Chamois, *Rupicara spp.*

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

Two species of chamois (*Rupicapra* spp.) are currently recognized: the Northern chamois (*Rupicapra rupicapra*), with seven subspecies, and the Southern chamois (*Rupicapra pyrenaica*), with three subspecies (Shackleton et al. 1997). Although both species are globally considered as "Least concern", some subspecies are considered "Vulnerable" (the Abruzzo or Apennine chamois, *Rupicapra pyrenaica ornata)*, or "Critically endangered", as the Tatra chamois (*Rupicapra rupicapra tatrica*). Threats depend largely on the population and subspecies, and include poaching, competition with livestock or other introduced wild ungulates, low genetic variability, hybridization with other introduced chamois subspecies, habitat loss and diseases (Aulagnier et al. 2008; Herrero et al. 2008). Among the diseases, sarcoptic mange and keratoconjunctivitis affect both Northern and Southern chamois population and a newly emerged pestivirus has strongly affected the Pyrenean chamois populations (González-Quirós et al. 2002a and 2002b; Marco et al. 2007; Rossi et al. 2007, Arnal et al. 2013, Serrano et al. 2015). Most of the chamois populations are hunted, which means that population size estimates must be previously carried out in order to establish sustainable hunting quotas.

Recommended method(s) for most accurate population estimation

Gold standard and key references: Estimates of chamois populations often rely on block counts (BC). In this type of direct count, several observer teams beat the complete study area simultaneously (Herrero et al 2011). Hence, BC provides a single estimate of the minimum number of chamois sighted in a given game unit (Herrero et al. 2011). Such a method produces estimates that have been traditionally used to estimate hunting quotas based on the minimum number of animals. Part of the value of this method relies in its yearly repetition in a number of chamois populations, due to its historical application in certain areas. It was recommended to perform two surveys per year, one in July to estimate reproduction rates and other during the rut (November) to estimate sex-ratio. This distinction was done since the low visibility of males during parturition period (Berducou et al. 1982; García-González et al. 1988 and 1992; Houssin et al. 1994; Herrero et al. 2011). This method is appropriated for chamois inhabiting open areas above the tree line, since this species shows a good diurnal detectability. The main criticism of this method is the systematic underestimation of population sizes, in special in areas of dense vegetation and reduced visibility. In addition, since only one estimate is obtained per sampling period due to the census effort required for exhaustively sampling the population, the precision of the estimated population size is unknown. For all these reasons, this method is mainly applicable in populations with a marked increasing or decreasing trend, but much less useful to detect interannual variations in established populations.

Mini-review of methods applied in Europe

3.1- General reviews

Several methods are currently being proposed as more reliable alternatives than BC (Loison et al. 2006; Dubray 2008; Herrero et al. 2011), and to cope with the increase in chamois numbers and their colonisation of forested areas (Herrero et al. 1996; Breitenmoser 1998, Loison et al. 2003; Dubray 2013), which have raised concern that simple total counts in open areas could severely underestimate population sizes (Houssin et al. 1994; Cano et al. 2009; Herrero et al. 2011). Moreover, such alternatives intend to decrease the census effort (measured as man hours) while increasing the reliability of the estimates by providing additional information on the sampling process (e.g. detection probability with the distance sampling methods; López-Martín et al. 2013). Another problem for count interpretation is that total counts systematically underestimate the total population (Pérez et al. 2011), and this underestimation most likely vary from year to year (Williams et al. 2002). What is more, there is an increasing interest in knowing precision of population estimates.

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

3.2.1-Index of population size (IPS)

This technique can be considered as the evolution of BC. The IPS is an abundance index (*sensu* Williams et al. 2002) calculated as the mean number of animals (kids excluded) observed in a pre-determined itinerary performed several times. Hence, precision of the index can be estimated. The IPS has been shown to be a reliable method to assess changes in population trends when compared to reference methods such capture-mark-recapture approach (Loison et al. 2006). IPS cannot be interpreted as an absolute estimate of abundance (e.g. for comparing abundances among populations) but must be used as a relative value for comparing trends within the same population. The reliability of IPS depends on the repeatability of the number of chamois observed during the repetitions of the same itinerary and the number of repetitions performed for each itinerary (García-González et al. 1992; Dubray 2008). As in other techniques, the variability of abundance estimates decrease as the number of surveys per year increases, and thus the sampling effort have to be adapted to local conditions and management goals (e.g. detection of 10% yearly trend over six years). It has to be noticed that trends can only be interpreted when the target population has been monitored at least five years.

3.2.2- Capture-mark-resighting (CMR)

CMR methods provide estimation with related uncertainty of the population size (e.g. Arnason et al. 1991). In chamois, CMR methods have shown a good correlation with distance sampling methods (García-González et al. 1992) and have been used to assess reliability of abundance indices such as IPS (Loison et al. 2005 and 2006). However, CMR lacks precision in chamois if not enough individuals are marked (Corlatti et al. 2015). CMR methods rely on a series of assumptions which must be verified and require a high proportion of marked individuals in the population to provide reliable estimates (Loison et al. 2006). As such, these methods are of limited practicability in a management context over large temporal and spatial scales.

3.2.3- Distance sampling (DS)

When marked individuals are not available, DS may be an interesting alternative for estimating population size while accounting for sampling variance (e.g. variation in detection probabilities). DS can be performed from data obtained in line transects, but it is not necessary to count the whole population but a representative fraction. In this method it is necessary to register the distance (or class of distances) from the observation point or line to the chamois (Buckland et al. 2001; Herrero et al. 2011; Pérez et al. 2011). The surveyed surface is known and thus local population density is estimated. On the other hand, DS does not require observing all the chamois in the area, and thus is an alternative to BC in forest or scrubland areas, where chamois detectability decreases significantly (García-González et al. 1992; Garín and Herrero 1997; Herrero et al. 2011). When used in chamois populations, DS has produced values mostly higher than block counts but with the block count value included within the 95% confidence interval provided by Distance sampling (Herrero et al. 2011; López-Martín et al. 2013). However, DS has also produced values lower than block counts, with block count value falling out of the 95% DS confidence interval, when used to estimate chamois numbers in complex and rough areas (Corlatti et al. 2015). In DS applied to mountain ungulates, such as the chamois, the use of different data analysis strategies and new approaches considering the density gradient from linear structures are recommended to improve the precision of density estimation (Marques et al. 2013; Pérez et al. 2014).

As compared to BC, CMR, IPS and DS have the advantage of providing the accuracy of the estimates computed instead of a single value and to provide estimates of detection probabilities (for IPS see recent advances in N-mixture models; e.g. Royle and Nichols 2003). However, for keeping continuity in setting management quotas, it can be necessary to simultaneously perform total counts or BC with any of the alternative methods for three to five years before quitting BC as census methodology (Corlatti 2013). Moreover, in any case for a realistic management plan it would be strongly recommended to combine the abovementioned methods of estimation with the indicators of ecological change. In fact, population size *per se* does not provide any functional information on the population-habitat system (e.g. density-dependence, see Morellet et al. 2007).

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

Indirect methods require less effort than direct methods, but rely on a series of assumptions which are seldom checked (Eberhardt 1978; Pollock et al. 2002; Williams et al. 2002). Several indirect indicators have been suggested in chamois (Crampe et al. 1997; Couilloud et al. 1999; Dubray et al. 2003), but they have not been validated; therefore, there is an urgent need to assess the usefulness of reliable indicators of ecological changes in chamois (Loison et al. 2006).

3.3.1- Indicators of Ecological Change (IEC)

According to Morellet et al. (2007), the indicators of ecological change are useful for monitoring the relationships between a given population and the local environmental conditions (e.g. resource availability). It has been suggested to track over time the variation of at least two different categories of indicators of ecological changes (IEC): one describing animal performance (e.g. kid body mass, Garel et al. 2011) and one describing relative animal abundance (IPS; Loison et al. 2006). This approach allows monitoring the interaction between a population and its habitat and can be used as a basis for adaptive management.

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

In chamois, hunting bags have not been extensively used as abundance index.

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

Camera trapping has been recently applied to estimate population abundance in chamois (Šprem et al. 2011). Interestingly, such methodology would be also valid for assessing daily patterns and population structure of chamois even in small populations (about 300 individuals). In a population with marked animals, such method can be used for assessing population density using mark-resight models.

When hunting bags are the only available information, Virtual Population Analysis of harvest data (Skalski et al 2010) can be used to reconstruct chamois' past population structures. Finally, post winter carcass collection is also useful to assess chamois' mortality and thus population dynamics as shown by Gonzalez and Crampe (2001).

APHAEA protocol (for harmonization at large scale)

The recommended APHAEA protocol should include a combination of repeated counts (e.g. IPS), along with a collection of additionnal information able to inform on sampling variance (e.g. distance), and information on other parts of the population-environment system (e.g. animal performance). BC require a high effort, which makes repeatability and application at large scales difficult. Moreover, IPS have the advantage with respect to BC of providing an estimation of the precision through repeatability. Nevertheless, BC should continue to be performed where they are currently being historically carried out, until plenty standardization of IPS on the field have been performed and can be use as a more reliable alternative for setting hunting quotas.

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Tables

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

Characteristic	Observations
Distribution	Mountain massifs in Southern Europe, Middle East and New Zealand (Catusse et al. 1996).
Population trends	Most populations increasing, some subspecies stable or showing local declines (Aulagnier et al. 2008; Herrero et al. 2008).
Density range	Density is highly variable depending on the population, ranging from 0.68 to 22.9 chamois per km^2 for both species (Dubray 2013; García-González et al. 1992; Herrero et al. 2011; López-Martín et al. 2013; Pioz et al. 2008; Prada et al. 2013; Solà and Riba 2013).
Main habitat	Both chamois species are found in alpine meadows, steep open rocky areas, and the forested (either mixed broadleaf and coniferous woodlands) valleys and lower slopes in mountainous regions (Nowak and Paradiso 1983; Sägesser and Keapp 1986; Pedrotti and Lovari 1999). Formerly considered to rarely if ever occur in forested areas (Nowak and Paradiso 1983), in recent years some populations have started to permanently inhabit forest (Mitchell-Jones et al. 1999).
Introduction-Releases	Northern chamois introduction have been carried out since as far as the XIX century (Norway, 1862; New Zealand, 1907 and 1913; France, Germany, Argentine, Russia and Poland, Catusse et al., 1996). Some of the less numerous subspecies (e.g. *R. r. balcanica*, *R. r. cartusiana*, and *R. r. tatrica*) are threatened by the deliberate introduction of subspecies from other geographic areas (especially *R. r. rupicapra*), leading to hybridisation and genetic swamping (Shackleton et al. 1997). Abruzzo chamois has been introduced in areas close to its original distribution with conservation purposes (Herrero et al. 2008), and successful Cantabrian chamois reintroduction programs have extended the distribution range of this subspecies in very low density areas, where natural recolonization was difficult, since 1980 (Pérez-Barbería et al. 2009).
Activity rhythms	Chamois are mainly diurnal, appearing in open areas most of the daylight (Lovari and Cosentino 1986) with a typical bimodal activity with two peaks (one at dawn and one at dusk). Chamois make altitudinal migrations from the forests in the valleys to the more open alpine meadows, staying above 1,800 meters during the warmer months of the year and entering lands below 1,100.metres (particularly for the Southern chamois) in late fall and winter, usually staying on steep slopes (Nowak and Paradiso 1983; Herrero et al. 1996; Pedrotti and Lovari 1999). However, such altitudinal migratory pattern is probably related to habitat features, since chamois may also inhabit the same altitude range during the whole year (Crampe et al., 2007).
Detectability	Easily detected in open areas in alpine meadows during daylight (Lovari and Cosentino 1986; Pépin and Gerard 2008).
Gregarism	Groups tend to join from dawn and coalesce, increasing group size throughout the day (Pépin and Gerard 2008).

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). Block Counts (BC), Index of Population Size (IPS), Capture-Mark-Resighting (CMR), Distance Sampling (DS), Indicators of Ecological Change (IEC), Hunting Bags (HB), Camera Trapp (CT).

Method	**BC**	**IPS**	**CMR**	**DS**	**IEC**	**HB**	**CT**
Abundance/ **D**ensity	A	A	A	A/D	-	A	A
Temporal/ **S**patial trends	T/S	T/S	T/S	T/S	T/S	T/S	T/S
Info on population structure (**Y**/**N**)	Y	Y	Y	Y	-	Y	Y
Precision	1	4	4	4	-	-	-
Seasonal independence	1	1	1	1	1	1	1
Visibility independence	1	1	2	1	5	5	4
Effort effectiveness	1	3	3*	4	4	4	3
Budget effectiveness	1	3	3*	3	4	5	3
Ease of learning	5	5	3	3	5	5	4
Applicable at large scales	3	4	3*	4	4	5	2
Useful at very low density	5	3	4	2	1	3	2
Useful at very high density	3**	5	5	5	5	5	5

* To obtain reliable estimates, a large proportion of the population should be marked (e.g. 2/3 with lincoln Petersen index; Strandgaard 1967)

** Provided BC are repeated yearly