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Original Study

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Current distribution of the Reeves' muntjac *Muntiacus reevesi* (Ogilby, 1839) in France

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Abstract: The Reeves' muntjac *Muntiacus reevesi* is an ungulate native to China and Taiwan that has been released into the wild in several continental European countries and the United Kingdom. We present recent records of the species in mainland France. We also investigated the dispersal rate and density of the established population in the Centre-Val de Loire region. The number of observations of *M. reevesi* was low in the period 2008–2016, increased sharply until 2019 and then decreased until 2023. From a comparison between the distribution in 2008–2012 and 2013–2017, the dispersal rate was estimated at an average of 3.2 km/year, and 7.6 km/year between 2013–2017 and 2018–2023. Based on a camera trap protocol, the population density was assumed to be very low in forested areas but estimated with a lack of robustness due to a single observation. Further efforts must be made to better assess the risk of an increase in the wild population of Reeves' muntjac in the Centre-Val de Loire region. To prevent potential impacts, rapid control measures can be put in place in the large area (10,800 km²) where muntjacs are now rapidly spreading.

Keywords: exotic deer; Reeves' muntjac; *Muntiacus reevesi*; invasive alien species; EU regulation 1143/2014

1 Introduction

Introduced herbivore species, such as ungulates, can have numerous impacts, particularly in terms of overgrazing and habitat depletion, which in turn alter ecosystem functioning (Volery et al. 2020). In continental France, four non-native cervid species was introduced into the wild: the Chinese water deer *Hydropotes inermis* (Swinhoe, 1870), the Sika deer *Cervus nippon* (Temminck, 1838), the European fallow deer *Dama dama* (Linnaeus, 1758) and the Reeves' muntjac *Muntiacus reevesi* (Ogilby, 1839). The small population of Chinese water deer is now extinct into the wild. While the status of the Sika deer and European fallow deer populations is well known and monitored by wildlife managers and hunters (Maillard and Saint-Andrieux 2021; Saint-Andrieux 2021), the current status of the Reeves' muntjac, a small and secretive ungulate species originating from China and Taiwan, remains poorly documented (Chapman 2022; Ward et al. 2021). This species was introduced towards the end of the 19th century and is still found in the wild in various countries on the European continent: Belgium, Denmark, France, Germany, Ireland, Netherlands, and United Kingdom (Tsiamis et al. 2017; <https://easin.jrc.ec.europa.eu/notsys/>). Other data indicate observations of Reeves' muntjac in Austria (<https://www.inaturalist.org>) (Figure 1A).

The status of Reeves' muntjac in captivity was surveyed in 2016: at least 34 establishments held Reeves' muntjacs, of which 28 were zoos, and six were privately owned, with nearly one hundred and 40 animals recorded as captive (Maillard 2017). Most of these establishments (80 %) kept few individuals (1–5). The current number of *M. reevesi* kept by private owners remain however underestimated.

The main aim of this research note was to refine the history of introduction of the Reeves' muntjac based on a historical document research. Its current distribution in the wild was characterised to infer the species range area and average spread rate over the last 15 years (see also Chapman 2022; Hurel et al. 2019; Ward et al. 2021). We also provide results from a camera-trapping protocol which was set in order to estimate the population density near the introduction point in the department of Indre-et-Loire where a wild population probably originated from individuals escaped from captivity (Hurel et al. 2019).

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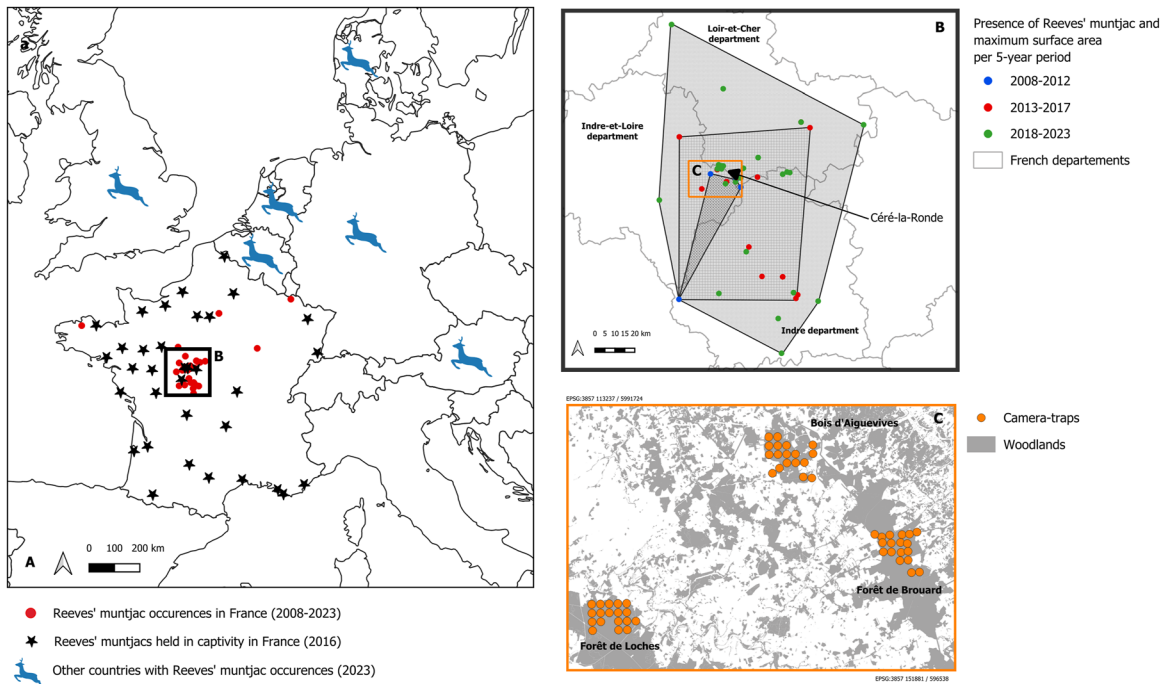


Figure 1: Distribution of Reeves' muntjac (A) in Europe and France (2008–2023), (B) with special emphasis on the Centre-Val de Loire region, and (C) detail of the camera-trap protocol set in the core area of muntjac records in spring 2021.

2 Materials and methods

2.1 Historical review: before 1940

Historical documents published before 1940 were searched at the online electronic library Gallica (<https://gallica.bnf.fr/accueil/fr/>), using the following keywords: “Muntjac”, “Cervulus”, “Muntiacus”, “Muntjac de Reeves”, “*M. reevesi*”, “*Cervulus reevesi*”, “Cervule de Chine”, and “Cervule de Reeves”.

2.2 Occurrence data

As part of the implementation of the Invasive Alien Species European Regulation No. 1143/2014, occurrence data have been regularly updated by collecting records from gamekeepers, wildlife managers, naturalists and hunters since 2016 (Hurel et al. 2019). In 2016, a database was created to store unique national records of Reeves' muntjacs, either found dead or alive, including date, location, number, and sex of individuals. Data were collected by a standardized form (Database OISON) by the agents of the French Biodiversity Office, and by hunters as they have been legally allowed to shoot Reeves' muntjacs since 2018 (Hurel et al. 2019). The data are centralised by two of us (P. H. & J.-F. M.). Additional Reeves' muntjac records were collected from online websites (<https://www.faune-france.org/>; <https://observation.org/>; <https://www.inaturalist.org/>), when

identification from a picture could be made. The online databases were last accessed on 31/12/2023, and all data were compiled in a geographical system (Qgis v3.2). All data are freely available at https://inpn.mnhn.fr/espece/cd_nom/61043/tab/sources.

We calculated the spread rates, Δ_r , in km/yr, as the square-root of the average of the square of the shortest and longest radial increased distances of the minimum convex polygons encompassing the invaded area ($\Delta_r = [(\Delta_{r\max}^2 + \Delta_{r\min}^2)/2]^{1/2}$; Andow et al. 1990, 1993) between the 2008–2012 and 2013–2017 period (10 years), and the 2013–2017 and 2018–2023 periods (10 years).

2.3 Camera-trapping protocol

We assessed population density in the core area of muntjac records in 2021 from a grid of 18 camera traps, each camera randomly distributed at an inter-distance of 600 m. Each grid, approximately covering 600–900 ha, was set in three mixed deciduous and coniferous forests for 15 consecutive days: between the 1st and the 15th April 2021 in the Forêt de Brouard (c. 4000 ha), between the 22th April and 6th May 2021 in the Bois d'Aiguevives (c. 1000 ha; city of Céré-la-Ronde, where captive muntjacs probably escaped in the early 2000s), and between the 11th and 25th May 2021 in the Forêt de Loche (3600 ha). We initially expected to use a density-based method from camera-trapping protocols

adapted for unmarked population of wild animals (Gilbert et al. 2021). As only one record of a single individual was obtained, we *a posteriori* used a simulation based method allowing to estimate which range in densities would have had allowed to capture a single animal without recapture from our 15-days trapping using our field design of traps. We used spatially explicit capture–recapture models under varying scenarios involving ‘proximity’ detectors (R package *secrdesignapp* 1.5: Efford and Boulanger 2019). The probability that the centre of activity of one individual matched only one camera-trap across our entire array of traps was set as $\lambda_0 = 0.02$, as observed on the field (1 individual observed over 42 camera-trap placements). A range of movement scale parameter (σ , in m) was inferred from published home range areas recorded for *M. reevesi* (ranging between 11 up to 168 ha from both females and males in native and introduced areas; see Chapman 2022). We assumed that home ranges were circular in shape, and σ was calculated as the radius r of a circle ($A = \pi r^2$, $r = \sqrt{A/\pi}$, and $\sigma = r$) to a range in home range area: 10 ha, 30 ha, 60 ha, and for 160 ha. One hundred replicates were run for each expected density ranging from 0.01 to 0.40 individuals/km² by increment of 0.01 or 0.05, to find out at which range of density only one individual would have been captured without recapture events.

3 Results

3.1 Historical records: 1854–1940

The occurrence of Muntjac deer species in France was first noticed as captive individuals brought from India, probably *Muntiacus muntjak*, by Dussumier in 1835 to the “Ménagerie du Muséum d’Histoire Naturelle” at Paris (Journal des débats politiques et littéraires 1835). Another citation indicates that a male of a Muntjac (probably *M. muntjak*, i.e., named “*Cerviolus muntjak*”) was kept in captivity in the “Jardin Zoologique d’Acclimatation” at Boulogne in Paris, and died during a typhus epidemic in 1865 (Leblanc 1865). Four Reeves’ muntjac were purchased from London Zoo to the “Parc de Beaujardin”, near Tours. A 15-month-old-female Reeves’ Muntjac was supplied to the “Ménagerie du Muséum d’Histoire Naturelle” in 1876 (Chapman et al. 1994) and in 1878, a pair of Reeves’ muntjac arrived possibly from Guangzhou or Ningbo in the east coast of China, reaching 45 specimens in 1891 in captivity (Milne-Edwards 1891). Milne-Edwards sent Reeves’ muntjac specimens to different zoos and also encouraged exotic animal donations to private owners (Milne-Edwards 1891; Pays-Mellier 1899; Trouessart

1900). A pair was introduced in a fenced area in the Forêt de Marly (department of Yvelines) in mid-April 1891 (de Bart 1891; Milne-Edwards 1891). Reproduction of captive Reeves’ muntjac was noticed before 1900 in two zoos: the Parc de Beaujardin (city of Tours, department of Indre-et-Loire; Cornély 1879, 1886), and in the Château de La Pataudière (city of Champigny-sur-Veudre, department of Indre-et-Loire: Pays-Mellier 1885, 1886, 1901). Some Reeves’ Muntjac were also translocated at the end of the 19th century in the presidential hunting forest of Rambouillet (department of Yvelines: de Dubord 1891). No viable populations became established in the wild at these sites (Ward et al. 2021).

3.2 Contemporary records: 1940–2023

Since little before 1940, several individuals of Reeves’ muntjac were kept in captivity in semi-enclosed gardens at the Parc Zoologique de Clères (department of Seine-Maritime: Dubost 1970, 1971). Some individuals escaped in the wild in the late 1950s to establish a localized population (Chapman 2022). No muntjac population is currently established around this zoo (J. Levrier, pers. comm), and up to the early 2000s, Reeves’ muntjac was not considered established in the wild in France (Grubb 2005; Timmins and Chan 2016).

3.2.1 Occasional records

A first occasional record was made in December 1979, one male being killed by a hunter in the city of Radepond (department of Seine-Maritime), 30 km far south of the city of Clères (Richard 1982). No evidence indicates this individual originated from the Clères’ population. Additional occasional observations were made since the 2010s (Chapman 2022): a male was killed on a road in Plounérin (department of Côtes-d’Armor) in October 2012 (Barboiron and Saint-Andrieux 2013), and a hunter shot another one in December 2017 in Thionville (department of Moselle). In 2020, a female was shot at Châtillon-sur-Seine (department of Côtes-d’Or). These animals probably escaped from private owners with no new observations in these localities since then. Between 2020 and 2023, a pair has been occasionally observed (5 records) in a small wood surrounding a pond from the city of Trilbardou (department of Seine-et-Marne).

3.2.2 Regular records

Since the 1990s–2000s, regular observations occur, especially in the region of Centre-Val de Loire (departments of Indre-et-Loire, Loir-et-Cher, and Indre: Chapman 2022; Hurel et al. 2019; Ward et al. 2021). Animals have escaped from a 120 ha

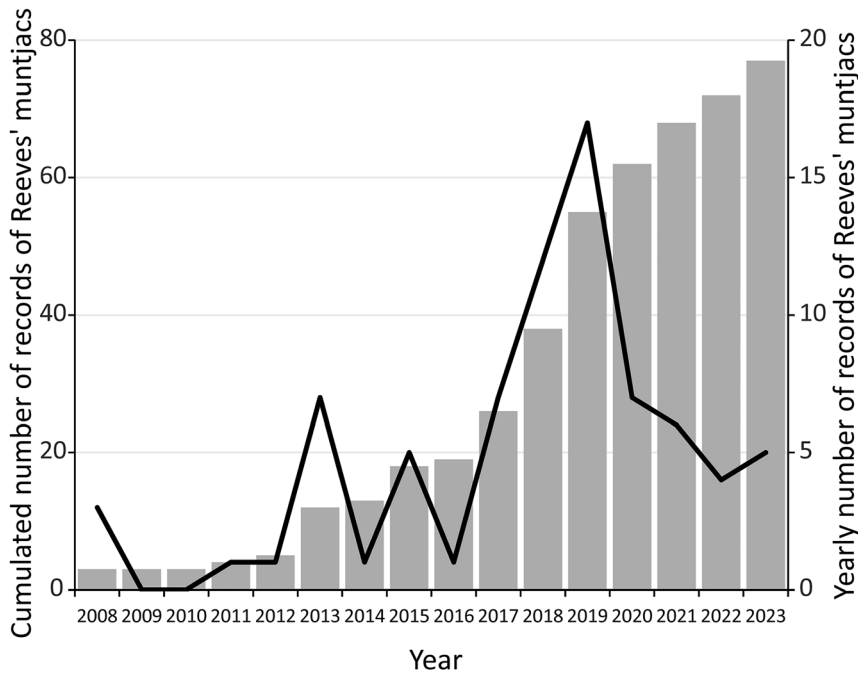


Figure 2: Dynamics of Reeves' muntjac records since 2008.



Figure 3: Detection of a female Reeves' muntjac by camera trap.

private enclosure in the Bois d'Aiguevives (City of Céré-la-Ronde, department of Indre-et-Loire: Hurel et al. 2019). From 2008 to December 2022, a cumulated number of 84 Reeves' muntjacs records were compiled (Figure 2): 69 were alive records, and 15 deaths. Overall, the number of records of Reeves' muntjacs in the wild remained at a low level between 2008 and 2016 across the metropolitan French territory, rising between 2017 and 2020, then decreased until 2023.

3.3 Range area and density

In the region of Centre-Val de Loire, records were concentrated around the commune of Céré-la-Ronde (Figure 1B).

The area covered by outermost polygon records during the 2008–2012 period reached approximately 540 km², increasing to 5,170 km² in the period 2013–2017, and to 10,800 km² for the period 2017–2023. The minimum radial distance between the polygon describing the distribution of Reeves' muntjac between 2008–2012 and 2013–2017 was 0 km, and the maximum distance was 45 km. This yielded to an average spread rate of 3.2 km/yr. The minimum radial distance between the polygon describing the distribution between 2013–2017 and 2018–2023 was 0 km, and the maximum was 107 km. This yielded to an averaged spread rate of 7.6 km/yr.

Under the hypothesis of home ranges areas ranging between 10 and 30 ha, the expected densities necessary and

Table 1: Results of simulations of the spatially explicit capture–recapture experiments, identifying the range in population density necessary to capture one individual without recapture from the three arrays of 18 camera-traps interspaced 600 m, set for 15-day occasions in the Bois d'Aiguevives and the forests of Brouard and of Loches between April and May 2021.

Home range areas (ha)	Movement scales (σ) (m)	Range in expected			
		Density (/km ²)	Mean ($\pm 1SE$) number of		
			Capture	Recapture	
10	180	0.25–0.40	0.8 ± 0.1 – 1.1 ± 0.2	0.1 ± 0.0 – 0.1 ± 0.0	
30	310	0.10–0.15	0.9 ± 0.1 – 1.3 ± 0.2	0.1 ± 0.0 – 0.2 ± 0.0	
60	440	0.05–0.07	0.8 ± 0.1 – 1.0 ± 0.1	0.2 ± 0.1 – 0.3 ± 0.1	
160	715	0.02–0.04	0.6 ± 0.1 – 1.2 ± 0.1	0.3 ± 0.1 – 0.5 ± 0.1	

sufficient to expect only one pictured animal on a single camera (Figure 3) would have had ranged between 0.10 and 0.40 muntjac/km² (Table 1) in forested habitats of the forests of Loches and Brouard and the Bois d'Aiguevives (Figure 1C) during the early spring in 2021. Under the hypothesis of home ranges areas ranging between 60 and 160 ha, expected densities necessary and sufficient to expect only one pictured animal on a single camera would have had ranged between 0.02 and 0.07 muntjac/km² (Table 1).

4 Discussion

A wild population of the Reeves' muntjac has established in the region of Centre-Val de Loire for approximately 15 years. The number of records gradually increased from 2008 to 2016, with a sharp increase between 2017 and 2019, decreasing over the 2020–2023 period. A general increase in the averaged spread rate was observed, with an estimated mean of 3.2 km/yr the 2008–2017 period, up to 7.6 km/yr for the 2013–2023 period. In introduced population with unaided dispersal events in the United Kingdom, Chapman et al. (1994) indicate a rate of spread near 1 km/yr. Besides that measures of spread rates are difficult to compare due to different methods used for calculations, the population spread in France appears much rapid to a simple prediction from natural mechanisms. It rather evokes additional spread due to intentional release or unintentional escape of individuals from private owners (Ward 2005).

In France, illegal releases after 2016 seem to have occurred, with however only a few additional records outside the Centre-Val de Loire population. Shooting by authorities since 2016, and legally allowed for hunters since 2018, may have contributed to a decrease in number of records since 2019, in a similar dynamics observed in

Belgium (D'hondt et al. 2023). Moreover, in 2019 and 2020, authorities ordered the complete eradication of Reeves' muntjacs in the 120 ha private enclosure in the Bois d'Aiguevives at Céré-la-Ronde. 40 animals were killed by hunters between February 2019 and 2020, and the park was declared free of Reeves' muntjac since then. The COVID breakdown during 2020 and 2021 may also explain a reduced number of observations in the wild, due to a decrease in searching and hunting activities, or where records may have never been reported to authorities.

Besides the lack of robustness of our modelling approach due to our single observation from our camera trapping field protocols, *a posteriori* simulation of spatially explicit capture–recapture models indicated a probable very low density of the muntjac population in the initial core area near the point of introduction (City of Céré-la-Ronde). Assuming that under low population density, the home range of Reeves' muntjac may have been above 50 ha in area (Chapman 2022; McCullough et al. 2000), our models suggests density was indeed very low. This is in contrast to the population density recorded in the United Kingdom, suggesting approximately up to 100 individuals/km² from five deciduous woods covering on average 96 ha (Cooke 2019) and associated impacts (Cooke 2021). Therefore, the potential impact of the muntjac on vegetation can be considered negligible in France to date. It appears that habitats up to a threshold of 10 individuals/km² do not require special protection from muntjac (Cooke and Farrel 2001; Cooke and Lakhani 1996). Also, such very low densities of Reeves' muntjacs may not affect roe deers fertility (Zini et al. 2023). Although any impact of the Reeves' muntjac may go unnoticed during its establishment and dispersal phase at low densities, special efforts should be made to monitor population which is spreading rapidly in the region of Centre-Val de Loire.

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Research ethics: No animals were experimentally used in this study.

Author contributions: The authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Competing interests: All other authors state no conflict of interest.

Research funding: None declared.

Data availability: All the data supporting the Reeves' muntjac distribution in France in the manuscript are included in the Supplementary material.

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- Supplementary Material:** This article contains supplementary material (<https://doi.org/10.1515/mammalia-2024-0022>).