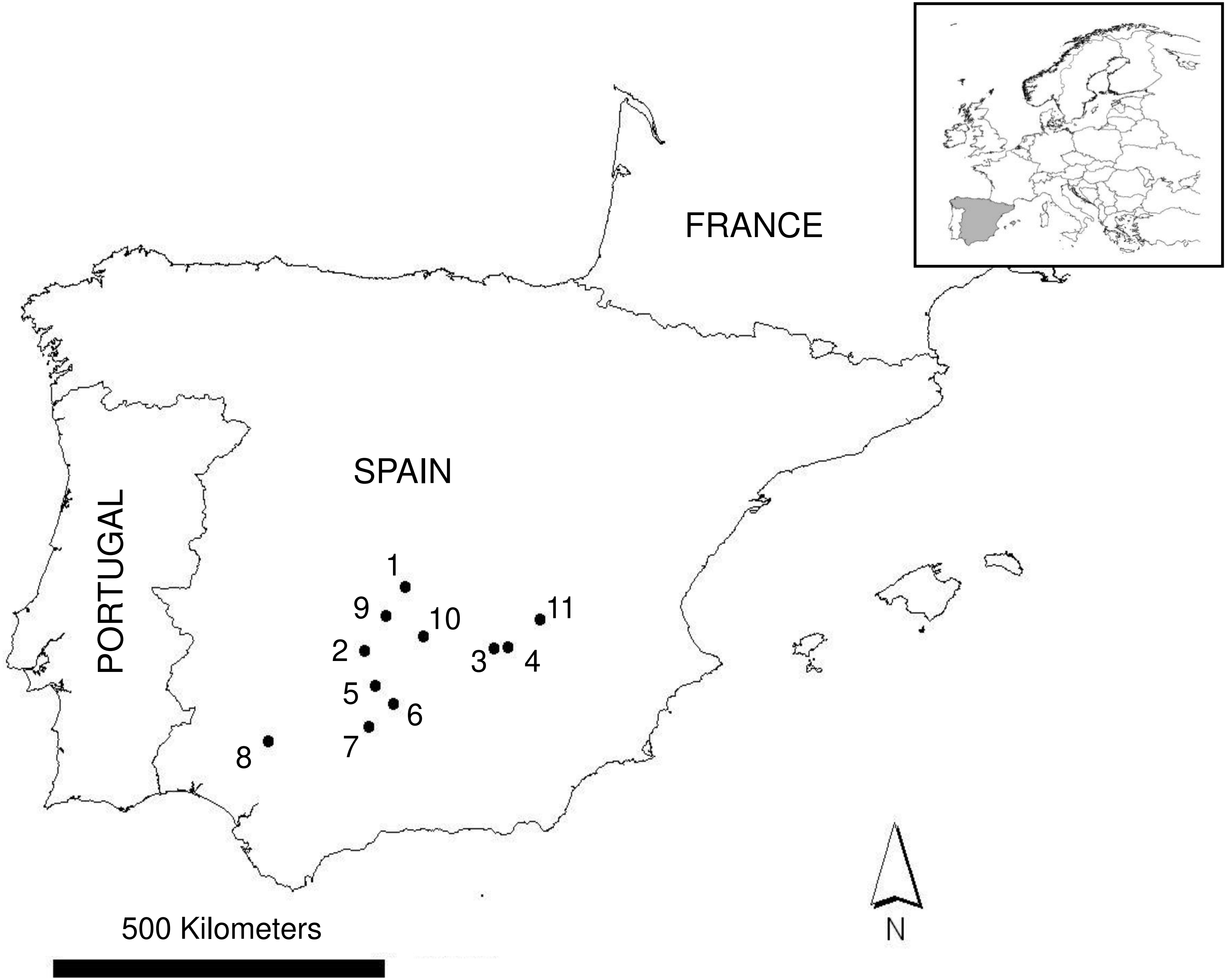
Fig. 1 Location of study areas in the Iberian Peninsula

Fig. 2 Rabbit density at each locality estimated from driving transects using the Distance Sampling method at night (DEN-N). Error bars represent the standard errors. Numbers correspond to the localities codes shown in Fig. 1

Fig. 3 Relationships and *P*-values between rabbit density estimates at night (DEN-N, dependent variable and reference method) and the independent variables (a-j) in summer. The RDI axis lacks units because it was obtained from a principal component analysis of the latrine (LATR), warren (WARR), rabbits (RAB) and scrapes (SCR) indices. Codes of variables are shown in Table 1

Fig. 4 Relationships and *P*-values between rabbit density estimates at night DEN-N (dependent variable and reference method) and (a) kilometric abundance index (KAI-N) at night in winter–spring, (b) KAI-N in summer, (c) cleared-plot pellet counts uncorrected by persistence (UNC) with pooled dataset from both seasons, and (d) cleared-plot pellet counts corrected by persistence (COR) with pooled dataset from both seasons

Figure



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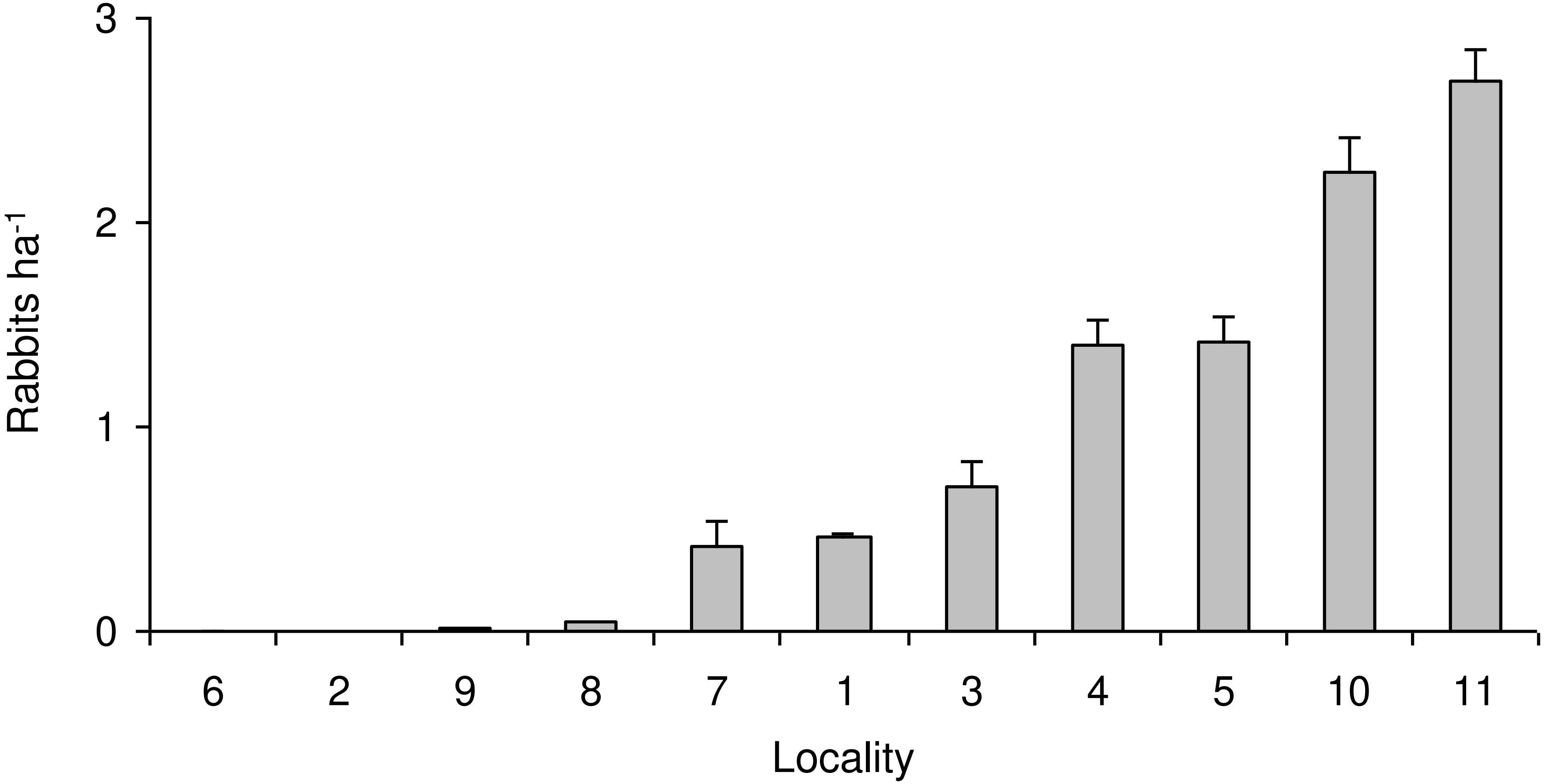
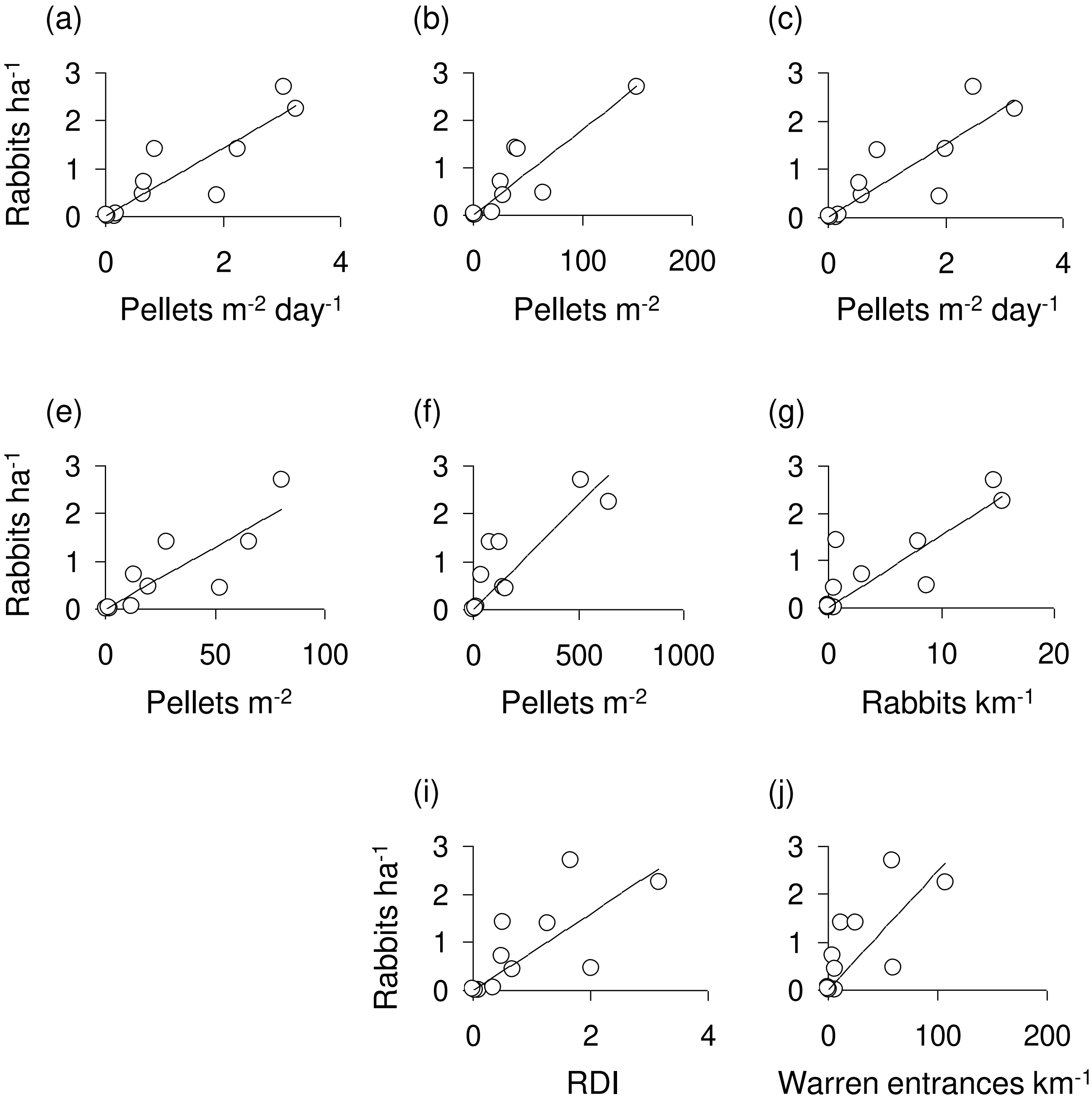
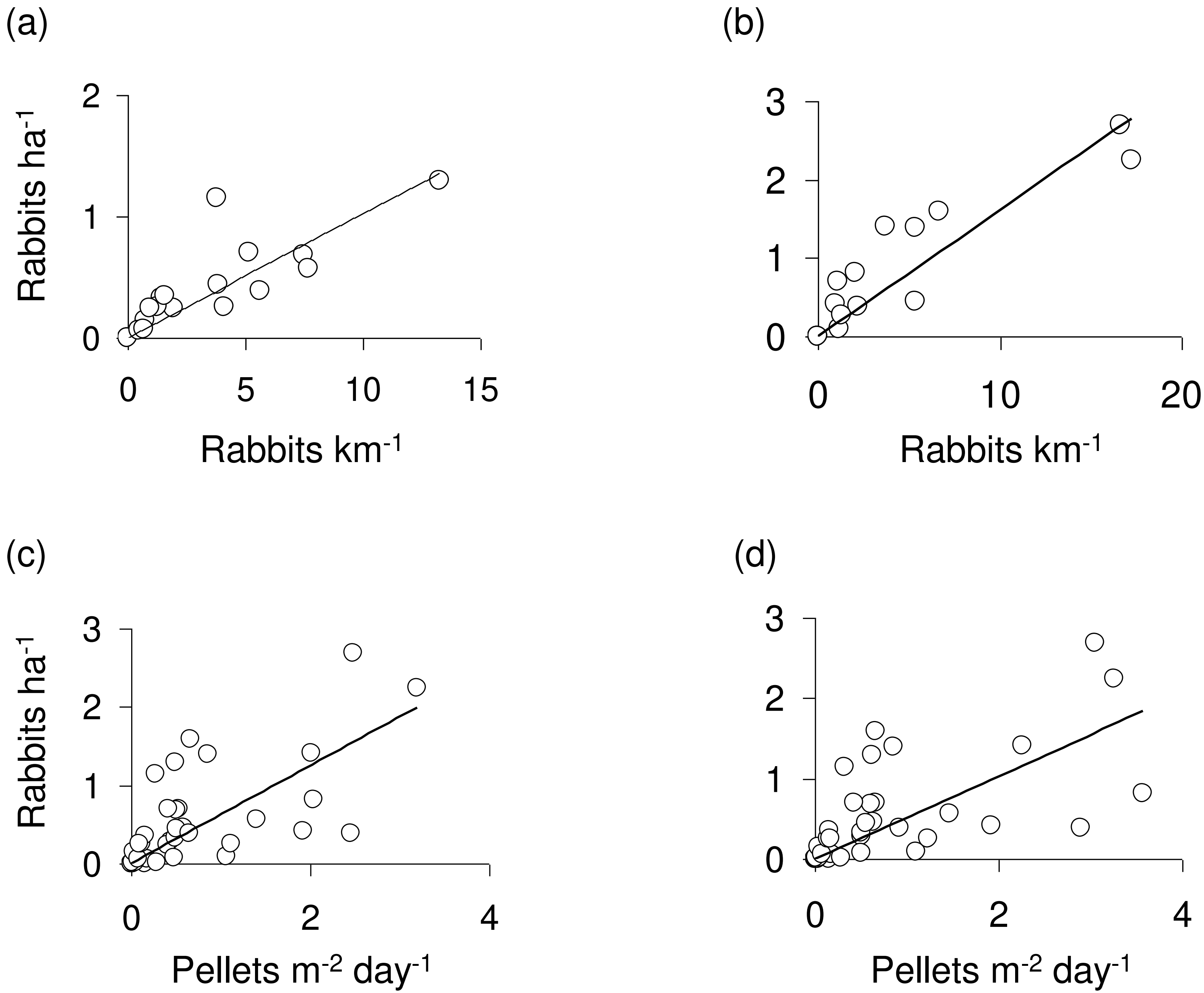


Figure



(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
Rabbits ha-1
Pellets m-2 day-1
Pellets m-2
Pellets m-2 day-1
Rabbits km-1
Pellets m-2
Pellets m-2
Rabbits km-1
Rabbits km-1
RDI
Warren entrances km-1

Figure



(a)
Rabbits ha-1
2
1
0
0
5
10
15
Rabbits km-1
(b)
3
2
1
0
0
10
20
Rabbits km-1
(c)
Rabbits ha-1
3
2
1
0
0
2
4
Pellets m-2 day-1
(d)
3
2
1
0
0
2
4
Pellets m-2 day-1