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Pitfalls in using counts of roaring stags to index red deer (*Cervus elaphus*) population size

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Abstract. Counting roaring stags during the rut has been proposed as a means to assess deer population size and trends but few, if any, attempts have been made to evaluate the reliability of this technique. By means of a commonly used field protocol, we assessed to what extent relative abundance estimates of red deer (*Cervus elaphus*) based on roaring-stag counts in the northern Apennines (Italy) were susceptible to exogenous and unpredictable sources of variability. By using up to 26 simultaneous observers in an area of 5218 ha, we estimated densities from 0.45 to 0.61 roaring stags per 100 ha in 3 consecutive years (1992–94), corresponding to annual changes in the number of counted roaring stags ranging from –21% to +35.7%. However, only in two of the three years were seasonal trends and peaks in roaring activity apparent, and timing of the survey was not always synchronous with the roaring peak. In addition, annual and nocturnal variation in roaring activity, and weather conditions during the survey, might have influenced the counts to some extent, probably determining high Type I and Type II error rates. We contend that additional sources of error, associated with unknown demographic and ecological settings, may further increase unreliability of the technique when it is used to estimate absolute density of red deer populations. We conclude by emphasising that managers should not use this method for population monitoring unless they can prove it can yield reliable results.

Introduction

Mature red deer (*Cervus elaphus*) stags use vocalisations (roars) during the rut to defend and control dispersion of their harem (Clutton-Brock and Albon 1979; Clutton-Brock *et al*. 1982; Bowyer and Kitchen 1987). Roaring performance (frequency, duration) is believed to allow males to assess their opponents' fighting abilities (Clutton-Brock and Albon 1979), to reduce hind dispersion in the harem (Bowyer and Kitchen 1987), and to influence mate attraction and advance ovulation, thus improving mating success (McComb 1987, 1991). As a consequence, roaring stags are easily detected during the rut and, on the basis of their acoustic and visual detection, Langvatn (1977) proposed a method to estimate red deer population size. Applied at the peak of the rut, this method models the social structure of the population as estimated from sightings and/or harvest data, and accounts for the proportions of roaring to non-roaring stags, both with and without harems, as well as for the size and composition of harems and other social units (Langvatn 1977). Bobek *et al*. (1986) later applied this method in the Bieszczady Mountains (Poland), in mountainous and forested ecosystems where other traditional techniques to estimate population size were difficult to apply. Since these first applications, the method has been successively adopted in other European countries (Albaret *et al*. 1989), particularly in Italy (Mazzarone *et al*. 1989, 1991; Murgia and Monni 1989; Mazzarone and Mattioli 1996; Mattedi *et al*. 1997; Cicognani *et al*. 2000), and field protocols have been developed to standardise the counts in order to maximise precision (Albaret *et al*. 1989; Mazzarone *et al*. 1989, 1991). In a similar format, the method has also been systematically used since the 1970s to monitor trends of the endangered Corsican deer (*C. e. corsicanus*) in Sardinia (Jenkins 1972; Murgia and Monni 1989; C. Murgia *in litteris*, and unpubl. data, quoted in Lovari *et al*. 2007). These successive applications, however, introduced two important simplifications with respect to the original Langvatn (1977) method: (a) counts of roaring stags are based entirely on acoustic detection from the distance, either by mobile (Albaret *et al*. 1989) or stationary (Mazzarone *et al*. 1991) observers; (b) red deer population size is estimated by equating the number of roaring stags acoustically counted, assumed to represent a complete count, to the (estimated) proportion of adult males (i.e. $\geq$4–5 years) in the population (Albaret *et al*. 1989; Mazzarone *et al*. 1991). In these applications reference is theoretically made to mature, harem-holding stags, as only stags that roar continuously during the survey are counted (Mazzarone *et al*. 1991).

Nowadays, following reintroductions and expansion of red deer populations in several localities in the central Apennines, the simplified version of the roaring-stag count technique is becoming increasingly popular among management authorities in Italy (P. Morini, pers. comm.; L. Carotenuto, pers. comm.), even though a formal evaluation of its reliability is still lacking. In addition, although the original method was intended for management applications (Langvatn 1977), the simplified version has also been used recently in research contexts (Apollonio *et al*. 2004; Mattioli *et al*. 2004). However, despite

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the opinion that in densely forested and mountainous areas this technique might represent a practical alternative to other methods (Bobek *et al.* 1986), it should be stressed that the roaring-stag count has never been formally validated against true population abundance (Langvatn 1977). More importantly, assumptions and theoretical implications of roaring-stag counts have been poorly evaluated in the light of the growing knowledge on the social and environmental complexity that affects reproductive and roaring activity of mature stags (Clutton-Brock *et al.* 1982, 1997; Bowyer and Kitchen 1987; McComb 1987, 1991; Pépin *et al.* 2001; Reby *et al.* 2001, 2005; Yoccoz *et al.* 2002; Reby and McComb 2003; Sánchez-Prieto *et al.* 2004; Loe *et al.* 2005).

Recognising some of the above problems, some authors proposed that the number of roaring stags detected acoustically can nevertheless be regarded as an index of the minimum number of mature stags in the population (Albaret *et al.* 1989). However, roaring performance in a local population, and the proportion of stags that engage in basal and contest roaring (*sensu* Clutton-Brock and Albon 1979), can be proximally affected by a multitude of ecological, social and anthropogenic factors (Langvatn 1977; Clutton-Brock and Albon 1979; Clutton-Brock *et al.* 1982, 1997; Bowyer and Kitchen 1987; Albaret *et al.* 1989; Pépin *et al.* 2001; Yoccoz *et al.* 2002; Sánchez-Prieto *et al.* 2004). Critical as they are, these factors are generally not accounted for, and their influence on roaring-stag counts is therefore difficult to assess in wild populations (Pépin *et al.* 2001). Moreover, as with any other population index, the reliability of roaring stags counts to monitor population trends should rest on a formal assessment of the variance and its components, which is not always feasible under field conditions.

In order to contribute to a more thorough assessment of the reliability of this technique, we hereby report the application of roaring-stag counts in a protected area of the northern Apennines, Italy (Ciucci and Boitani 1993; Catullo 1996). As we deemed the original Langvatn (1977) approach not applicable in our study area due to the rough topography and dense vegetation, we adopted the field protocol of Mazzarone *et al.* (1989, 1991). However, because of theoretical and methodological considerations, we refrained from using this method to estimate absolute density of red deer, aiming instead at an index of relative abundance (Albaret *et al.* 1989). Because population parameters (actual density, social structure) of the local red deer population were unknown, as were other indices of relative abundance, we could not provide a test to formally validate the technique. Rather, by assessing the nature and extent of exogenous sources of variability that affected roaring-stag counts, our aim was to emphasise some inherent limits and fundamental problems of the technique as it is currently being applied. Accordingly, by presenting these data, we do not mean to encourage using roaring-stag counts to estimate either relative or absolute density of red deer.

Materials and methods

Study area

We acoustically detected roaring stags during the rutting season in a mountainous protected area (Orecchiella Natural Park, 5218 ha) along the northern Apennines, Italy (44°12′N, 10°23′E). Roaring-stag counts were conducted in all main valley systems within the study area, excluding minor portions of the park where the species has not been consistently detected (Fig. 1). The area is characterised by rough topography and altitudes ranging from 800 to 2054 m above sea level. About 72% of the area is covered by extensive forests, mostly beech (*Fagus sylvatica*) from ≥900 m, and mixed forests (*Quercus cerris*, *Ostrya carpinifolia*, *Carpinus betulus*, *Acer campestre*, *Fraxinus ornus*) at lower elevations. Alpine meadows (11%) and pastures (8%) are scattered throughout the area. Villages and other centres of human activity are scarce and restricted to lower elevations (<1000 m). Climate is Mediterranean cold-temperate, with mean temperatures ranging from 3.3°C in January to 15°C in July. Mean annual and summer precipitation exceeds 1800 mm and 280 mm, respectively. Four ungulate species are found in the area: red deer, roe deer (*Capreolus capreolus*), mouflon (*Ovis orientalis*) and wild boar (*Sus scrofa*), all being the consequence of reintroduction and restocking programs carried out by the Forest Service and local hunting associations (wild boar) in the 1960s and 1970s. In particular, red deer were reintroduced in the area during 1966–72, using ~15 founders from the Tarvisio red deer population (Mattioli *et al.* 2001). Although no formal estimation of the abundance of the local red deer population had been previously carried out, interviews with game wardens and anecdotal information suggested that at the time of this study the population was slowly but steadily increasing, in line with other reintroduced red deer populations in the northern Apennines (Mattioli *et al.* 2001).

Methods

Following a field protocol previously developed to count roaring red deer stags in similar settings (Mazzarone *et al.* 1989, 1991), we applied the technique in three successive rutting seasons from 1992 to 1994. Each year, to count the number of roaring stags in the population, we recorded the number and vocal activity of roaring stags (see below) during the peak of the roaring activity (peak counts). In order to synchronise the dates of the peak counts with the peak in roaring activity, we made reference in the first year of the study to peak roaring dates described in other red deer populations at similar latitudes (Mazzarone *et al.* 1989, 1991). In the following two years, peak-count dates were then scheduled according to the peaks in roaring activity that we detected in the previous years (Ciucci and Boitani 1993). For logistic reasons, and to limit the number of operators required while maximising the acoustic coverage of the area, peak counts were conducted separately, without replication, in four adjacent recording districts (Fig. 1), and the survey was therefore completed on four successive nights each year. Recording districts were defined according to main topography (ridges, valley bottoms) and aggregated dispersion of red deer units during the rut, as determined by field surveys and roaring activity. Recording districts averaged (±s.d.) 690 (±198) ha and, including a buffer area around each district; we acoustically sampled an area of ~3100 ha in total. We selected 11–14 recording stations in each district, for a total of 51 stations for the whole study area (Fig. 1). Stations were chosen to ensure complete acoustic coverage of the district, by selecting topographical vantage points while avoiding wind-exposed aspects or elevations and other sites susceptible to

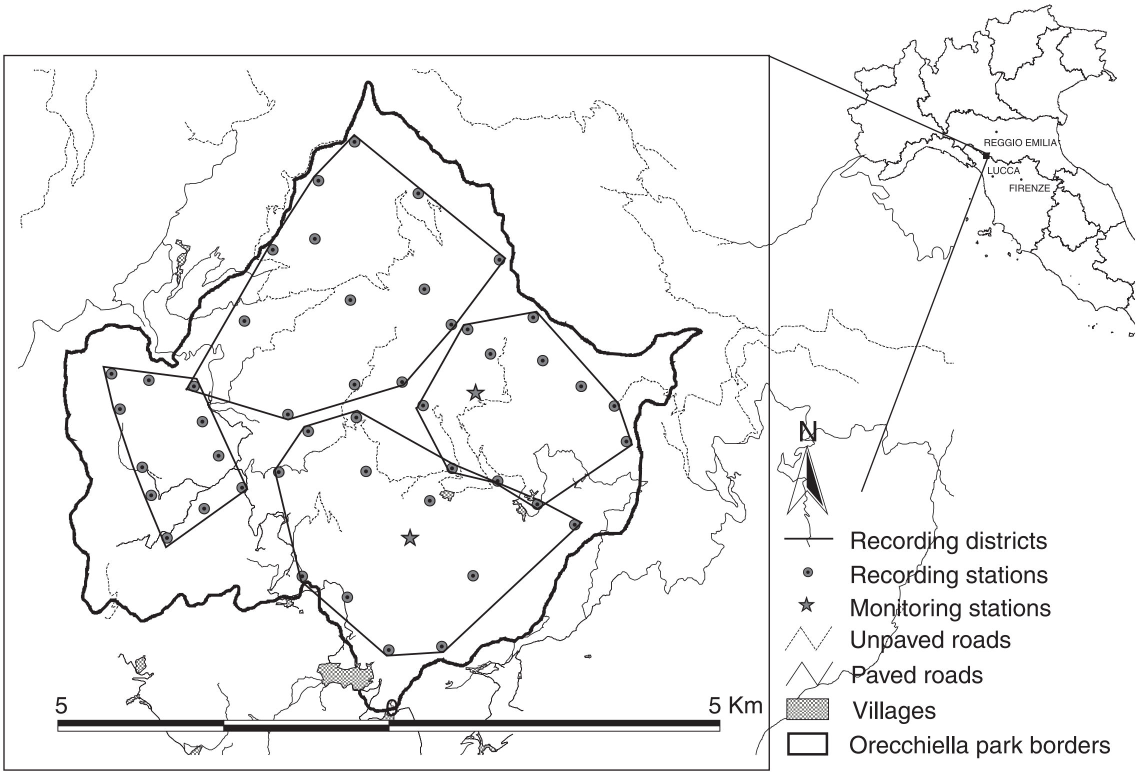

Fig. 1. General location of the study area in northern Italy. The inset shows the recording stations and districts used to detect roaring stags during the rutting season, from 1992 to 1994 (Orecchiella Natural Park, Italy).

environmental noise. The distance between adjacent recording stations within each district averaged 847 (±65) m, and ranged from 757 to 911 m (Table 1). We employed two observers per station, and up to 26 operators were simultaneously involved in each district every night. From each station, each pair of observers monitored the vocal activity of roaring stags continuously during 4-h sessions (21:00–01:00 hours), recording the time (±1 s) and the azimuth (±2°) of each roar (*sensu* Clutton-Brock and Albon 1979, p. 149) with the aid of a moving arrow on a goniometric frame fixed to a pole and previously aligned to the north using a compass (Mazzarone *et al*. 1989). Triangulation was subsequently used to locate roaring stags more accurately, by plotting azimuths simultaneously recorded from ≥2 recording stations on a 1 : 10 000 scale ortophotomap.

Table 1. Characteristics of the recording districts, and number of stations, used to carry out roaring-stag counts in the Orecchiella Natural park, Italy (1992–94)

Recording district	Area (ha)	Recording stations *n*	Recording stations Distance[A]	Hectares per station
1 (south)	839	14	852 ± 359	59.9
2 (east)	628	12	868 ± 210	52.3
3 (north)	856	14	911 ± 165	61.1
4 (west)	438	11	757 ± 204	39.8
All	3100[B]	51	847 ± 65	60.8

[A]Mean ± s.d. (m) between adjacent stations.
[B]Including a buffer area around each district.

Following Mazzarone *et al*. (1991), we counted only stags that roared continuously through the 4-h session.

To evaluate *a posteriori* the degree of synchronicity between the peak counts and the actual peak in roaring activity, we also reconstructed the phenology of the roaring performance throughout the rutting season by recording roaring activity both before (preliminary-count survey) and after (successive-count survey) peak dates. Carried out from two recording stations located in different rutting grounds within the study area (Fig. 1), preliminary- and successive-count surveys were based on 4-h recording sessions (21:00–01:00 hours) systematically replicated on alternate days throughout the rutting season.

In addition, 2–4 days before the expected peak, 12-h recording sessions (20:00–08:00 hours) were also carried out to determine the peak in roaring activity during the night. We limited these sessions to crepuscular and nocturnal hours as anecdotal evidence obtained during other field activities indicated a sharp decline in roaring activity during daylight hours.

During the rutting season, daily minimum and maximum temperatures and precipitation were recorded at meteorological stations in the study area (Comunità Montana della Garfagnana, Istituto Idrografico di Pisa). We used the Spearman coefficient to assess correlation between indices of roaring activity (i.e. the number of roaring stags and the number of roars heard per hour) recorded throughout the rutting season, and their relationship with daily temperature and rainfall. We used polynomial regression to examine seasonal patterns and expected peak in roaring activity using the mean number of roaring stags and roars heard per hour, as recorded during preliminary- and successive-count surveys. Likewise, to investigate nocturnal variation in roaring activity, we used polynomial regression by examining the relationship between the two indices of roaring activity, recorded during the 12-h nocturnal sessions, and time. In case no seasonal or nocturnal trends were detected, we compared both indices of roaring activity to an expected uniform distribution by Kolmogorov–Smirnov one-sample test to highlight significant departures on a daily or hourly basis.

Results

During the three years of the study, roaring activity was detected from late August up to mid-October, but we actively monitored it throughout the rutting season (preliminary- and successive-count surveys) from the second week of September until the first week of October, for a total of 3–4 weeks during each rutting season (Fig. 2). Throughout each rutting season, the mean number of roaring stags heard per hour was correlated with the mean number of roars heard per hour ($0.83 \leq r_s \leq 0.85$, $12 \leq n \leq 13$, $P < 0.0001$). With the exception of 1994, both vocal indices revealed a temporal trend which, fitted by quadratic regression models, showed a rapid ascent during the second week of September, a peak around the third (1993) or the fourth (1992) week of September, and a decline afterward (roaring stags, 1992 and 1993: $0.64 \leq r^2 \leq 0.78$, $4.15 \leq F_{2,9} \leq 18.21$, $0.0005 \leq P \leq 0.005$, roars, 1993 only: $r^2 = 0.48$, $F_{2,9} = 4.15$, $P = 0.05$). Temporal trends in roaring activity were not synchronous from year to year, and roaring peaks, when detected, were quite unpredictable on an annual basis within an interval of ~10–12 days, and were of variable duration (Fig. 2). By the first week of October, a marked decline in roaring activity was detected in all three rutting seasons, and in all cases it coincided with abrupt deterioration of weather conditions. Accordingly, both indices of roaring activity were positively correlated with temperatures during all three rutting seasons, and inversely correlated with rainfall in 1994 (Table 2). Minimum daily temperatures and rainfall recorded throughout the rutting season did not differ, on average, among the three years, whereas maximum daily temperatures were, on average, ~5 and 6°C higher in 1992 than in 1994 and 1993, respectively ($F = 6.86$, $P = 0.003$).

During the 12-h nocturnal sessions (n = 2, 4 and 3 in 1992, 1993 and 1994, respectively), there was no significant trend in the

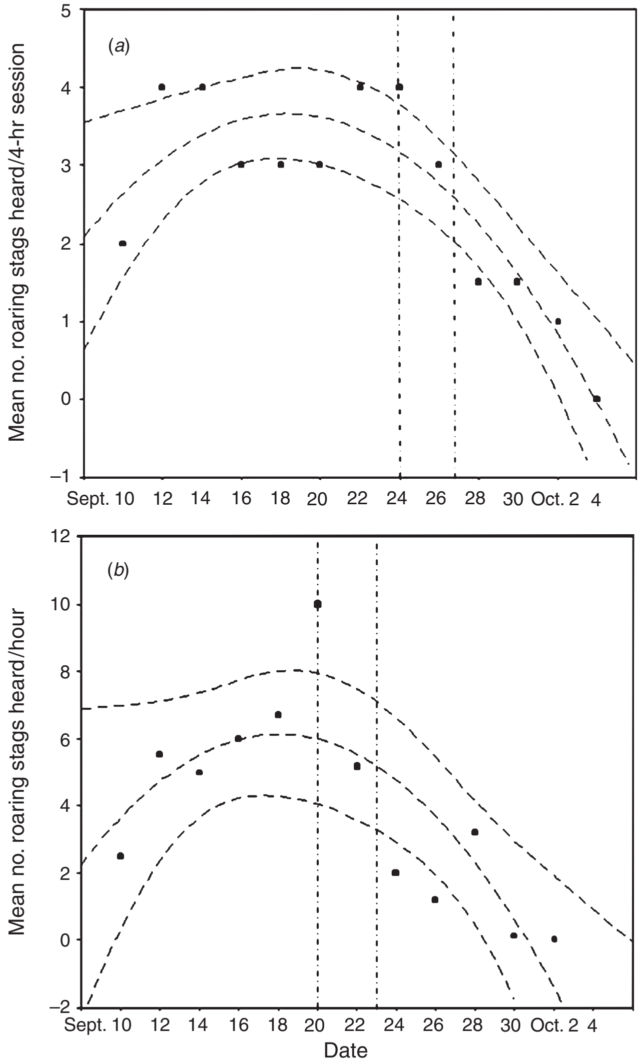

Fig. 2. Phenology of the roaring performance in 1992 (*a*) and 1993 (*b*) as described by quadratic regression models (±95% CIs). The number of roaring stags was monitored throughout the rut from two stations using 4-h recording sessions (21:00–01:00 hours) on alternate days. In 1992, only the number of roaring stags per session was recorded. In 1994, no peak in roaring activity was detected (see text). Vertical dotted lines depict the day-interval chosen for the peak counts each year (Orecchiella Natural Park, Italy, 1992–94).

Table 2. Correlation (Spearman's *r*) between roaring performance, indexed both as mean number of roaring stags counted per hour and mean number of roars heard per hour, and maximum daily temperature and daily rainfall throughout the rutting seasons from 1992 to 1994 (Orecchiella Natural Park, Italy)

See legend of Fig. 2 for additional details

Year	Temperature (daily maximum, °C)						Rainfall (mm)					
	Roaring stags[A]			Roars[B]			Roaring stags[A]			Roars[B]		
	r_s	n	P	r_s	n	P	r_s	n	P	r_s	n	P
1992	0.76[C]	13	≤0.00	n.r.	–	–	–0.50[C]	13	≤0.08	n.r.	–	–
1993	0.79	12	≤0.00	0.71	12	≤0.01	–0.41	12	≤0.21	–0.34	12	≤0.31
1994	0.73	13	≤0.01	0.72	13	≤0.01	–0.69	13	≤0.01	–0.48	13	≤0.11

[A]Mean number of roaring stags per hour.
[B]Mean number of roars per hour.
[C]Temperature and rainfall versus mean number of roaring stags per 4-h session.

mean number of roaring stags heard per hour between 20:00 and 08:00 hours (roaring stags: $0.20 \leq r^2 \leq 0.42$, $1.17 \leq F_{2,9} \leq 3.33$, $0.08 \leq P \leq 0.35$; roars: $0.03 \leq r^2 \leq 0.35$, $0.16 \leq F_{2,9} \leq 2.46$, $0.13 \leq P \leq 0.84$), and the number of roaring stags detected hourly did not deviate from uniformity (Kolmogorov–Smirnov, $D = 0.50$, $n = 12$, $P > 0.05$), with the sole exception of 1992 (Kolmogorov–Smirnov, $D = 0.67$, $n = 12$, $P < 0.01$) (Fig. 3*a*). However, the number of roars heard per hour deviated from uniformity in all three rutting seasons (Kolmogorov–Smirnov, $0.42 \leq D \leq 0.58$, $n = 12$, $P < 0.05$), although peaks in roaring activity were not synchronous from year to year (Fig. 3*b*).

We carried out peak counts each year between the third and the fourth week of September (Table 3, Fig. 2) but they were possibly delayed 2–3 days with respect to the highest levels of roaring activity (Fig. 2). From 1992 to 1994, we acoustically detected a total of 14–19 roaring stags in 1992 and 1993, respectively, corresponding to 0.45–0.61 roaring stags per 100 ha (Table 3). In 1993 we detected a substantial increase in the counts (35.7%), in all but one recording district, followed by a decrease (–21%) in 1994, even though marginal recording conditions were reported in the last two districts during this year (Table 3). Weather and acoustic conditions were not always comparable during and across the surveys, and moderate to high wind conditions, especially when associated with heavy precipitation, might have compromised both roaring activity and observers' hearing capabilities (Table 3).

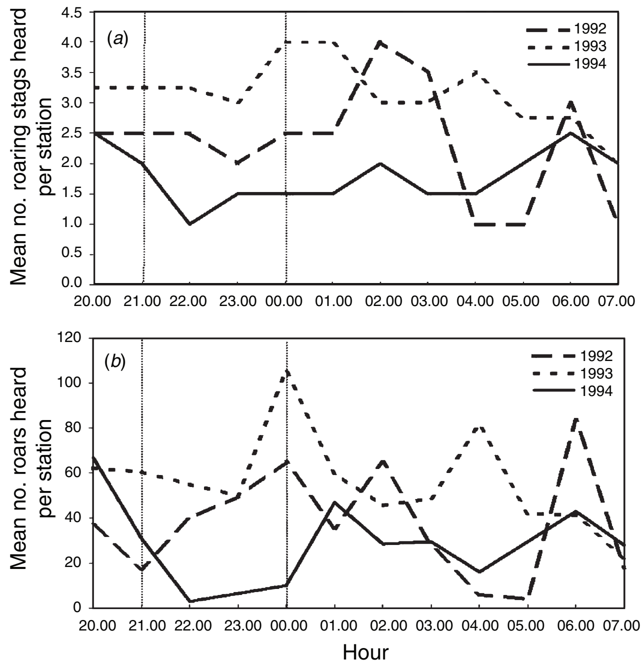

Fig. 3. Variability in the number of roaring stags (*a*) and roaring activity (given roars) (*b*), as detected in the days immediately preceding the peak counts, recorded from two stations using 12-h recording sessions throughout the night. Vertical dotted lines identify the time-interval chosen to conduct the peak counts (Orecchiella Natural Park, Italy, 1992–94).

Discussion

Seasonal trends and duration of the roaring activity in our study area were similar to those reported elsewhere (Clutton-Brock *et al.* 1982; Pépin *et al.* 2001). However, the onset and peak of the rutting season in our population appeared to be ~1–3 weeks earlier than in other red deer populations at different (Norway: Langvatn 1977; Loe *et al.* 2005; Poland: Bobek *et al.* 1986; Rum Island: Clutton-Brock and Albon 1979; France: Loe *et al.* 2005) or similar (Italian Apennines: Mazzarone *et al.* 1989, 1991) latitudes. This suggests that, rather than latitudinal and climatic factors (cf. Loe *et al.* 2005), social and ecological correlates of local populations may be involved. Adult stags of prime age usually breed earlier than younger stags, and older ones

Table 3. Results of the roaring-stag counts carried out in the Orecchiella Natural Park, Italy, during the rutting seasons from 1992 to 1994

Year	Starting date	Recording district	Roaring stags No.	No. per 100 ha	Rain	Wind	Mimimum temperature (°C)
1992	September 24	1	4	0.48	No	No	11
		2	5	0.80	No	Low/moderate	10
		3	3	0.35	No	Low/moderate	10
		4	2	0.46	No	Low/moderate	8
	Total		14	0.45			
1993	September 20	1	6	0.72	No	No	15
		2	7	1.11	No	No	15
		3	4	0.47	No	Moderate/high	13
		4	2	0.46	Low	High/intense	14
	Total		19	0.61			
1994	September 19	1	8	0.95	No	No	5
		2	5	0.80	Low	No	5
		3	0	0.00	Heavy	Low	15
		4	2[A]	0.46	Heavy	High	14
	Total		15	0.48			

[A]As adverse weather conditions did now allow the counts in this district, the number of roaring stags in 1994 was based on the mean proportion of roaring stags detected in the same district in the previous 2 years.

cease their rutting behaviour sooner (Clutton-Brock *et al*. 1982; Yoccoz *et al*. 2002). Although the age structure of our study population was unknown, its protected status since reintroduction may have resulted in an older age structure than in harvested populations, and correspondingly earlier roaring activity (Langvatn 1977; Bobek *et al*. 1986). Also the age composition of females, although unknown in our population, might affect temporal patterns in breeding and rutting, as a high proportion of yearlings or young females seems to be correlated with less synchronous and predictable breeding seasons (Loe *et al*. 2005).

Whatever the underlying factors, and as with any population index (White 1992; Anderson 2001, 2003), it is not possible to formally evaluate the reliability of the roaring-stag counts if basic population parameters are unknown. However, in addition to demographic, social and ecological characteristics of the investigated reed deer populations, many other factors may affect roaring performance and therefore roaring-stag counts. In our application, onset and duration of the roaring peak were variable on an annual basis and difficult to predict, so that the synchronicity between peak counts and the peak in roaring activity varied from year to year. Weather and climatic factors, which affect both roaring performance and observers' recording capabilities (Langvatn 1977; Albaret *et al*. 1989; Pépin *et al*. 2001) also varied quite unpredictably, adding substantial uncertainty to the final counts. In addition, although we did not observe any nocturnal trend in roaring performance, it varied on an hourly basis and from year to year, and this variability can affect reliability of the counts when these are based on a temporal sample of the roaring activity during the night (Albaret *et al*. 1989; Mazzarone *et al*. 1989, 1991). While, on the one hand, synchronicity among the roaring-stag survey, roaring peak, and adequate weather conditions are of critical importance for limiting exogenous variability in the counts, these same factors, on the other hand, appear quite variable from year to year, are hardly predictable, and may interact, affecting roaring-stag counts to an unknown extent. In light of these considerations, the substantial annual variation that we detected in roaring-stag counts should not be interpreted exclusively in terms of population change, as many other proximate factors might be involved. For example, the 35.5% increase we detected in 1993 might have been affected by (a) the sharper, unimodal peak of the roaring activity in 1993 with respect to 1992 and 1994 (cf. Fig. 2*b*), and/or (b) the higher synchronicity we obtained between the peak counts and the roaring peak (both seasonally and nocturnally; cf. Figs 2 and 3), and/or (c) the slightly milder temperatures and better recording conditions in 1993 than in 1992 (Table 3). Similar considerations can be made for the other years as well, contrasting the 1993 versus the 1994 counts and the 1992 versus the 1994 counts (i.e. potential Type I and Type II errors, respectively). These exogenous sources of variability are quite unpredictable and they can be hardly accounted for even by the strictest field protocols. Although preliminary- and successive-count surveys (Mazzarone *et al*. 1991) are useful in interpreting the counts in the light of the observed synchronicity with the peak in roaring activity, in case of asynchronous counts and/or marginal recording conditions they cannot quantitatively solve the problem.

How can differences in roaring-stag counts be interpreted in the light of the above considerations? One way to proceed would be to assume that large and consistent changes in the population would be detected notwithstanding the inherent variability in the counts (Gibbs 2000). This would recommend this method in management contexts where neither precision nor accuracy is particularly critical (e.g. appraisal of the long-term trends of a reintroduced population). The red deer population in the Mt Arcosu Reserve in Sardinia, for instance, has been monitored by means of roaring-stag counts for more than 10 years (1989–98), indicating an increase from 50 to 180 roaring stags and providing, in 1998, a density estimate that was comparable to that obtained through pellet-group counts (Lovari *et al*. 2007). Given such a difference in population size over such a long period, it would be difficult to be sceptical about the observed increase, notwithstanding the inherent variability in the roaring-stag counts on an annual basis. However, when differences in population size are expected to be smaller, or when the time frame over which trends are monitored is shorter, uncertainties in the counts would make the use of this index unreliable. Experimentally quantifying variance in roaring-stag counts in representative field conditions would therefore provide a further step towards a more through evaluation of the technique.

Another way to proceed would be to modify the field protocol in order to allow for replication in the counts (Mazzarone and Mattioli 1996; Mattedi *et al*. 1997). For example, by increasing the number of observers we might have provided at least one replicate in the counts in our four-day survey. One replicate would have provided not only a more robust count of the number of roaring stags, but also a rough estimation of its variance useful to formally evaluate the feasibility of the roaring-stag count to monitor population trends (Thompson *et al*. 1998; Elzinga *et al*. 2001) through *ad hoc* power analyses (Gerrodette 1987; Gibbs 2000). The value of replicated counts, however, rests on the assumption that all are synchronous with the peak in roaring activity, which actually represents a temporally moving target of relatively brief duration. Moreover, replicated counts can be logistically and operationally challenging, as in order to ensure an adequate dispersion of recording stations (i.e. to safely assume that the probability of detection of roaring stags is equal to 1), the number of observers simultaneously engaged should be substantially increased (doubled or tripled in our case). Hiring and training such observers for nocturnal field operations is not a trivial matter, as it increases organisation and logistic effort, and can be problematic (e.g. increased interobserver bias, disturbance to deer and other wildlife, etc.).

On more theoretical grounds, adoption of the simplified version of the roaring-stag count technique, either to estimate relative or absolute red deer density (Albaret *et al*. 1989; Mazzarone *et al*. 1989, 1991), rests on the basic assumption that the number of roaring stags is linearly correlated with population size and density. However, Langvatn (1977) recognised that, in addition to weather conditions, the proportion of roaring stags in the population and their roaring performance depend on factors that are not easily appraisable, such as population density and interindividual distances, age of the stags, and the progression of oestrus in both stags and hinds. More recent evidence suggests that rutting and roaring behaviour of red deer stags is affected by population density and structure (Clutton-Brock *et al*. 1997; Yoccoz *et al*. 2002; Loe *et al*. 2005), the age and body condition of the stags (Clutton-Brock and Albon

1979; Clutton-Brock *et al.* 1982; Pépin *et al.* 2001; Yoccoz *et al.* 2002), the proportion of females in the population, their activity and dispersion in the harem and their physical condition (Bowyer and Kitchen 1987; Clutton-Brock *et al.* 1997; Langvatn *et al.* 2004), and the quality and dispersion of the resources (Sánchez-Prieto *et al.* 2004). Unfortunately, these factors were not appraised in previous applications of the roaring-stag technique (e.g. Mazzarone *et al.* 1989, 1991; Mattedi *et al.* 1997; Mattioli *et al.* 2004), a problem further amplified by the theoretical weakness of the simplified over the original Langvatn (1977) method. We contend, in fact, that equating the number of acoustically detected roaring stags to the proportion of adult males observed in the population seems a too simplistic and unreliable procedure, as some of the stags visually observed may be too young, too old, or in too poor condition to hold harems, and they may or may not roar at all, or may display roaring rates different from harem-holding stags, i.e. those most likely to be detected acoustically during the roaring-stag counts (Clutton-Brock and Albon 1979; Yoccoz *et al.* 2002). In addition, due to known biases in compositional counts caused by differential visibility of the various age and sex classes (Vincent and Bideau 1982; McCullough 1993; McCullough *et al.* 1994), the simplified version may also introduce additional sources of uncertainty in the final population size estimates. For example, the reported 8.9% increase in the number of roaring stags in two successive years in the Acquerino red deer population (Northern Apennines, Italy) built up to a 21% increase in the size of the whole population due to a concomitant decrease in the visually estimated proportion of adult males in the population (Mazzarone and Mattioli 1996).

Management implications

In areas where other traditional methods are difficult or too expensive to apply, detection of roaring stags may provide a convenient means to reveal red deer presence, distribution, dispersion and location of rutting grounds. Under restricted circumstances (i.e. long-term monitoring of large and consistent changes, such as in the Corsican red deer population) this technique might also provide a gross indication of population trends (Lovari *et al.* 2007). However, no published study currently proves that this method can be used to reliably assess and monitor red deer population size. Both inaccuracy (e.g. error in the counts, incomplete counts assumed to be complete, unknown relationship between population size and the number of roaring stags detected) and low precision might affect roaring-stag counts. We found that logistical constraints, as well as timing of the survey in relation to the phenology of the rutting season and prevalent weather conditions, may add considerable variability that reduces interpretability and reliability of roaring-stag counts. Although improved field protocols might allow for replication in the counts, therefore providing an estimate of their variance, this can be problematic and often impractical in field conditions. In addition, if the social and ecological correlates of rutting behaviour, known to affect number and detection of mature stags, are not accounted for (cf. Langvatn 1977), roaring-stag counts cannot be reliably assumed to reflect absolute population density. Accordingly, where human disturbance can interfere with roaring activity (Langvatn 1977; Walsh *et al.* 1991), the putative relationships between number of roaring stags and population size can be even more problematic.

Due to several weaknesses on both methodological and theoretical grounds, we therefore caution on the use of this methodology. Managers should not adopt roaring-stag counts for population assessment and monitoring unless they are able to prove the technique can yield reliable results, a demonstration which is lacking at present.

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