Red deer, *Cervus elaphus*

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

The red deer (*Cervus elaphus*) is a native European cervid widely–but patchily–distributed throughout most of Europe, although it is absent from northern Scandinavian peninsula (Apollonio et al. 2010). It is a long-lived herbivore with a high degree of sexual dimorphism. Accordingly, the sex-age structure of red deer populations is important. Reintroductions/restocking have taken place in most countries where the species occurs (Linell and Zachos 2011), and the importance of these actions was substantial in depicting current distribution (see e.g. Acevedo and Cassinello 2009). At the short term, red deer distribution can be also affected by human pressure (hunting pressure) which causes emigration from disturbed areas and immigration into areas where densities have been reduced (Putman 2012).

Red deer inhabit open woodlands, upland moors and open mountainous areas (sometimes above the treeline), natural grasslands, pastures and meadows (Lovari et al. 2013). As other wild ungulates in Europe, red deer populations have increased their density in the last decades (Apollonio et al. 2010). This increases human-ungulate conflicts, as red deer may cause significant damage to farming and forestry (e.g. Putman et al. 2011), road traffic (e.g. Groot Bruinderink and Hazebroek 2002) and livestock and public health (e.g. Gortázar et al. 2006). Consequently, red deer populations should be controlled by hunting (20-30% annual harvest) in order to minimize the deleterious effects of red deer expansions on ecosystem functioning (Côté et al. 2004).

From an epidemiological perspective, in certain regions red deer are reservoirs for the *Mycobacterium tuberculosis* complex (Gortázar et al. 2012) and for bluetongue virus (García-Bocanegra et al. 2011). Red deer are also involved in the epidemiology of numerous other viral, bacterial and parasitic diseases of medical and veterinary importance.

Recommended method(s) for most accurate population estimation

There is no single best method to estimate red deer density (e.g. Acevedo et al. 2008; Morellet et al. 2011). However, line transects and the application of distance sampling procedures (see Thomas et al. 2010) can be considered as the gold standard method as it offers a good compromise between sampling effort and accuracy of population density estimates. It was successfully applied to red deer populations in both Mediterranean and northern environments (Smart et al. 2004; Acevedo et al. 2008). Distance sampling allows complex modelling to estimate detection probabilities of animals not easily observed in the wild (Borchers et al. 2002). Moreover, it allows incorporating covariates, which provide additional information about detectability and hence improve the fit of models as well as the precision of estimates (Marques and Buckland 2003).

Mini-review of methods applied in Europe

General reviews

European wildlife managers are using 19 different methods to estimate wild ungulate abundance (Morellet et al. 2011), including both direct and indirect ones (reviewed by Mayle et al. 1999; Acevedo et al. 2008; Morellet et al. 2011). These methods were mostly described for Atlantic woodland-pasture habitats, but were also assessed and used across different environments in Europe. Among the battery of available methods to estimate red deer population abundance, the choice depends on local conditions of the population under study, resource availability and requirements in terms of precision and accuracy.

Direct methods (i.e. based on the direct observation of animals)

In open habitats, direct counts are the most suitable method for estimating deer density (e.g. Mayle et al. 1999; Morellet et al. 2011). Depending on the study requirements, direct counts can be used as an index of population abundance, such as the kilometric abundance index. This index performs better considering groups instead of individuals (Acevedo et al. 2008; Garel et al. 2010). Direct counts can be converted into population density using detectability functions fitted with the distance sampling procedure (e.g. Acevedo et al. 2008), but the strong requirements in data analysis possibly makes this method too complex for widespread use, for instance in mountain regions. Population density can also be obtained by total counts after attracting the animals to highly visible sites (Morellet et al. 2011), for example by means of supplementary feeding and during the rutting period (Rodríguez-Hidalgo et al. 2010). In woodlands, direct count methods require higher sampling efforts and the results are potentially both imprecise and inaccurate (Staines and Ratcliffe 1987; Mayle et al. 1999).

Indirect methods (i.e. based in the detection of presence signs, but not animals)

Pellet counts

In woodlands red deer abundance is generally estimated by indirect methods, frequently by counting dung (Putman 1984). The two main techniques are the Faecal Standing Crop, FSC, and Faecal Accumulation Rate, FAR (Staines and Ratcliffe, 1987; Smart et al. 2004). These data can be converted into estimates of deer population density by applying specific deer defecation rates and dung persistence periods – only defecation rates are required when working with FAR. Smart et al. (2004), working with roe deer reported that FSC provides more accurate estimates than FAR. However, it was suggested that precision of red deer abundance indices based on FSC can be enhanced by considering the size (number of pellets) of the pellet groups (Acevedo et al. 2008). Thus, when the minimum pellet group size is fixed, the FSC method becomes more similar to the FAR method, in which plots are cleaned and no old pellets are counted (Staines and Ratcliffe 1987).

Indicators of ecological change (see Morellet et al. 2007)

Despite the strong conceptual basis of the indicators of ecological change and their usefulness to monitor wildlife population, their consideration further the pioneer studies on roe deer (e.g. Morellet et al. 2007; Chevrier et al. 2012) is scarce. In red deer this includes measurements of browsing (browsing index) based on highly palatable species (Acevedo et al. 2008) and, potentially, the use of other indicators of animal performance such as the Kidney Fat Index (Rodríguez-Hidalgo et al. 2010; Santos et al. 2013) or spleen mass (Corbin et al. 2008).

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

In hunted populations, data on the number of deer seen during hunting activities can be transformed into a relative abundance index, which was also validated as a reliable indicator of red deer population trend (Mysterud et al. 2007). However, some parameters related to hunting success (e.g. hunting effort and hunting effectiveness) are able to distort the final estimates and therefore these indices should be treated with extreme caution when used for monitoring. On broader scales, hunting statistics can provide time trends on population abundance, provided the hunting effort is maintained (Apollonio et al. 2010).

Others (i.e. include other relevant method – direct or indirect – applied or susceptible to be applied on the target species)

Statistical modelling is another way to estimate red deer population abundance for a given territory. Modelling allows relating data on the species (presence/absence, abundance, fitness, etc.) with environmental variables in order to obtain an output that is related with the habitat suitability for the species. Model predictions should be validated with independent data as indicators of population abundance since there are several factors modulating that relation. In the context of an epidemiological study, for instance, the distribution of red deer abundance in mainland Spain was recently obtained using spatially explicit modelling procedures (Acevedo et al. 2010).

APHAEA protocol (for harmonization at large scale)

Direct counts on transects using the distance sampling procedure (by day or with spotights) to estimate habitat-stratified densities, and other variations of transect methods yielding density data.Although it is difficult to generalize for a broad range of settings, densities below 1 individual per square km will represent low densities in a European context; those between 1 and 10 red deer per square km will represent medium densities; and those above this limit will represent high densities. This division, although arbitrary, has important implications for epidemiology and disease control.

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Tables

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

Characteristic	**Observations**
Distribution	Wide distribution in Europe, present in almost all countries (Mitchell-Jones et al. 1999; Lovari et al. 2013).
Population trends	As other ungulates it is increasing in most European countries (Milner et al. 2006; Apollonio et al. 2010).
Density range	From 1 to 69 individuals per km^2 (e.g. Acevedo et al. 2008), but typical population density range from 2 to 20 individuals per km^2 (Lovari et al. 2013): densities from 1 to 10 per km^2 are usual in Atlantic sites and densities of over 10 occur locally in Atlantic sites and are common in Mediterranean ones.
Main habitat	Transition areas between woodland and scrubland (see Lovari et al. 2013).
Introduction-Releases	Frequent, since red deer are also farmed. Generally, they are carried out using a reduced number of individuals (Linell and Zachos 2011)..
Activity rhythms	In general, two daily activity peaks, one at 7-9 a.m. and another one at 6-12 p.m. (Soriguer et al. 1994), with seasonal variation mainly in extreme environments (Georgii and Schröder 1983).
Detectability	High, mainly during the rutting period (Carranza 1986).
Gregarism	Spatio-temporal segregation between sexes excepting the rutting season. The social unit is the familiar group composed by a female and their progeny of the last 2-3 years (Clutton-Brock et al. 1982).

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	**Gold standard**	**Kilometric abundance index**	**Browsing index**	**Pellet counts**	**Hind foot length & fitness indices**
Abundance/ **D**ensity	DA	A	A	A/D	A
Temporal/ **S**patial trends	T/S	T	T	T	T/S
Info on population structure (**Y**/**N**)	Y	Y	N	N	N
Precision	4	4	3	3	3
Seasonal independence	3	2	4	5	2
Visibility independence	3	2	4	5	5
Effort effectiveness	4	4	3	5	5
Budget effectiveness	3	3	4	4	4
Ease of learning	3	5	3	5	5
Applicable at large scales	3	3	3	4	
Useful at very low density	3	4	4	3	
Useful at very high density	5	4	2	4	