Mediterranean mouflon, *Ovis gmelini musimon x Ovis* sp.

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

From a neolithic origin in Mediterranean islands (Cyprus, Sardinia and Corsica), mouflon have been introduced to diverse habitats over a wide geographical area (Marchand et al. 2013), often to increase local diversity of wild game species, after variable levels of hybridization with wild and domestic ovines (Uloth 1972, Cugnasse 1994). While all mouflon populations present in continental Europe today are issued from introductions (Apollonio et al. 2010), native populations are still present in Mediterranean islands. These latter originated from domestic wild herds of sheep likely introduced around 5000-6000 BC (Vigne 1992). Accordingly, mouflon have been forced to face habitats ranging from Mediterranean areas to continental forests of central Europe. In addition, mouflon introductions have raised issues of competition with native species (Bertolino et al. 2009) and of impacts on ecosystems (e.g. forestry: Homolka 1993, Babad 1997; island biodiversity: Garzón-Machado et al. 2010), emphasizing the need to develop/use relevant monitoring tools for setting hunting quotas.

Mouflon are involved in the epidemiology of numerous viral, bacterial and parasitic diseases of medical and veterinary importance. Mouflons have been shown to have direct or indirect signs (high antibody titers) of the following infections: *Anaplasma phagocytophilum* (Lopez-Olvera et al. 2008), bluetongue virus (Rossi et al. 2014), chlamydiosis (*Chlamydia abortus*, Salinas et al. 2009), caprine arthritis-encephalitis virus (Guiguen et al. 2000), Q fever (*Coxiella burnetii*, Lopez-Olvera et al. 2008), paratuberculosis (*Mycobacterium avium* ssp *paratuberculosis*, Lopez-Olvera et al. 2008), keratoconjunctivitis (*Mycoplasma conjunctivae*, Marco et al. 2009), abortive salmonellosis (*Salmonella abortusovis*, Dupraz 2004), Schmallenberg virus (Rossi et al. in press), and toxoplasmosis (*Toxoplasma gondii*, Aubert et al. 2010). At coproscopic examination, *Eimeria*, *Giardia*, *Moniezia*, *Dicrocoelium*, *Fasciola*, *Trichuris* and other strongyles have been found (Bourgoin et al. unpublished). Other diseases have been searched for in a limited number of individuals (*Leptospira* sp., *Mycoplasma agalactiae* and *Neospora caninum*): none of the tested individuals was infected, however this does not preclude the possibility of low prevalence of these diseases. Mouflons are also expected to be susceptible to diseases affecting ruminants in general, such as brucellosis and tuberculosis. However, the exact epidemiological role of mouflon populations in the transmission of all these infections remains to be determined.

The taxonomic naming of mouflon is probably one of the most confusing among ungulate species. This confusion arises both for its latin and common names. Instead of the current recommendation (e.g. Gentry et al. 2004) suggesting the use of *Ovis aries* as latin name, we chose here to follow the taxonomic recommendation of Cugnasse (1994) and to use as such *Ovis gmelini musimon* x *Ovis* sp for mouflon populations other than the ones present on Mediterranean islands (Cyrpus, Sardinia and Corsica – *Ovis gmelini musimon*). However, we encourage readers to refer to other scientific publications on this very special topic (e.g. Hiendleder et al. 2001, Gentry et al. 2004, Rezaei et al. 2010).

Recommended method(s) for most accurate population estimation

Despite a long history of refinements in design and development of census methods (Caughley 1977; Seber 1982; Eberhardt and Simmons 1987; Lancia et al. 1994; Buckland et al. 2000; Pollock et al. 2002), few attempts have provided satisfactory results except for capture–mark–recapture methods (Schwarz and Seber 1999) and distance sampling (Buckland et al. 2004) that allow accounting explicitly for sampling variance (providing estimates of detection probability and/or temporary emigration from the sampled area). CMR methods, embracing a large family of statistical models (e.g. see Buckland et al. 2000 for a review), are among the most reliable to estimate population size of mouflon across the range of habitat where they have been introduced.

However, mark–recapture or mark–resight techniques are usually costly and time-consuming (Link and Sauer 1997). They require the capture and marking of a large proportion of the population (Strandgaard 1967) and must satisfy several assumptions to generate reliable estimates. These assumptions are rarely met. Most of these methods can therefore be of limited feasibility in a management context where monitoring often takes place over large areas with limited budgets. Similarly, underlying assumptions of distance sampling methods (e.g. random transects) can be hardly achievable, especially in mountain environment, questioning the interest of such an approach for ungulates monitoring. Approaches using count statistics can then be a reliable alternative, well adapted when cost and effort to estimate total population size are prohibitive and information on relative differences in abundance over time or space is sufficient (Eberhardt and Simmons 1987; Pollock et al. 2002; Williams et al. 2002). Count statistics include numerous methods, such as the number of ungulates seen while walking a transect (Vincent et al. 1991, Garel et al. 2010). If a standardized method is used to obtain the count statistic, and the detection probabilities are kept constant across time (or corrected by including covariates influencing the detection probability but not the true population size), then the count statistics provide reliable index of abundance (validated in numerous ungulates species in France: Vincent et al. 1991, Garel et al. 2005, Loison et al. 2006, Garel et al. 2010). It has to be noted that recent statistical advances (e.g. Royle and Nichols 2003, Royle 2004) have provided insights on how repeated counts, along with adjusted protocols (e.g. Farnsworth et al. 2002), can be informative to estimate detection probability/temporary emigration). These statistical methods are still been rarely applied when analysing count statistics and for the monitoring of ungulate populations but should constitute in a near future (very) relevant alternatives.

Mini-review of methods applied in Europe

(Source : Apollonio et al. 2010) In several European countries (e.g., Netherlands, Romania, Serbia) mouflon populations are restricted to fenced areas such as game reserves, or to islands, mainly for hunting purposes. These populations often receive supplementary feeding and no specific census protocols are usually applied. In these countries, and some others, the only abundance index is the number of animal harvested. This lack of data/interest probably originated from the status of exotic species and the anecdotal level of presence of the species as compared to native species.

In many other countries where mouflon are mostly free-ranging and where yearly variations in abundance are monitored, methods based on the direct observation of animals are the rule, with a high diversity of approaches and a recognized lack of standardization among and within countries. The following methods are used: driving census, vantage point/block count, census on feeding site... Most approaches are interpreted as an estimate of true population size (i.e. probability detection = 1 or constant throughout the sampling period), often based on a single or on annual counts. When used as a relative index of abundance to detect trend in the population, count statistics computed from helicopter or foot surveys (with 5 repetitions) have been shown to reliably monitor year-to-year changes in mouflon populations in mountainous areas (Garel et al. 2005a).

To be reliable indices of population abundance, indices based on counts should be directly proportional to population size. Such a condition implies a constant detection probability, which rarely occurs in practice. Multiple approaches are available when this assumption is not met: adjust the model with covariates likely to influence detection probability (but not true density; for example temperature, observer experience in detecting mouflon; Garel et al. 2005a,b) and/or follow standardised protocols so that these covariates are kept constant across locations and years. Finally, as it is done with distance sampling (Buckland et al. 2004), some authors have suggested to use specific monitoring designs and models to estimate detection probability (e.g. Nichols et al. 2000; Farnsworth et al. 2002; Pollock et al. 2002; Royle 2004).

APHAEA protocol (for harmonization at large scale)

Recently, Morellet et al. (2007) challenged the usefulness of attempts to obtain reliable population size estimates for the management of large herbivores. Population size *per se* does not provide any functional information on the population-habitat system, such as density-dependence. Morellet et al. (2007) therefore suggested tracking over time the variation of at least three categories of indicators of ecological changes (IEC) describing animal performance (e.g. lamb body mass; Garel et al. 2007), herbivore impact on habitat (so far no method has been validated in mountain ungulates; in roe deer, see Morellet et al. 2001), and relative animal abundance (standardized foot or aerial surveys; Garel et al. 2005a). This approach should allow managers to achieve their specific objectives better than by relying on rough estimates of population size not including/correcting for sampling variance.

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Tables

See next page.

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

Characteristic	Observations
Distribution	Highly depending of introduction performed. Absent from some countries (e.g Greece) and restricted to game reserves or islands in several others (e.g. Belgium, Denmark, Portugal). Mainly distributed in continental forests for eastern countries and in mountain ecosystems in western countries.
Population trends	In general increasing in countries where the species was originally well established; growth rates hampered in some places by the recovery of populations of natural predators.
Density range	From 0.5 to 18.9/km² (average = 4.0/km²) in natural populations (because under-estimation of the true population size is the rule for ungulates, these densities correspond to minimal values)
Main habitat	In countries with significant population of mouflon, animals have been introduced to habitat ranging from deciduous woodlands at low elevation to alpine mountains. Preferred habitat corresponds to large open areas dominated by grass and high-visibility habitats near escape terrain (rugged, steep slopes)
Introduction-Releases	Frequent
Activity rhythms	Bimodal activity rhythm with two peaks (one at dawn and one at dusk)
Detectability	Highly habitat-dependent, but relatively high due to the gregariourness of the species
Gregarism	Spatio-temporal segregation between sexes except during the rut. The social unit is a group of females and their young of both sexes up to 2 years

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	Capture/ recapture	Distance sampling	Count statistics	Performance (e.g. body mass)
Abundance / **D**ensity	AD	AD	A	A
Temporal / **S**patial trends	TS	TS	TS	TS
Info on population structure (**Y**/**N**)	Y	Y	Y	Y
Precision	5	4	3	3
Seasonal independence	4	4	2	2
Visibility independence	4	4	2	5
Effort effectiveness	1	3	4	5
Budget effectiveness	1	3	4	5
Ease of learning	2	3	4	5
Applicable at large scales	1	4	5	5
Useful at very low density	5	3	4	3
Useful at very high density	3	4	4	5