European roe deer, *Capreolus capreolus*

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Last update

17.12.2015

Brief description of the species/group of species: basic ecology and its relevance from an epidemiological perspective

The European roe deer (*Capreolus capreolus* L.) is a medium-sized (15-40 kg) ungulate that is widespread all over western and central Europe, from Mediterranean countries to Scandinavia, and from the British Isles to the Caucasus. Although primarily associated with deciduous woodlands or woodland ecotones, roe deer occur in most habitat types, from lowlands to above 3,000 meters of elevation, and from closed forests to open fields. Roe deer are quite tolerant to human disturbance (Linnell and Andersen 1995, Basille et al. 2009) and commonly occupy farmlands, agrosystems or suburban gardens. Roe deer are weakly dimorphic in size, females being about 10% lighter than males.

Roe deer are highly sedentary and occupy home range of increasing size with increasing habitat openness (from 30 to 300 ha, Hewison et al. 1998). Males are seasonally-territorial from 3 years of age onwards. The territoriality period spans half the year (from March to October); females are not territorial but do defend a small core range around newborn fawns after parturition. Rut occurs in summer (from mid-July to mid-August). The mating system is a weak polygyny for a male mates with 3-5 females only in a given rut. Females make excursions out of their normal range during rut and can mate with several males within a reproductive season (Debeffe et al. 2014). Females give birth to one to three fawns (in relation to their body mass, Hewison & Gaillard 2001) each year from 2 years of age onwards. The family group is constituted in September and breaks the next April. Fawns of both sexes can disperse from their natal range (Gaillard et al. 2008). The mortality is high throughout the first year, low from 1 to 8 years of age, and increases again from 8 years of age onwards due to senescence (Gaillard et al. 2013). Females have higher survival rates than males at all ages but during the first year of age (Gaillard et al. 1993a).

Among diseases that are frequently present in roe deer and can be transmitted to domestic species or humans are Schmallenberg virus (Linden et al. 2012), *Babesia sp*. EU1 (Bastian et al. 2012), *Bartonella sp*. (Dehio et al. 2001), *Anaplasma phagocytophilum* (Jin et al. 2012) and *Toxoplasma gondii* (Gamarra et al. 2008). Roe deer populations also strongly contribute to maintain tick populations and influence tick-borne disease risk (Rizzoli et al. 2009). Among other potentially important diseases, rare cases of *Mycobacterium bovis* (Gortazar et al. 2012), *Coxiella burnetii* (Rijks et al. 2011), pestiviruses (Fisher et al. 1998) and *Mycobacterium avium subsp. paratuberculosis* (Daniels et al. 2003) have been diagnosed in roe deer.

Recommended method(s) for most accurate population estimation

There is no best method to estimate population abundance and the "gold standard" will depend on the project objectives, the required accuracy and precision, and the available manpower. For scientific purposes, line transects (e.g. Buckland et al. 2004) seem, however, to offer the best compromise between reliability and comparability (in time and space) of population density estimates, and the effort to produce in the field to collect the appropriate data. For management purposes, the Pedestrian kilometric index (Vincent et al. 1991) offers a suitable approach to monitor relative abundance in time for a given site.

Mini-review of methods applied in Europe

General reviews

A large range of census methods has been used to assess roe deer abundance (reviewed by Cederlund et al. 1998, Gaillard et al. 2003). Most methods, based either on hunter-related technics or on abundance index, do not account for imperfect and variable detection probabilities of animals. They lead therefore to biased measures of abundance most often severely under-estimated (Strandgaard 1972, Gaillard et al. 2003). In intensively monitored populations, more reliable methods like capture-mark-recapture or line transect (see Schwarz and Seber 1999 for a review) are usually favored and implemented.

Statistically-based estimates of population size

Methods belonging to this category provide the most robust, accurate and unbiased estimates of population size and density of roe deer populations. They are always more costly to carry out in the field than indicator of relative abundance (see methods in sections from 3.3) and are, hence, currently restricted to populations intensively monitored.

Capture-mark-recapture methods (CMR)

This method, derived from the Petersen-Lincoln estimator (Strandgaard 1967, Gaillard et al. 1986), provides a reliable estimate of population size with associated confidence interval. The application of this method requires individually recognizable roe deer (*e.g.* using tags, collars, or natural idiosyncrasies). The assumption of a closed population from a demographic point of view is the main weakness of the CMR methods as currently applied. CMR has been successfully used at Dourdan, Chizé and Trois-Fontaines (France) and at Kalö (Denmark) for decades and serves as a reference method to test and to validate indicators of abundance (see below). In addition to population size, CMR methods allow estimating survival, reproductive, fidelity and movement rates of roe deer. The high costs of CMR implementation restrict its use to intensively monitored populations. *The method is prohibitively expensive for routine management and almost impossible to implement at a large geographical range.*

Line transect

Also based on strong theoretical and mathematical background, line transect is a widely used method to estimate population density for a large range of species (Buckland et al. 2004). The method has been successfully implemented on Italian roe deer (Focardi et al. 2005). However, low encounter rates, shyness and flight behaviour hampered its application to roe deer populations (Cederlund et al. 1998, but see Gaillard et al. 1993). In combination with night vision equipment, these problems can be partially alleviated and the line transect methodology has been successfully used for roe deer (Gill et al. 1997). Formal validation of the method remains to be done but the method is promising when the costs of night vision equipment can be afforded. Statistical refinements of the method allow accounting for variation in time and space of detection probability and for animal behaviour such as gregariousness. *Line-transect methods probably offer the best cost-to-benefit ratio to estimate roe deer population size reliably*.

Indicators of relative abundance

All methods described below do not provide biologists with a proper estimate of population size or density, being not based on statistical estimators of this parameter. Instead, they are useful alternative to assess relative population abundance of roe deer which, when carried out for a long enough period of time (5-6 years), can provide relevant information about whether a population is stable, increases or decreases over time. By no mean such indicators should be used for comparison of population abundance across sites because it does not estimate detection probabilities of animals (which vary in time and space).

Pedestrian kilometric index

The Pedestrian kilometric index is the number of deer seen per distance unit while walking standardized transects (not necessarily linear). The pedestrian kilometric index correlates nicely with population density (as given by reference methods) though the relationship differs among sites (see Vincent et al. 1991 for details). This method is currently widely and successfully used in France for roe deer management purposes (see section 3.4 below). Recently, Franke et al. (2012) implemented an airborne kilometric index for deer populations using, during winter when tree-leaves felt-off, an aircraft and a high-resolution thermal camera allowing to cover large areas (> 20,000 ha). *This method is appealing and adequate to monitor roe deer abundance in time but cannot be used for cross-site comparisons*.

Spotlight road counts

The number of counted roe deer at night using spotlights from cars on specific transect has been used to estimate population abundance in France. The reliability of spotlight road counts was checked in France for roe deer and was found to be very low (Gaillard et al. 2003). *Spotlight road counts should not be recommended* for roe deer.

Pellet-group counts

Deer abundance is often inferred from pellet group counts (Putman 1984, Davies 1986) because these methods are relatively cheap and quick to implement. Most assumptions underlying this method are either not checked empirically (*e.g.* constant defecation rate of deer in time and space: Cederlund et al. 1998) or are unsafely extracted from literature and applied to different sites with different environmental conditions (*e.g.* constant rate of pellet disappearance). When coupled with line transects and distance sampling procedures, pellet counts could provide a reliable measure of roe deer abundance, as reported in Spain (Acevedo et al. 2010). Overall, *this method needs to be carefully evaluated for roe deer* before any implementation and general use.

Drive counts

These methods encompass drive-counts, stalking or net-catches (see Cederlund et al. 1998 for a review) and have been repeatedly used on roe deer (e.g. de Crombrugghe 1969, Denis 1985). Attempts to validate the method against population size estimates showed strong evidence for marked underestimation of population size (up to 2/3) and are considered as non-reliable for research or management purposes (Cederlund et al. 1998). More recently, Borkowski et al. (2011) concluded that drive-counts are likely to be inadequate to measure deer abundance whatever population density. *Other relative abundance indices should be preferably applied*, being less costly and less prone to error.

Indicators of ecological change (fawn body mass, female recruitment, browsing index)

In response to the marked increase of roe deer populations in the seventies-eighties, census methods have been found to be inefficient (Gaillard et al. 2003). An alternative approach has thus been implemented. This approach is based on the concept of density-dependence and consists in assessing the ranking of a population along the continuum going from colonizing to well-established populations facing with strong resource limitation. This new approach has been presented in details by Morellet et al. (2007). Nowadays, an array of indicators that describe three compartments of the population-environment system has been identified. First, the kilometric index provides a reliable indicator of population abundance (Vincent et al. 1991). Second, the fawn body mass (Maillard et al. 1989, Gaillard et al. 1996) allows assessing the roe deer performance. Last, the browsing index (Morellet et al. 2001) and an oak browsing index (Chevrier et al. 2012) provide information about the relationship between the roe deer population and its habitat. *It is important to inform each of the three compartments to get a reliable picture of the population functioning and take the appropriate management rules*.

Hunting bags (i.e. indices based on data derived from hunting activities)

When hunting is not limited by quotas, hunting bags can be used as an index of relative density in time. This index of population abundance is currently in use in several countries (Austria, Germany, Hungary, Portugal, see Apollonio et al. 2010) and especially in Norway where it is intensively analysed (e.g. Grotan et al. 2005). Imperio et al. (2010) found that hunting bags not corrected for hunting effort can lead to misleading estimates of population abundance. *Its use may be limited to large spatial scale comparisons (country level) and for long-time series (at least a decade)*.

APHAEA protocol (for harmonization at large scale)

Roe deer population size and trend have been proved especially difficult to estimate reliably based on classical census methods or hunted-related approaches. In the state of art of population monitoring of that species, the approach based on the Indicators of Ecological Changes (ICE) is the best and should be recommended provided the three components of the population-environment system (namely the population abundance, the roe deer performance, and the impact of roe deer on woody plants) are informed.

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Tables

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Table 1. Peculiarities of the species that modulate the methods to be used.

Characteristic	Observations
Distribution	Wide distribution in western and central Europe, present in almost all countries (Linnell et al. 1998).
Population trends	As most large herbivores in Europe, roe deer have increased a lot in abundance and geographic range across Europe (Apollonio et al. 2010). However, since the late 90ies, abundance seems to reach a plateau or show a slight decrease in most countries (Apollonio et al. 2010).
Density range	Population density of roe deer is highly variable depending on the habitat type and environmental context. When facing harsh environmental conditions, predation by large carnivores, and hunting, population density could be as low as 1 or 2 per km2. On the other hand, in temperate forests with no large predator and no or limited hunting, densities can overpass 40 per km2.
Main habitat	Woodland mainly, with an increasing use of agrosystems since the late 70ies
Introduction-Releases	(Spain Frequent, Portugal, Italy, France)
Activity rhythms	Roe deer are polyphasic, alternating phases of activity and resting (about 8-10 activity periods over 24 h). High synchrony of activity at dawn and dusk, and high synchrony of rest during midday.
Detectability	Low in forested habitats, more conspicuous in open lands where they can gather in large groups (>10 individuals).
Gregarism	Function of habitat openness; positive association between habitat openness and group size. So far, only limited evidence for sexual segregation between sexes (at least in closed habitat, Bonenfant et al. 2007).

Table 2. Classification of the different methods (all cited in this species' review) based on desirable characteristics for monitoring populations from an epidemiological perspective (1-very low, 5-very high).

Method	Line-transect	Capture-recapture	Kilometric index	Browsing index	Pellet counts	Hind foot length	Hunting bags
Abundance / **D**ensity	D	D	A	A	A/D	A	A
Temporal / **S**patial trends	T/S	T/S	T	T	T	T/S	T
Info on population structure (**Y**/**N**)	y	y	y	n	n	n	y
Precision	5	5	4	3	2	3	3
Seasonal independence	2	4	2	4	5	2	2
Visibility independence	4	4	2	4	5	5	5
Effort effectiveness	3	2	4	3	5	5	5
Budget effectiveness	2	1	3	4	4	4	5
Ease of learning	2	2	5	3	5	5	4
Applicable at large scales	2	2	3	3	4	4	5
Useful at very low density	2	3	4	4	2	2	3
Useful at very high density	5	5	4	2	1	5	5