

## Cooke's index: A simple, cost-effective method for multiple practitioners to estimate European rabbit abundance

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### ABSTRACT

The development of evidence-based tools that help to monitor wildlife populations is essential to assess the success of management interventions. Here, we evaluated the reliability of a simple method to estimate the abundance of the European rabbit (*Oryctolagus cuniculus*), which is likely one of the most managed vertebrate species worldwide. Cooke's method involves noting the distribution and frequency of sightings of rabbit fecal pellets and accordingly scoring the abundance of rabbits on a scale 0–5. To assess its reliability, we used information collected during 101 rabbit surveys conducted across mainland Spain during the summer of 2022. In each 4-km walked transect, we estimated rabbit abundance using Cooke's method every 400 m (i.e., 10 indexes), and pellet counts (2 plots per 100 m walked, i.e., 80 counts), which were used as a reference index. Our results revealed a strong correlation between the estimates of rabbit abundance obtained using Cooke's method and the number of pellets counted per m<sup>2</sup> regardless of the statistical approach used. This suggests that Cooke's method provides a simple and inexpensive way of estimating the abundance of European rabbits, which we believe that can be very useful for non-expert land managers after a very short training period. Importantly, our findings demonstrate that it is reliable to estimate rabbit abundance in different land uses. In addition, Cooke's method can be used in different seasons, is not affected by circadian activity of rabbits, seems to work well across the whole range of rabbit abundance, and may be useful for estimating rabbit abundance at different spatial scales. As everyday people rather than scientists are generally involved in managing European rabbits, we strongly recommend this simple method that allows rabbit abundance to be quickly estimated so that management decisions can be made. More broadly, we encourage researchers to investigate the usefulness of similar monitoring tools for other mammal species that are often surveyed through counting their pellets.

### 1. Introduction

Wildlife impacts, defined as circumstances where people, consciously or unconsciously, negatively impact wildlife, or alternatively where wildlife negatively impacts the well-being or livelihoods of people (Young et al., 2005; Young et al., 2007), have substantially increased in the current era of the Anthropocene. In this context, efforts aimed at reducing such impacts (e.g., to increase numbers of declining species or to control invasive aliens) need evidence-based wildlife

monitoring systems to assess to what degree management interventions have been successful (Bisbal, 2001). Indeed, generously funded initiatives are increasingly launched to develop tools that help to monitor wildlife populations. For example, the ENETWILD project, funded by the European Food Safety Authority (EFSA), attempts to improve European capacity for monitoring wildlife populations by developing standards for data collection and validation, and eventually creating and promoting a data repository (<https://enetwild.com/>).

The European wild rabbit (*Oryctolagus cuniculus*) is likely one of the

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most managed vertebrate species across the world. Native to the Iberian Peninsula in southern Europe, it has been introduced in many regions in all continents except in Antarctica and in more than 800 oceanic islands (Delibes-Mateos et al., 2023). In its native range, the European rabbit is a multifunctional keystone species and ecosystem engineer (Delibes-Mateos et al., 2008a). Iberian rabbit populations declined sharply over the past decades as a consequence of habitat loss and the outbreak of two viral diseases (reviewed in Delibes-Mateos et al., 2023), which led to huge conservation initiatives that aimed to restore rabbit numbers; for example, thousands of rabbits were released in protected areas to sustain the populations of endangered predators that rely on this prey (Carro et al., 2019). Similarly, hunters have made huge investment to recover rabbit numbers, as this is one of the main game species in Spain and Portugal (Delibes-Mateos et al., 2014). Game management includes not only rabbit restocking, but also habitat improvement, predator control or rabbit vaccination (Delibes-Mateos et al., 2008b). Paradoxically, rabbit populations have experienced recent substantial growth in some farmland areas within Spain, leading to severe crop damage (Delibes-Mateos et al., 2018). In such places, rabbits are managed to reduce their numbers mainly through intensive hunting (Ríos-Saldaña et al., 2013, Delibes-Mateos et al., 2014). By contrast, in areas where it has been introduced, the attributes of the rabbit as an ecosystem engineer have made it one of the most harmful pest species due to its devastating impact on native ecosystems and the significant economic damage it causes to farming (Thompson and King, 1994, Cooke, 2012). For this reason, there is continuing effort to reduce rabbit numbers and associated effects (Priddel et al., 2000, Cooke et al., 2013).

In this context, it is essential to develop evidence-based methods that permit practitioners, including land managers, conservationists, farmers, and hunters, to estimate the abundance of rabbits and monitor the success of their interventions either to reduce or increase rabbit numbers. Unfortunately, most available wildlife monitoring tools require significant effort and resources and usually need to be implemented by expert researchers (Ferreti, 2019, Descalzo et al., 2021). For example, counting fecal pellets in random plots is one of the most frequently used and accurate methods for estimating rabbit abundance (Palomares, 2001, Fernández de Simón et al., 2011, Guerrero-Casado et al., 2020, Cubas et al., 2021), but this method is extremely time-consuming, particularly in high-density areas. Counting rabbits, often referred to in the literature (e.g., Fernández de Simón et al., 2011, Cruz et al., 2013, Cabezas-Díaz and Virgós, 2022), is also costly and, importantly, expert knowledge is required to make precise estimates from raw data (Marchandeu et al., 2006, Barrio et al., 2010a). Recently, Cabezas-Díaz and Virgós (2022) proposed counting rabbit latrines, which is less time-consuming, as a good index to estimate rabbit abundance, but its usefulness was tested in only one habitat type where rabbits generally reached very high numbers and was questioned in previous studies (Fernández de Simón et al., 2011, Guerrero-Casado et al., 2020). Furthermore, such detail is often unnecessary for determining whether rabbit populations are so low they are a conservation concern in natural areas in Spain or high enough to be a problem in countries like Australia. As everyday people rather than scientists are generally involved in managing rabbits, what is needed is a simple method that allows the abundance to be quickly estimated so that management decisions can be made, and scientists have a social responsibility to make their findings and any applications readily accessible.

In line with this approach, a simple method was originally developed and partially validated in Australia to assess the impact of rabbits on native plant biodiversity (Cooke and McPhee, 2007, Cooke et al., 2008), and has subsequently been considered by some rabbit management practitioners in Europe. Termed 'Cooke's' method (Cubas et al., 2021), it involves noting the distribution and frequency of sightings of rabbit fecal pellets then scoring the abundance of rabbits on a scale 0–5 (Table 1, Cooke and McPhee, 2007, Cubas et al., 2021). The main benefits of this monitoring tool are that it is inexpensive, and can easily be applied by non-expert practitioners after a simple demonstration.

**Table 1**

Description of the rabbit abundance score (Cooke's method). Adapted from Cooke and McPhee (2007).

Rabbit abundance score	
To assess rabbit abundance, take 15 min to inspect a selected site (about 2–3 ha) on foot. Keep moving to cover as much of the area as possible, noting the patterns and distribution of any rabbit faeces or pellets you see. Score the abundance of rabbits according to the following 0–5 scale.	
0:	No faeces found.
1:	Isolated faeces in small groups (5–10) separated from each other by more than 10 m.
2:	Groups of scattered faeces separated from each other by less than 10 m.
3:	Faeces common in large groups in the half of the search area.
4:	Faeces abundant, often in large groups, but not so many to cover the entire search area.
5:	Very abundant. The faeces are always present throughout the search area.

Furthermore, it enables logical decisions to be made towards managing rabbit populations. For example, if rabbits are very patchily distributed (scores 1, 2) it should be obvious that rabbit feeding territories do not overlap and therefore there is a good chance that plants that are normally highly susceptible to rabbit damage can germinate and grow in rabbit-free patches. Contrarily, where rabbits are expected to maintain pasture diversity by suppressing invasive grasses, higher scores (4, 5) should confirm that rabbit abundance is adequate for the task.

In this study, our main aim was to assess the reliability of Cooke's method to estimate rabbit abundance. Previous research showed that estimates using this method were correlated with the number of rabbit warren entrances in south-eastern Australia (Cooke and McPhee, 2007) and with pellet counts in Canary Islands (Cubas et al., 2021). However, both studies were conducted in areas where the rabbit is invasive, in very specific habitat conditions (i.e., in areas with soft soils where rabbit could build warrens in southern Australia, and on a volcanic oceanic island) and were based on estimates made in a relatively low number of sites (e.g., 27 in Canary Islands; Cubas et al., 2021). The novel contribution of our study is that: i) it presents for the first time a large-scale assessment of the reliability of Cooke's method across mainland Spain (Fig. 1), the rabbit's native area, ii) it covers a wide diversity of land uses, and the reliability of Cooke's method on each of those is assessed, and iii) rabbit abundance was estimated using both the Cooke's method and a reference method (i.e., pellet counts, Fernández de Simón et al., 2011) in multiple different sites (Fig. 1, but see also Materials and methods).

## 2. Materials and methods

To assess the reliability of the Cooke's method, we used information collected during 101 rabbit surveys conducted across mainland Spain in 2022 (Fig. 1); fieldwork was carried out in summer when rabbits reach their maximum annual densities in Spain (Beltran, 1991). These surveys were part of a larger project that aimed to estimate rabbit population trends since the early 1990s (Blanco and Villafuerte, 1993). In 1993, one rabbit survey was performed in each 1:100,000 map area (Army Cartographic Service) within mainland Spain, but doubled in areas where the Iberian lynx (*Lynx pardinus*) and the Spanish imperial eagle (*Aquila adalberti*) were present (Villafuerte et al., 1998, Delibes-Mateos et al., 2008b). In 2022, we repeated only 101 of the 311 surveys carried out in 1993 due to logistic constraints. The selection of the subset of repeated surveys aimed: 1) to cover the full range of rabbit abundance (i.e., from low to high rabbit abundance); 2) to consider a diversity of land uses (Table 2); 3) to ensure a good spatial coverage of mainland Spain (Fig. 1).

Each survey consisted of a 4-km walked transect conducted by two observers (Delibes-Mateos et al., 2008b, Fernández de Simón et al., 2011). During the transects, rabbit abundance was estimated using Cooke's method every 400 m; i.e., after walking 400 m, observers agreed on a score of rabbit abundance on the 0–5 scale according to the pellets



Fig. 1. Location of the 101 sites where rabbit abundance surveys that included both Cooke's method and pellet counts were conducted in summer of 2022.

they had seen (Table 1, 10 indexes along the 4-km transect). In addition, rabbit abundance was estimated as pellets counted per  $m^2$ . To do so, 2 circular plots (18 cm radius, i.e.,  $0.1 m^2$ ) were randomly located at the end of every 100 m walked, and all the pellets inside the plots were counted. Following the recommendations of Mutze et al. (2014), counting pellets on a latrine was avoided; according to these authors, a latrine consists of  $\geq 40$  pellets in a  $0.1 m^2$  counting plot. This resulted in 80 pellet counting plots on each transect; an average of these counts was calculated and used as a reference index of rabbit abundance as this method has been proved to be very accurate of rabbit numbers (Palomares et al., 2001, Fernández de Simón et al., 2011, Mutze et al., 2014). In sum, we obtained mean estimates of rabbit abundance in each of the 101 surveys using both Cooke's method and the number of pellets counted per  $m^2$ . In addition, we estimated visually the predominant land use in each transect. Main land uses considered were: natural vegetation, farmland areas, mixed areas of natural vegetation and crops, *dehesas*, and *peri-urban* areas (see a brief description of land uses in Table 2).

We wanted to evaluate whether Cooke's method allows predicting the pellet counts in plots and if land use type could hamper this capability. The difference in scales between Cooke's method (ranks ranging 0–5) and pellets in  $0.1 m^2$  circular plots (continuous variable ranging 0–10.34) may lead to an exponential relationship (e.g., Mutze et al., 2014). Thus, we followed the analytic approach proposed by Mutze et al. (2014) and used both linear and non-linear procedures to model this relationship and test our hypotheses.

First, we linearized the relationship by applying the  $\log + 1$  (natural logarithm plus one) transformation to rescale both the site-averaged ranks of the Cooke's method and the site-averaged pellet counts in circular plots. In this way, they were both on the same scale and avoided taking  $\log(0)$ , then we added land use (categorical factor, five classes) as

an interaction in the model. Finally, we fitted this model using major axis regression (see also Cabezas-Díaz and Virgós, 2022), implemented in the package "mart" (Warton et al., 2012). Since there were no differences in slopes among land uses and partial  $R^2$  were all very high (see Table 2), for simplicity, we did not include the land use interaction in our non-linear fitting of non-transformed variables. We fitted this model using non-linear least squares ("nls" function, package "nlme", Pinheiro et al., 2021) in R (R core Team, 2020). Scripts to perform the analyses are available under request to the authors.

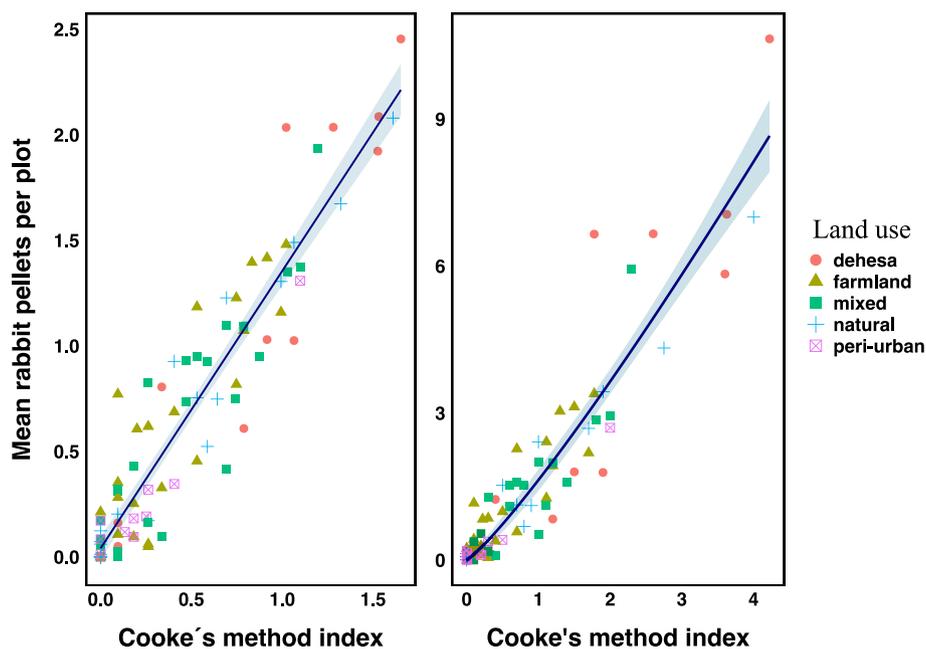
### 3. Results and discussion

We found a strong correlation between the estimates of rabbit abundance obtained using Cooke's method and the number of pellets counted per  $m^2$  (Fig. 2, Table 2). Both the linear and non-linear approaches identified strong, positive correlation between Cooke's method and pellet counts (Table 2), and both identified a strong, positive prediction of Cooke's method on pellet count (Fig. 2). Although the non-linear approach provides a better fit (AIC 211 vs 218), linearizing facilitates the estimate of interactions with land use type, and thus we based our discussion on the latter. Our results are consistent with previous studies (Cooke and McPhee, 2007, Cubas et al., 2021) and suggest that Cooke's method provides a simple way of estimating the abundance of European rabbits. In this study, the degree of correlation between the scores of Cooke's method and the reference method was even stronger than that reported by Cooke and McPhee (2007) and Cubas et al. (2021) in Australia and Canary Islands, respectively. This may be explained by the considerably higher number of points surveyed in the present study in addition to the more powerful statistic approach employed. Furthermore, Cooke and McPhee (2007) compared Cooke's index with the number of rabbit warren entrances, which is very variable

**Table 2**

Correlations between two sets of estimates of rabbit abundance based on fecal pellet counts and Cooke's method across 5 land use categories. Upper and lower limits for 95% confidence intervals are provided for both elevation and slope for each fitted regression (1 per land use class). Parameters of the test of difference of slopes across habitats and of the non-linear correlation between both variables are also shown.

Land use	N		Elevation	Slope	R <sup>2</sup>	p value	
<b>Natural vegetation:</b> including forests and Mediterranean scrublands	24	<b>estimate</b>	0.197	1.301	0.959	<0.001	
		<b>lower limit</b>	-0.026	1.196			
		<b>upper limit</b>	0.065	1.414			
<b>Farmland areas:</b> arable land devoted to agriculture (cereal crops, corn, olive trees, almond trees, etc.)	24	<b>estimate</b>	0.008	1.489	0.767	<0.001	
		<b>lower limit</b>	-0.150	1.251			
		<b>upper limit</b>	0.166	1.772			
<b>Mixed areas:</b> intermingled areas of natural vegetation and farmland areas	25	<b>estimate</b>	0.039	1.342	0.815	<0.001	
		<b>lower limit</b>	-0.098	1.122			
		<b>upper limit</b>	0.177	1.604			
<b>Dehesas:</b> man-made ecosystems characterized by a savannah-like physiognomy that are typical in southern Iberian Peninsula	17	<b>estimate</b>	-0.021	1.404	0.916	<0.001	
		<b>lower limit</b>	-0.214	1.214			
		<b>upper limit</b>	0.173	1.623			
<b>Peri-urban:</b> areas of scattered urban growth with hybrid landscapes of fragmented and mixed urban and rural characteristics	11	<b>estimate</b>	0.023	0.929	0.943	<0.001	
		<b>lower limit</b>	-0.052	0.662			
		<b>upper limit</b>	0.097	1.305			
<b>Difference in slopes:</b>			<b>LRS</b>	<b>DF</b>			
			6.882	4		0.142	
<b>Non-linear regression (formula: <math>y \sim a * (x^b)</math>)</b>			<b>estimate</b>	<b>std. error</b>	<b>t value</b>		
			a	1.633	0.109	15.010	<0.001
			b	1.158	0.062	18.770	<0.001



**Fig. 2.** Correlations between two sets of estimates of rabbit abundance based on fecal pellet abundance (counted in 0.1 m<sup>2</sup> plots). Left, the linearized (log-transformed with natural logarithm) relationship between indexes derived from Cooke's method and abundance values obtained through the fecal pellet count method. Right, same relationship using raw values and a non-linear model. Shaded regions represent standard deviation.

depending on soil characteristics and rabbits' social behavior (Parer and Libke, 1985); thus, their estimates using this reference method could likely decrease the correlation.

This is not the first approach of this kind. For example, in New Zealand, the modified McLean rabbit infestation scale is commonly used (NPCA, 2012). It is similar but scores rabbit abundance on a scale of 1–8 rather than 0–5. Management decisions are made based on the score. For example, if the Waikato Regional Council receives a complaint about rabbits, the modified McLean scale is used to check the severity of the infestation. Note that such action is to protect surrounding landholders and prevent a rabbit problem spreading. For the scoring of this method, the sighting of rabbits or burrows are also involved, which, together with the greater number of categories, makes it more complex in its use than Cooke's method.

A major benefit of Cooke's method is that it can be used by non-experts after a very short training period (e.g., learning to differentiate between pellets of rabbits and those of other wildlife species), which contrasts with other wildlife monitoring tools that require training staff and, often, the supervision of qualified biologists (McComb et al., 2020). This makes Cooke's method readily accessible for different practitioners involved in rabbit management. We have demonstrated that it could be adequate for a large-scale assessment of rabbit abundance in Spain, where more needs to be done because it is essential for the identification of suitable areas for the restoration of rabbit-dependent predators like the Iberian lynx (Garrote et al., 2020). In conservation programs of rabbit predators, rabbit abundance is often estimated by counting rabbit latrines, but this method has been questioned by some authors (Fernández de Simón et al., 2011, Guerrero-Casado et al., 2020) and Cooke's method presents some advantages over latrine counts and other indexes (see below). In addition, this tool may contribute to efficient decision-making and management in areas where rabbits cause damage either to the natural environment or to farming (Cooke, 2012). This method of monitoring abundance gives farmers or conservationists an independent means of anticipating rabbit damage to crops or native plants, protecting the area or promoting control of the species. Additionally, in Spain it could be useful for verifying "emergency areas" where intensive rabbit control has been exceptionally requested and permitted because of the heavy crop damage (Delibes-Mateos et al., 2020). In this context, Cooke's method could be used to assess the relationship between rabbit abundance and crop damage, and in particular to evaluate how the availability of natural food affects such relationship (Barrio et al., 2010b). Importantly, this method does not require any material and therefore it is inexpensive, which is very relevant given that severe budget constraints are often faced by practitioners who monitor wildlife (McComb et al., 2020).

Furthermore, the strong  $R^2$ , similar slopes and confidence intervals for model elevation crossing the zero value found for our land use categories (Table 2) indicate that Cooke's method is reliable for different land uses including farmland, natural-vegetated areas and *peri*-urban habitats (e.g., gardens and parks). Besides, it can be used in any season and is not affected by circadian activity of rabbits. This is a major advantage over other monitoring methods such as counting rabbits, which requires that rabbits are active outside warrens and detectable (Fernández de Simón et al., 2011); this often occurs at night (Barrio et al., 2010a), which poses an extra sampling effort. In addition, Cooke's method seems to work well across the whole range of rabbit abundance, which does not occur with other methods. For example, Guerrero-Casado et al. (2020) suggested that latrine counts may underestimate rabbit abundance in areas with low number of rabbits, where estimating rabbit density using DISTANCE software is also impossible when the number of sightings is low (Buckland et al., 2004). Remarkably, Cooke's method may be useful for estimating rabbit abundance at different spatial scales such as small farmland plots to larger areas like hunting estates or even protected areas. This is another important advantage over other methods used to monitor rabbits. Counting rabbits or their signs, such as latrines or warren entrances, along transects requires

usually surveying a minimum distance, between 1 km and 30 km transect to yield accurate population counts (Palomares, 2001, Williams et al., 2007, Cabezas-Díaz and Virgós, 2022).

Cooke's method may only be roughly converted to density values (Cooke and McPhee, 2007, Cooke et al., 2008), making this a potential limitation since some critical management thresholds are currently based on such rabbit population density thresholds. For example, rabbit densities of at least 1–4.6 rabbits/ha during autumn and spring respectively are necessary to sustain territorial breeding Iberian lynx (Palomares et al., 2001). Also, several studies have suggested that a threshold density of 0.5 rabbits/ha completely inhibits regeneration of some plants in Australia (Cooke et al., 2010, Bird et al., 2012). Despite this, new thresholds based on the scores of Cooke's method could be set, thus becoming useful for decision-making regarding rabbit management.

Another possible drawback of this method is potential differences in scoring among observers. However, Cooke and McPhee (2007) found high correlation between pairs of observers examining a range of different sites. In addition, we carried out a concordance test in southern Spain which revealed a significant agreement among the scores provided by 9 observers at 10 different sites (Kendall's coefficient of concordance = 0.523,  $\chi^2 = 42.4$ ,  $p < 0.001$ ). Nevertheless, the number of rabbits in that study area was medium to low (0–3 median scores), and therefore further investigations, particularly in high-density areas, are needed to confirm this apparently low observer variation. In any case, it would be possible to 'correct' for observer bias where several observers take part in a survey by scoring a set area where rabbit pellets in plots have already been counted.

#### 4. Conclusion

In conclusion, our study implies that Cooke's method is a reliable alternative to fecal pellet counts as an estimate of rabbit abundance that is inexpensive and accessible to rabbit management practitioners across the native and invasive distributions of the European rabbit. Furthermore, it opens the possibility of developing similar monitoring tools for other mammal species that are often surveyed through counting their pellets. These would include other lagomorph species like hares (Murray et al., 2002), ungulates (Acevedo et al., 2010) or wallabies (Hayward et al., 2005), among others. Nevertheless, it would be essential for researchers to check the reliability of this method in each species before it is applied in the field.

#### CRedit authorship contribution statement

**Miguel Delibes-Mateos:** Conceptualization, Investigation, Methodology, Writing – original draft. **Francisca Castro:** Investigation, Writing – review & editing. **Luis Arias de Reyna:** Investigation, Writing – review & editing. **Agustín Camacho:** Data curation, Formal analysis, Writing – review & editing. **Brian Cooke:** Methodology, Writing – review & editing. **Rafael Villafuerte:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

The data that has been used is confidential.

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