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PAPER

Acoustic analysis of some characteristics of red deer roaring

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Abstract

Different strategies have been adopted to track and monitor red deer (*Cervus elaphus*) populations according to different habitats and ecosystems. The population census techniques usually carried out are time consuming and involve lot of manpower. A method that relies on individual animal signs like acoustic indices could be useful to support the wildlife management, since vocalisations can encode and transmit a variety of biologically significant information. The present study considered 460 roars recorded from 14 adult deers, from five to eight years old. Recordings were performed in five different locations of northern-central Italy. The acoustic spectrum of each roar was analysed in order to extract its main features, namely: the fundamental frequency (F0), the peak frequency (PF), the sound length (SL) and 24 frequency bins of 174.3 Hz, representing the sound distribution between 50 and 4233.2 Hz (F1 to F24). Statistical analyses showed that individuality and age of animals were significant on F0 ($P < 0.001$), PF ($P < 0.001$) and SL ($P < 0.001$). Results also showed a correlation among the 24 F-variables of roars emitted by deer of similar age ($r > 0.90$; $P < 0.001$), indicating that age could influence the spectral features of roaring. The roaring frequency variables appear to be indicators of the individuality of male deer, even if the strong influence of age on the emitted sounds could compromise the reliability of the method over long periods of time.

Introduction

Red deer *Cervus elaphus* are widely distributed across Europe and have increased in both

abundance and geographical range in recent decades (Milner *et al.*, 2006). Red deer populations have increased over the last century as a result of direct and indirect causes, such as the availability of forage resulting from changes in land use of agricultural and silvicultural practices, and the climate. Furthermore, protection from overhunting and poaching, the use of selective harvesting regimes, supplementary feeding in winter, and reintroduction programmes have all contributed to rising numbers (Milner *et al.*, 2006).

This population growth and distribution of red deer has brought benefits to hunters but also damage to forestry and agricultural sectors (Gill, 1990). As a result, in many areas management objectives are beginning to change from species protection to population control (Milner *et al.*, 2006). Deer management, considering the benefits and damage, should aim for a balance between harvesting and conservation. For these reasons, it is important for the deer managers to know how the population is evolving.

Different strategies should be adopted to adjust population density according to different habitats and ecosystems (Meriggi *et al.*, 2009). The main step is the population census, which involves manpower, financial resources, and cooperation of forest and urban entities. A wildlife count requires an expert team and a considerable financial investment. The main objective of this activity is to count the number and distribution of wildlife species and to compare them with previous counts. In this way, the extent of human activities in the ecosystem is also indirectly evaluated. Standard techniques estimate deer number per unit area and this information is used to identify threats to wildlife and address conservation plans (Cook and Gray, 2003).

The census methods commonly used, such as the distance sampling (Buckland *et al.*, 2005) or the capture-mark-recapture (ISPRA, 2013), are based on a direct count and involve marking animals, transecting, spotlight surveys, thermal imaging, camera censuses and hunter observation data. In open habitats, direct census counts of individual populations are the most suitable method currently available although their accuracy and reliability have occasionally been questioned (Smart *et al.*, 2004).

Deer abundance in woodland is generally estimated by indirect methods, frequently requiring the faecal pellet count. The two main techniques are the Faecal Standing Crop and Faecal Accumulation Rate (Smart *et al.*, 2004).

Traditional visual methods are the most frequently used, but the planning must be very

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accurate and must take into account several issues like the non-random distribution or the grouping of animals due to their gregarious behaviour, and the seasonal and circadian variation in activity of the species object of the count. Any census technique must therefore be conducted at optimal lifecycle moments (Witmer, 2005).

Regarding the faecal counts the accuracy is affected by the persistence period, and by the measure of defecation rate, which varies between period of year and individuals (Smart *et al.*, 2004).

Nevertheless, while population size estimation can be useful in order to monitor the overall population trends, it generally cannot yield a precise number of deer in the population. The awareness about population actual size can provide a basis for decisions relative to harvest management, and a census method that relies on individual animal signs like acoustic indices could potentially be useful.

Individual acoustic identification may in fact serve to evaluate the number of adult males participating in reproduction in a population and was proposed to track individuals over time (*acoustic marking*) in order to derive estimates of survival and dispersal as an alter-

native to physical marking methods (Bocci *et al.*, 2013). Auditory counts were used to survey deer that are highly vocal during courting and they produce valuable distributional and abundance data (Reby and McComb, 2003a). Furthermore, stag roars can convey information on identity, condition, size and maturity of the sender (Bocci *et al.*, 2013; Charlton *et al.*, 2007, 2008). When individuals are characterized by a such significant acoustic distinctiveness, spectrographic analyses of roars could help individual recognition and serve for counting purposes as well as for tracking individuals, thus being useful for conservation and management purposes (Vögeli *et al.*, 2008).

Instead of aiming at an individual recognition, as discussed by previously cited authors, the present study aimed to identify a simple approach to support the traditional visual census methods for red deer stags through the analysis of their vocalizations.

Materials and methods

Study areas

Recordings were performed in three different areas located in northern Italy: i) Lepontine Alps, 450 m asl, natural reserve, mountain, broad-leaved trees and conifers; ii) Rhaetian Alps, 470 m asl, enclosed corral, mountain, grass and broad-leaved trees; iii) San Sebastiano Po, 350 m asl, enclosed corral, hill, broad-leaved trees. Recordings were performed also in two areas located in the northern Apennines of central Italy: i) Regional Park of Suviana and Brasimone Lakes, 880 m asl, extensive farming, mountain, broad-leaved trees and conifers; ii) Northern Tuscan Apennines, 380 m asl, enclosed corral, plain, grass and broad-leaved trees.

Animals were chosen in enclosed areas of different size (from about 1000 to 10,000 m²) in which the presence of female and/or other males and the age of individuals were known. Areas 1 and 4 were partitioned into large fenced sub-areas and for this reason they were classified as *wildparks*.

Sampling and data analysis

In this research, 14 adult roaring red deer (*Cervus elaphus*) stags were recorded during the mating season from late August to October 2013. Individuals of known age were chosen according to the indication provided by the management of each area. A single day recording session was performed for each deer. The animals were five to eight years old (Table 1) and were confined in farm corrals or in natural

wildlife reserve either alone or in small groups. The sample population was constituted by 14 adult stags, three of which were 8-year old, six were 7-year old, four were 6-year old, and only one was 5-year old. This stag was anyway included in the analysis because the quality and the number of roars recorded were so high that those data could increase the variability of the population of study.

Recordings were made at specific checkpoints at a maximum distance of 50 m from the animals using a spotlight for visual identification. In enclosed environments, like corrals, the recordings were made from fixed post while in larger parks it was possible to switch positions by following moving herds via observation towers. In this way, it was possible to visually observe the moment of the roaring and therefore identify the audio files by deer and location (Table 1). During the mating period, recordings were collected mostly in the night or at twilight. Windy and rainy days were avoided in order to minimize any interference and to enhance the sound quality. For audio collection, a long gun highly directional microphone (Sennheiser ME 67) was used. This type of instrument allows the operator to follow animal's voice and to discriminate against sound not emitted from the main pick-up direction. The sensor was connected to a handheld digital recorder (Marantz PMD 620) and sounds were recorded as uncompressed WAV files 24-bit at 44.1 kHz sample rate on a SD flash media.

Audio playbacks were processed using Adobe® Audition® 3 manually extracting single roars from single stags. Individual sounds were then analysed both in a home designed sound analysis program based on Matlab®

(Mathworks) and in Praat 5.3.51 (Boersma and Weenink, 2013) to extract the main acoustics features like fundamental frequency (F0, representing the lowest frequency of a periodic waveform), peak frequency (PF, representing the frequency of maximum power) and sound length (SL, in seconds).

The PF was calculated by a 20th order Auto Regressive (AR) estimation and FFT (Fourier Fast Transform) Power Spectrum Density (PSD) (Pardey *et al.*, 1996; Silva *et al.*, 2010). The order of the model was set to 20 according to the Akaike information criterion (AIC). The AIC integrates the method of Maximum Likelihood to estimate parameters and the likelihood-ratio test to discriminate the hypotheses; it is also widely used to determine the order of the AR models (Moddemeijer, 1998).

The values were extracted by a moving window (Hamming window with a length of 128 samples and with a 50% overlap) over the total vocal call.

Average Power Spectrum Density (A-PSD) of each signal was calculated (Hanning window) for the F0 analysis. The frequency resolution resulted as the ratio of the sample frequency (44.100 Hz) to the FFT size (253). The analysis resulted therefore in 24 frequency bins of 174.3 Hz, representing the sound distribution between 50 and 4233.2 Hz (F1 to F24).

These variables averaged the distribution of energy in the frequency domain over the total length of the signal, defining the vocal features of each deer.

Data distribution of F0 (Hz), PF (Hz) and LS (s) of each sound were analysed by the MEAN Procedure of SAS 9.2 for Windows (SAS Institute Inc., Cary, NC, USA).

Table 1. Population study and age of recorded deer.

Subject	Age, years	No. of calls (overall)	Habitat	Males present	Females present
1	5	49	C	Yes	Yes
2	6	31	W	Yes	No
3	6	49	C	Yes	Yes
4	6	31	W	No	No
5	6	46	W	Yes	No
6	7	30	C	No	Yes
7	7	26	W	Yes	No
8	7	29	C	No	Yes
9	7	33	C	Yes	No
10	7	28	C	No	Yes
11	7	27	W	Yes	Yes
12	8	20	W	Yes	No
13	8	33	C	Yes	Yes
14	8	28	W	No	Yes

C, Corral; W, Wildpark.

Variance analysis: individuality

The F1- F24 variables were tested with the CORR Procedure (Pearson Product-Moment Correlation) in order to identify the relation within and among deer (SAS 9.2 for Windows). The subject (SUB, 14 roaring deer) and age (AGE, 4 levels, from 5 to 8 years old) were considered as fixed effects in the model used to evaluate the variability of the 24 F-variables, the F0, the PF and the SL (GLM procedure of SAS 9.2 for Windows. SAS Institute Inc., Cary, NC, USA). The interaction between SUB and AGE was not included in the model because the aim of this study was to test the effect of the individual and the age separately. Furthermore, the interaction would be possible in case of multiple recordings (at different ages) of the same stag.

Variance analysis: habitat

The GLM Procedure of SAS 9.2 for Windows (SAS Institute Inc., Cary, NC) was used to evaluate the effects of environmental condition on the number of calls. In the model the calls were included as dependent variables, while the habitat (HAB, 2 levels, corral or wildpark), the presence of females (FEM, 2 levels, yes or no), and the presence of other males (MAL, 2 levels, yes or no) were included as independent variables.

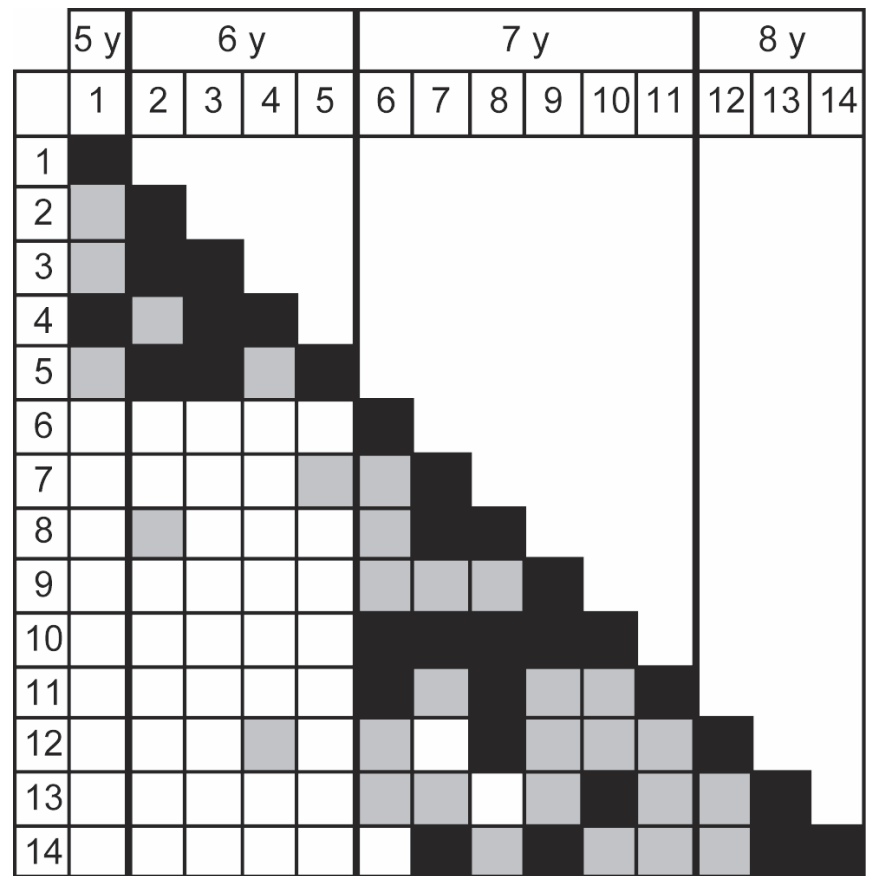


Figure 1. Correlation of the 24 F-variables within and among deers. Black slots indicate correlation above 0.90, grey slots represent correlation above 0.80, and white slots mean low correlation ($r < 0.80$).

Table 2. Mean and standard deviation of fundamental frequency, peak frequency, and sound length.

Subject	AGE, years	No. of calls/hour	F0, Hz		PF, Hz		SL, s	
			Mean	SD	Mean	SD	Mean	SD
1	5	20	150	15	1036	120	1.35	0.35
2	6	12	135	24	905	92	1.50	0.51
3	6	20	201	12	870	94	1.40	0.43
4	6	12	140	22	887	101	1.57	0.75
5	6	18	95	19	777	94	1.27	0.35
6	7	12	80	15	382	43	2.60	1.20
7	7	10	120	18	283	36	1.40	0.28
8	7	12	101	16	216	32	2.80	0.57
9	7	13	93	16	273	33	1.36	0.38
10	7	11	112	19	258	43	2.40	1.10
11	7	11	150	20	304	39	1.34	0.29
12	8	8	123	21	202	32	1.52	0.31
13	8	13	85	13	251	28	2.06	0.48
14	8	11	96	17	305	55	1.97	0.73

F0, fundamental frequency; PF, peak frequency; SL, sound length.

Results

For each deer, an audio file of about 5 hours was obtained. After a preliminary screening, the audio files were edited in order to remove noisy sessions and to isolate the clearer sounds. A total of 730 suitable individual sounds from 14 males were manually labelled from the recorded data by an operator and then analysed. 460 sounds were classified as roars. The remaining sounds were classified as 185 coughs (sudden harsh noises, emitted in particular by subjects 4, 7, 11 and 12) and 85 short and guttural sounds (not assigned to roars during the selection process since their peculiar characteristics). The analysis focused on the larger and most relevant group of sounds identified, namely the common roars. Means and standard deviations of F0, PF, and SL of each roaring deer were determined (Table 2).

Results from the variance analysis: individuality

Correlations among the 24 F-variables with in stags were high ($r > 0.95$; $P < 0.001$), indicating that there was no significant difference among roars emitted by the same stag. Among deer, correlations of the 24 F-variables were higher in animals with similar age ($r > 0.90$; $P < 0.001$), while correlation values were lower ($r < 0.80$; $P < 0.001$) among those animals with a larger age gap (Figure 1). Despite the small size of the population and the inclusion of only one 5-year old individual (for which it is not possible to distinguish between the nested effect of age and individuality), the levels of significance of the AGE and SUB effects were high and are reported in Table 3; the 24 F-variables are all significant (AGE: $P < 0.01$; SUB: $P < 0.001$, results not shown in the table).

Estimated values of F0 and PF were higher ($P < 0.001$) in younger stags (180 Hz and 1036 Hz, respectively, for the five year old stag), while in older animals those values were lower (98 Hz and 258 Hz, respectively, for eight year old stags). The results showed that longer sounds were a feature of older animals ($P < 0.01$; Figure 2). The level of significance of AGE effect ($P < 0.01$) showed that animals' vocal features tend to be different in stags of different age. The effect of each deer (SUB) was highly significant ($P < 0.001$) for all the acoustic variables considered in the model (F0, PF, SL, and 24 F-variables). GLM results and comparisons among subjects and ages are reported in Table 3 and Figures 2 and 3, respectively.

For the AGE and the SUB effects, the variation in F0, PF and sound length (Figures 2 and

3) was visible. Considering the F0 and the PF (Figures 2a and 3a), the variation caused by AGE and SUB effects tend to decrease from younger to older stags ($P < 0.001$), or when they are grouped by age. Regarding the variation in sound length as a function of the age (Figure 2b), it seems to follow an increasing trend, with a possible relation between this acoustic parameter and the age of the roaring deer

($P < 0.01$). Despite the variation observed in F0, PF, and sound length, as a function of the subject ($P < 0.001$), from the results reported in Figure 3, it emerged that it is not possible to relate the roar to a specific individual, since different subject of similar age could emit roaring with overlapping parameters.

Examples of acoustic profiles of a 5-year old stag and a 8-year old stag, normalized for

Table 3. Level of significance of subject and age effect on fundamental frequency, peak frequency and sound length.

	Subject	Age
F0	***	***
PF	***	***
SL	***	**

F0, fundamental frequency; PF, peak frequency; SL, sound length. ** $P < 0.01$; *** $P < 0.001$.

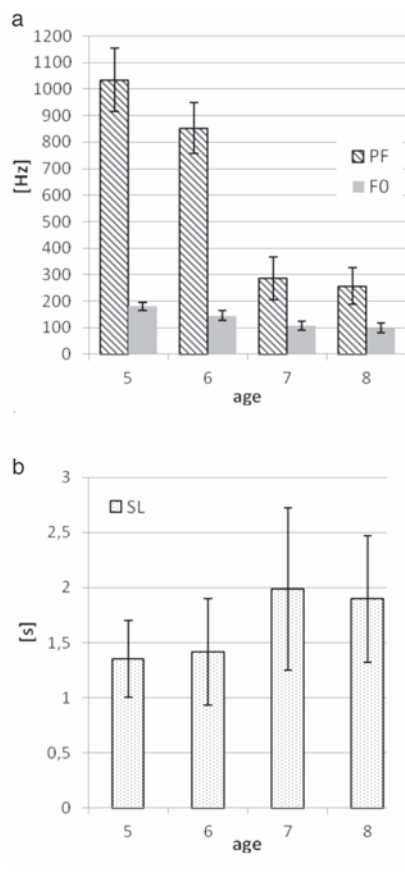


Figure 2. Variation in: a) fundamental frequency F0 and peak frequency (PF; overall level of significance: $P < 0.001$), and b) sound length (SL; overall level of significance: $P < 0.01$), according to the age of roaring deer. Values are expressed as LSMEANS \pm SEM.

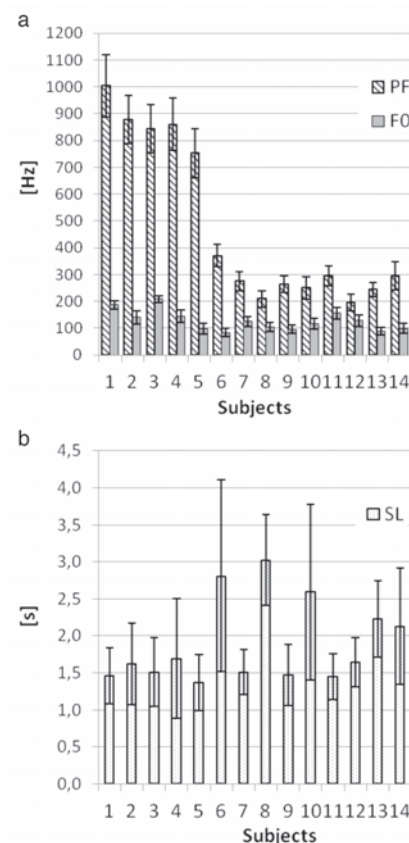


Figure 3. Variation in: a) fundamental frequency F0 and peak frequency (PF; overall level of significance: $P < 0.001$), and b) sound length (SL; overall level of significance: $P < 0.001$), according to the roaring deer (ordered by increasing age). Values are LSMEANS \pm SEM.

amplitude in order to compensate the effect of distance, are reported in Figure 4. All the roars emitted by the same individual are represented, subdivided in frequency intervals.

Results from the variance analysis: habitat

The analysis of variance showed an influence of environmental effects on the number of calls. The number of calls resulted related to the habitat ($P < 0.01$), to the presence of other males ($P < 0.01$), and to the presence of females as well ($P < 0.05$). Corral male deer vocalised more than those in wild parks, on average 14.3 *vs* 11.9 calls/hour respectively. The presence of other males in the neighbourhood recording positively influenced the number of calls emitted (14.0 *vs* 11.7 calls/hour, when males were present) such as the presence of the females, with 13.7 calls/hour when

females were present *vs* the 12.5 that were emitted when no females were in the surroundings.

Discussion

In our study all the parameters investigated were shown to be strictly related to the age of the caller and varied considerably among subjects as confirmed by the statistical significance of all the variables analysed. Individuality and age of animals have been found to have significant effects on fundamental frequency (F0), peak frequency (PF) and sound length (SL) of roaring, but those effects do not allow the identification of a specific individual due to the overlapping of sound parameters. Other parameters that were use-

ful in describing the individuals were the 24 F-variables, which averaged the distribution of energy in the frequency domain over the total length of the signal, defining the *vocal footprint* of each deer at the moment of the census. These variables (F1-24) have the potential to provide accurate information about the caller, evidence that was already available from past literature results (Fitch and Reby, 2001; Reby and McComb, 2003b). For example, in Figure 4, spectral profiles of the call of a 5-year old and 8-year old stags are shown. It can be easily seen how the two sounds differ from each other, in particular regarding the peak frequency (PF). The information provided by the 24 F-variables and the peak frequency (Table 3) could help to identify individuals, since no significant difference ($P < 0.001$) occurs within the acoustic parameters of roars of each stag. Nevertheless, as shown in Figure 1, correlations of the 24 F-variables can be significant ($r > 0.90$) for animals with similar age. This implies that each individual emits roars with specific features, but also that different animals could emit roars with similar characteristics in terms of frequency variables. The results are in line with those achieved in a previous study (Bocci *et al.*, 2013), in which frequency variables allowed a 72% individual discrimination.

Acoustic signals were already investigated (Bradbury and Vehrencamp, 1998; Pépin *et al.*, 2001; Wyman *et al.*, 2008), showing that they encode and transmit a variety of biologically significant information such as age, size, physical condition, competitive ability, and mating success.

Nevertheless, the effect of the age is relevant on the acoustic parameters typical of each sound (Figure 1). Therefore, the roars emitted as the stags' age increases will be characterized by lower fundamental frequency, lower peak frequency and longer duration sounds. For these reasons, acoustic census alone cannot be used to follow individual stags year by year. As a consequence, this approach can be adopted to describe the age distribution of the roaring stags and to support the wildlife management through the development of information technology systems able to record and process audio data.

Regarding the number of sounds emitted, the influence of type of habitat and social context resulted in significant effects. The number of roars varied according to the habitat (more in the corral than in wildparks) and to the presence of males or females (more when deer of either sex were present). This analysis is however inadequate to deeply understand how the environmental conditions influence

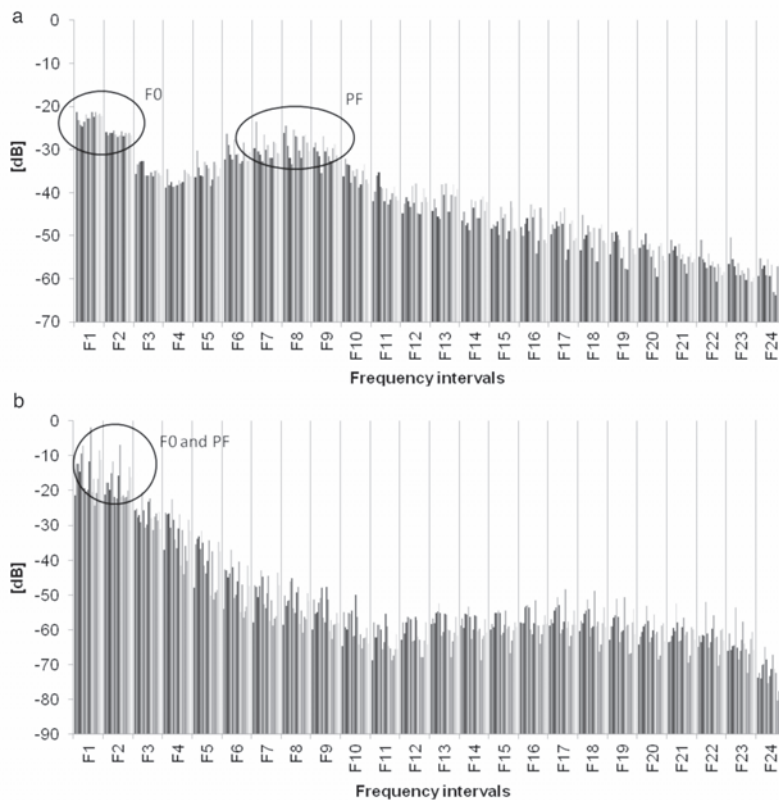


Figure 4. Examples of acoustic profiles of: a) five-year old stag, and b) eight-year old stag, normalized for amplitude in order to compensate the effect of distance. All the roars emitted by the same individual are represented, subdivided in frequency intervals. It can be observed how the same animal emitted similar sounds, while sounds could vary among individuals, especially if the age was different. F0, fundamental frequency, PF, peak frequency.

the number of roars, since more detailed information is required (*e.g.* proximity of other males and/or females, duration of the contact, numbers involved, *etc.*). The gathering of these data was outside of the scope of the present work. Nevertheless, even if this analysis is primarily qualitative, it shows how a census method based only on the roaring count could be misrepresentative. A similar conclusion was reported also by Douhard *et al.* (2013).

Conclusions

The present study aimed to identify a simple approach to support the traditional visual census methods for red deer stags through the analysis of their vocalizations. The roaring frequency variables appear to be indicators of the individuality of male deer, even if the strong influence of age on the emitted sounds compromises the reliability of the method over long periods of time. Indeed, each individual emits roars with specific features, but it can also be observed that different animals can emit roars with similar characteristics in terms of frequency variables.

Nevertheless, the study of the frequency spectrum of the male deer roaring could be useful to support the wildlife management through the development of information technology systems able to record and process audio data to monitor the structure of populations. Of course, the methodology should be further investigated to identify the proper parameters, in combination with other traditional approaches to distinguish and monitor males in a deer population.

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