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Non-invasive acoustic detection of wolves

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ABSTRACT

Monitoring wolves (*Canis lupus*) is a difficult and often expensive task due to high mobility, pack dynamic, shyness and nocturnal activity of this species. Wolves communicate acoustically through howling, within pack and with packs of the neighbourhood. A wolf howl is a low-frequency vocalization that can be transmitted over long distances and thus it can be used for monitoring. Elicited howling survey is a current method to monitor wolves in different areas all over the world. Elicited howling, however, may be invasive to residential wolf packs and could create possible negative reactions from the human population. Here we show that it is possible to detect wolves by recording spontaneous howling events. We measured the sound pressure level of wolf howls by captive individuals and we further found that elicited howling may be recorded and clearly identified up to a distance of 3 km. We finally conducted a non-invasive acoustic detection of wolves in a free-ranging population. The use of passive sound recorders may provide a powerful non-invasive tool for future wolf monitoring and could help to establish sustainable management plans for this species.

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Introduction

Wolves (*Canis lupus*) have been nearly exterminated in central and western Europe during last century (Breitenmosen 1998). During the last two decades an increase of wolf populations in Europe has been observed (Trouwborst 2010; Kaczensky et al. 2012; Chapron et al. 2014). Wolves can recolonize historic areas, or colonize new areas and thus effective tools for monitoring wolf populations are needed. Wolf surveying is a difficult and often expensive task due to high mobility, pack dynamic (changes in pack composition over time), shyness and nocturnal activity of this species (Blanco and Cortés 2012). Employing electronic devices such as camera traps and sound recorders can reduce extensive nocturnal field work and thus costs of monitoring. The use of camera traps is a relatively cheap and widespread method for animal surveys (O'Connell et al. 2001; Burton et al. 2015). Camera

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traps may be placed on strategic sites such as trails or rendezvous places. However, they only cover a limited range and in large and inaccessible areas this technique may not always provide satisfactory information about wolf presence (Blanco and Cortés 2012). Wolves may also actively avoid camera traps because of the camera's sound, light or odour emissions (Rieche 2014; Meek et al. 2014).

Wolves use howls to advertise territory ownership (Joslin 1967; Harrington and Mech 1979) and for intra-pack communication (Joslin 1967; Theberge and Falls 1967; Harrington and Asa 2003). Howling activity has been found to be more intense during summer, when packs occupy restricted areas (home-site) (Mech 1970; Gazzola et al. 2002; Nowak et al. 2007). Wolves have been reported to emit howls both when patrolling territorial boundaries and inside their territory (Zimen 1971; Nowak et al. 2007). The howl is a low-frequency vocalization that, depending on local topography and wind conditions, can be transmitted over long distances (Joslin 1967; Henshaw and Stephenson 1974; Harrington and Mech 1978a), allowing wolf detection over wide areas.

The elicited howling survey is a common method to monitor wolves in different areas all over the world (Harrington and Mech 1982; Gazzola et al. 2002; Nowak et al. 2007; Palacios 2015; Passilongo et al. 2015). This approach consists in the acoustic stimulation produced through human-simulated wolf howls or playback of actual wolf howls, at different vantage points generally during the night (Harrington and Mech 1982). Wolves may then respond to the howling stimulus and therefore wolf presence can be confirmed (Harrington and Mech 1982). So called "howlboxes", self-contained devices that broadcast a simulated wolf howl and record howls made in response, have been previously tested, showing different results on the effectiveness of automated recording of howls (Ausband et al. 2011; Brennan et al. 2013). Elicited howling, however, may be invasive to residential wolf packs (Brennan et al. 2013; Anhalt et al. 2014) and could create possible negative reactions from the human population. Furthermore, wolves do not always vocally respond to an acoustic stimulus (Harrington and Mech 1982; Brennan et al. 2013). They react to the howling of unfamiliar individuals in different ways, from retreating silently to remaining and replying vocally or approaching (Harrington and Mech 1979). The reaction may also depend on their resources (e.g. fresh prey), social context (e.g. presence of pups) and on the stimulus (Harrington 1987).

Nowak et al. 2007 documented spontaneous howls in a free-ranging wolf population throughout the year, with highest howling activity between July and October. Spontaneous howls could thus be recorded by a permanently installed device which does not require an observer's presence (Harrington and Mech 1978b; Curless 2007; Nowak et al. 2007). Passive acoustics has been widely used to monitor insects (Roca and Proulx 2016), amphibians (Steelman and Dorcas 2010; Willacy et al. 2015), birds (Furnas and Callas 2014; Zwar et al. 2014; La and Nudds 2016), marine mammals (Zimmer 2011; Thomas and Marques 2012; Sousa-Lima et al. 2013) and different terrestrial mammals (Zeppelzauer et al. 2014; Burns et al. 2015; Heinicke et al. 2015; Zsebők et al. 2015; Kalan et al. 2016).

The aim of this study is to investigate the potential of a non-invasive wolf survey by detecting spontaneous howls with automatic recorders, without broadcast of acoustic stimuli. To determine the active space of the howling, we measured the sound pressure levels of human-simulated and actual wolf howls. We then determined the maximum distance at which a human-simulated wolf howl (as proxy of true wolf howl) can be recorded with an acoustic device. Finally, we tested in the field the possibility to detect wolves through passive recording, in an area with assured wolf presence.

Material & methods

Sound pressure level of wolf howling and maximal recording distance

Measurements were carried out at the Nature Reserve and Wildlife Park Goldau, Switzerland on a pack of European wolves. The observed pack was composed of five individuals (2 males: one and five years old, 3 females: all five years old). The sound pressure levels of elicited howls were measured using testo816 sound lever meter (auto level, 30–130 dBA) (Testo AG, Moenchaltorf, Switzerland). The sound level meter was positioned in the direction of the howling wolves without any topographic obstacles between device and sound source. The distance to the sound source was measured using a Victory PRF Laser Rangefinder (Zeiss, Wetzlar, Germany). Sound pressure level measurements from the different distances were subsequently calculated to a distance of 2 m from the sound source using the formula:

$$Lp2 = Lp1 - 20\log(r2/r1) \tag{1}$$

Recordings took place between 6 pm and 10 pm under good weather conditions (no rain and no or only marginal wind) during the months of July and August 2014.

Measurements for maximal distance detection of howls were conducted in the valley Plasselbschlund in the Swiss Prealpes (see Supplementary material). There was no rain and no or only marginal wind during the recordings. Three flat howls were emitted by one single person and amplified with the help of a traffic cone. The howls were directed to the recorders. The howling series were repeated at eleven different distances from the recorders between 100 and 4650 m (Supplementary material). The sound pressure levels of six howls were measured at a distance of 2 m using testo816 sound level meter (auto level 30–130 dBA) (Testo AG, Moenchaltorf, Switzerland). Howls were recorded using Songmeter SM2+ (Wildlife Acoustics, Inc., USA) (Sample Rate: 4000 Hz, Encoding: 16 bit, Wave format) and a directional microphone; Sennheiser ME67 on K2 connected to Sony recorder PCM-M10 (sample rate: 22,050 Hz; encoding: 16 bit; Wave format).

Acoustic detection of wolves in a free-ranging population

The study was carried out in the province of Arezzo (northeastern Tuscany, Italy). The area is mainly covered by forests of deciduous trees. The altitude ranges between 300 and 1,654 m above sea level. The spatial distribution and reproductive success of wolves have been monitored in the area since early 1990s (Mattioli et al. 1995; Apollonio et al. 2004; Scandura et al. 2011; Apollonio et al. 2013).

We conducted passive acoustic monitoring between August 24th and September 22nd (30 nights). We used 6 SM3 Songmeters (Wildlife Acoustics, Inc, USA) to record wolf howls. These devices are weatherproof sound recorders equipped with two omnidirectional microphones. The recorders were placed within an area where wolf presence had been detected previously during the regional wolf-monitoring program (Gazzola et al. 2002; Passilongo et al. 2015). The recording sites were chosen according to the following criteria: (a) maximum cover area, avoiding major topographic obstacles which could distort sound perception; (b) near a road or a track accessible by car; (c) on the most elevated accessible position (Figure 1). Recorders were fixed on trees at a height of 2.5 m from the ground. According to the results of the preliminary test on the propagation distances, recorders were positioned in a “conservative” design at a mean between-device distance of 1398 m (±SD 175 m)

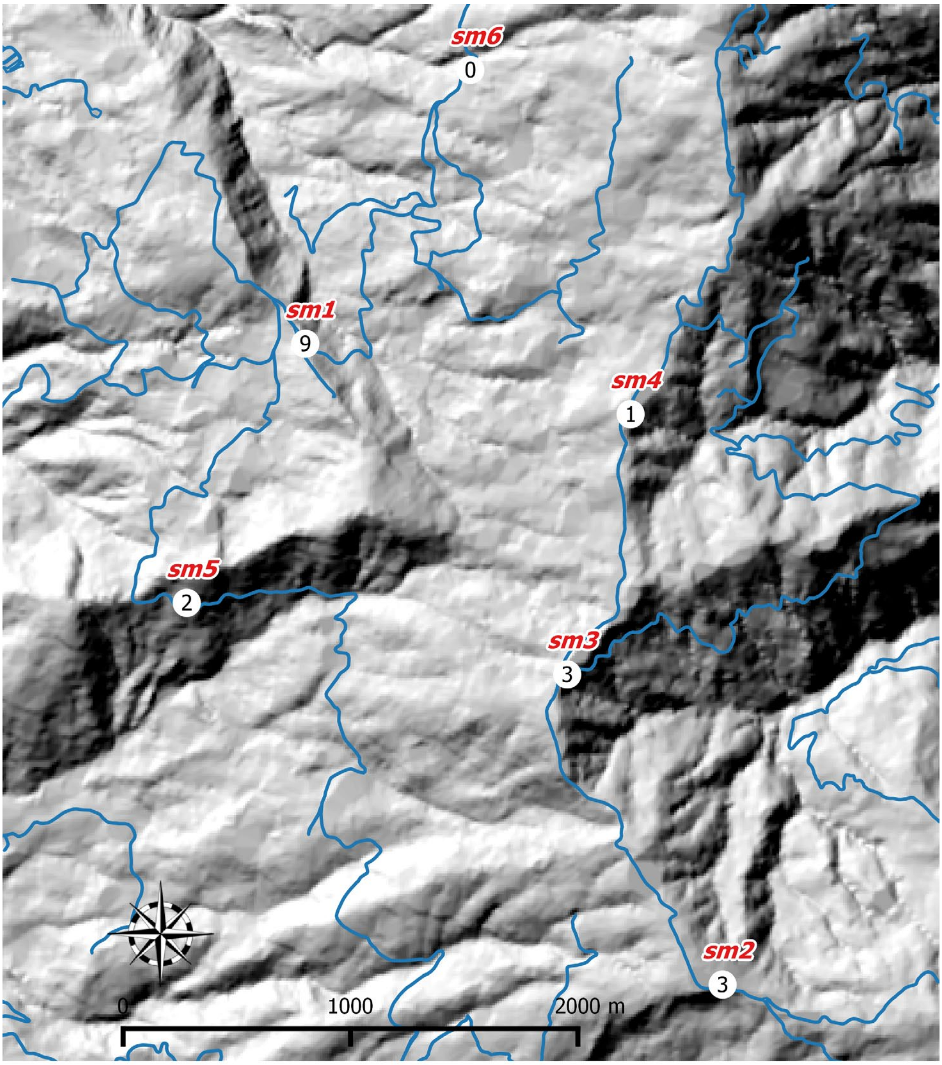

Figure 1. Map with the distribution of the songmeters (sm) in the field. Numbers in the white circles indicate wolf recordings during the 30 nights of monitoring.
Note: The blue lines indicate the roads in the study area.

(Figure 1). The devices were programmed to record every night for 11 consecutive hours (7 pm–6 am solar time). Recordings were saved in WAV format and both microphones were set to amplify the sound each 12 dB (sample rate: 8,000 Hz; encoding 16Bit).

To identify wolf howls, each audio recording was visually scanned using the software Raven Pro 1.5 (Hanning window, 2048 DFT samples, 3.91 Hz frequency grid spacing, 5.75 Hz bandwidth) (Bioacoustics Research Program 2014). All recordings were scanned by one author (M.G.) and verified by a second author (D.P.). Detected howls were classified as "single howl" (one howling individual) or "choral howl" (two or more howling individuals). The time of emission, duration, time difference (minutes) from sunset and midnight, minimum and maximum frequencies were calculated. For the choral howl, the minimum number of howling individuals was determined following the methodology highlighted in Passilongo et al. (2015), thus counting contemporaneous howls in the spectrogram. In two cases, the same howling sequence was identified on two or more songmeters. We measured the descriptive variables only on the recording where the howl showed the highest frequency, which is expected to be the one that had been recorded from the closest distance (Wiley and Richards 1978).

A Kruskal–Wallis test was performed to investigate differences among songmeters in the hourly distribution, duration and in the minimum and maximum frequency of howls. Tukey's means comparison test was performed to investigate the hourly distribution of howls in relation to geographical location of songmeters. To avoid biased results we performed all among-songmeters comparisons only using single howls, since not all songmeters recorded choral howls. Statistical analyses were performed in JMP 11 (SAS Institute 1989–2007).

Results

Sound pressure level of wolf howling and maximal recording distance

The fundamental frequency of the wolf howls in the Wildlife Park ranged between 300 and 400 Hz. Captive wolves howled with a mean sound pressure level of 107.8 dBA at 2 m distance (Table 1). The mean sound pressure level of human-simulated howls at 2 m distance was 89.9 dBA ($N = 6$). The fundamental frequencies of the human-simulated howls ranged between 240 and 540 Hz, in a similar range compared to original captive wolf howls found in this study 300–400 Hz and also similar to flat howls in free-ranging wolves (Passilongo et al. 2010). Three harmonics of the howls were clearly visible on the spectrogram at a recording distance of 3,060 m (Supplementary material). Traces of the howls were still visible on the spectrogram at a recording distance of 4,620 m (Supplementary material).

Acoustic detection of wolves in a free-ranging population

We recorded a total of 18 spontaneous howls (15 single howls, 3 choral howls), with a daily rate of 0.6 howls. We successfully recorded at least one howl in 33% of the considered nights. Five out of six songmeters were able to record at least one howl (Table 2). Choral howls were recorded on four songmeters. In these chorus, a mean number of 2.33 ± (SE) 0.33 individuals was detected.

The majority of the howls (55.6%) occurred between 19 and 23 pm. The peak of howling activity (33.3%) was observed between 20 and 21 pm (Figure 2). A second peak of activity

Table 1. Captive wolves' sound pressure level measured at different distances and sound pressure level calculated for 2 m distance using formula $Lp2 = Lp1 - 20 \log (r2/r1)$.

Sample ID	Distance (m)	Sound pressure level (dBA)	Sound pressure at 2 m level (dBA)
1	25	89.3	111.2
2	25	87.5	109.4
3	22	84.7	105.5
4	37	84.0	109.3
5	35	81.3	106.1
6	28	78.3	101.1
7	35	79.2	104.0
Mean			107.8

Table 2. Number of single and choral howls recorded on each songmeter.

ID songmeter	Single howls	Choral howls
sm1	8	1
sm2	2	1 (1)
sm3	3	1 (1)
sm4	0	1 (1)
sm5	2	0
sm6	0	0

Note: Numbers in brackets indicate howls that have been recorded on at least one other songmeter.

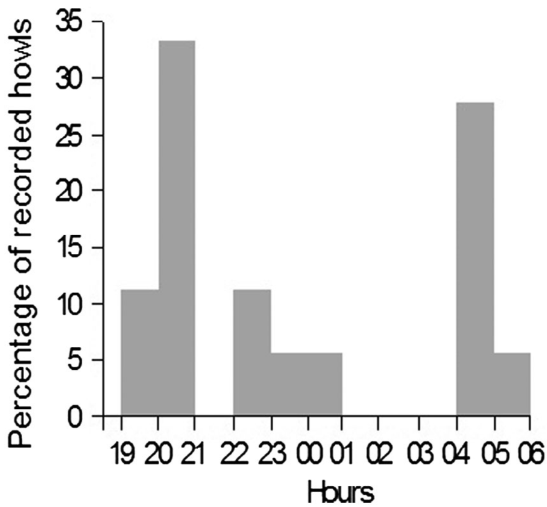

Figure 2. Hourly distribution of recorded spontaneous howls ($N = 18$).

occurred between 4 and 5 am (27.8%; Figure 2). The hourly distribution of howls significantly differed among songmeters ($X = 11.636$, df = 3, $p = 0.020$; Figure 3). The howls recorded by the songmeter located at one of the northern position (sm1; Figure 3) occurred earlier in the morning, compared to those of other songmeters (sm2, sm3, sm5) ($p < 0.05$, Tukey's means comparison test). Single howls on songmeter sm1 occurred significantly further from midnight than howls on other songmeters (sm2, sm5; $p < 0.05$, Tukey's means comparison test) ($X = 8.346$, df = 3, $p = 0.039$).

Single howls had a mean duration of 2.41 ± (SE) 0.35 s, while choral howls had a mean duration of 24.33 ± (SE) 7.84 s. Duration of single howls differed significantly among songmeters (X = 8.166, df = 3, $p = 0.043$).

Howl fundamental frequency ranged between 287 and 1208 Hz (mean frequency 609.18 ± (SE) 44.82 Hz). For single howls, fundamental frequency ranged between 354 and 925 Hz, while for choral howls between 287 and 1208 Hz. No differences among songmeters in the minimum and maximum frequency of howls were detected (min: $X = 6.525$, df = 3, $p = 0.163$; max: $X = 6.138$, df = 3, $p = 0.189$).

Discussion

This study shows that it is possible to record simulated wolf howls at an adequate quality on distances as far as 3 km from the source. Joslin (1967) was able to hear captive wolves at a

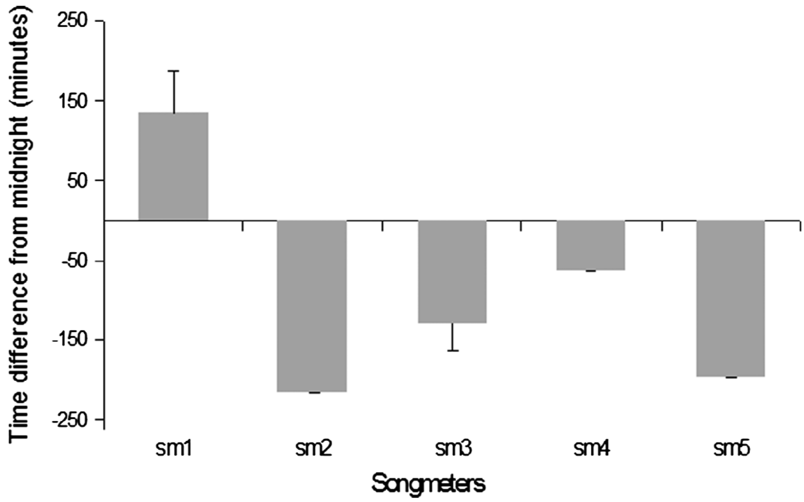

Figure 3. Time difference (in minutes) between howl occurrence and midnight for each songmeter ($N = 18$). Mean and SE are shown.

distance of 6 km. Harrington and Mech (1978a) report distances up to 10 km and Henshaw and Stephenson (1974) report a maximum distance of 16 km. However, the mean distances at which a wolf howl could be heard by humans in habitats covered with forest were 3.2 km (Harrington and Mech 1982) and 1–2 km, respectively (Nowak et al. 2007). Our measurements showed that the sound pressure levels of our imitated howls were lower compared to the howls of captive wolves; thus it is possible that wolf howling can be recorded at even greater distances. With a radius of 3 km for one recorder it is therefore theoretically possible to cover a circular area of about 28 km^2. Snow, Vegetation and landscape relief such as mountain ranges and hills as well as sound sources such as wind, rivers, and anthropogenic noise may reduce the detectability of howl events (Forrest 1994; Halfwerk et al. 2011; Maciej et al. 2011; Morrill et al. 2013). In our simulation test it was not possible to detect the howls on the spectrogram at a recording distance of 2 km because the sound source was behind a small range. Thus optimal placement is important with regard to maximal cover. However, there might be a trade-off between maximal cover and wind expose on the range of a mountain where wind could disturb the recording.

In a systematic study on spontaneous wolf howling Nowak et al. (2007) followed radio-collared wolves in Poland. They recorded spontaneous howls around the year and noticed highest howling activity between July and October (Nowak et al. 2007). Our test on free-ranging wolves in Italy in August and September shows that it is possible to detect wolf presence using a passive automated recording system. Wolf presence has been reported in this area already for many years (Capitani et al. 2006; Davis et al. 2012). In the year of this study, wolf presence has been confirmed with camera traps and scat collection about 2 months before the study took place. In our "conservative" design we have used about one songmeter per 3 km^2. Our results show that in certain cases the same howl was recorded by more than one device, suggesting that the distance between songmeters could be enlarged to cover a bigger area.

In accordance with previous studies on captive and free-ranging wolf packs, maximum howling activity has been observed during the first hours after sunset with a second peak in the early morning (Rutter and Pimlott 1968; Zimen 1971; Harrington and Mech 1978b; Nietlispach 2014). Nowak et al. (2007) reported a maximum howling activity during the 4 h before midnight. Recording time and thus battery life as well as time for data analysis can be reduced when concentrating on the time windows where howling events are most likely to occur. In the present study this was during the 4 h after sunset and the 2 h before civil light in the morning. We visually scanned all the recorded material. This visual inspection requires about 35 min for an 11-h recording, thus 18.8 times faster than by listening in real-time. In future, the implementation of an automated recognition system for wolf howls could further speed up data analysis and reduce costs. Moreover, the calibration of specific settings could trigger the device to record only when sounds in a specified frequency range are detected, reducing energy consumption and labour-intensity on the analysis (Curless 2007; Zeppelzauer et al. 2014).

The majority of our recordings consist of howls emitted by single individuals. It is possible that spontaneous howling is important in aggregating packs by promoting the gathering of members (Theberge and Falls 1967; Nowak et al. 2007; Mazzini et al. 2013). Beside single howls, also choral howls have been recorded in the study area. Choral howls indicate not only wolf presence; they also provide information about the minimal number of wolves (Passilongo et al. 2015) and pack identity (Zaccaroni et al. 2012). Spontaneous howls (range: 287–1208 Hz) are consistent in frequencies with simulated howls (193–1356 Hz, Passilongo et al. 2010); however, further investigations are needed to compare spontaneous and simulated vocalizations and to discriminate between adult and younger wolf vocalizations. Passive automated recordings might reveal recent reproduction within the pack, as young wolves (<6 months) perform different howling, in structures and frequencies, than adults (Harrington 1986; Nikolskii et al. 1986; Palacios 2015). It might be even possible to identify individuals upon their vocal fingerprint (Tooze et al. 1990; Root-Gutteridge et al. 2014). Further potential lies also in the spatial information, as for example in triangulation studies where the exact position of sound emission could be revealed (Blumstein et al. 2011; Mennill et al. 2012).

Wolf howl tracking is commonly carried out by direct howl stimulation and subsequent recording of wolf response by a group of operators. Automated broadcasting/recording systems have been developed to reduce labour costs and night work associated with acoustic surveys (Ausband et al. 2011). However, these devices seem to be efficient only when wolves are extremely close to the recording system (Ausband et al. 2011; Brennan et al. 2013). Moreover, whether these stimulations influence wolf spatial behaviour is subject of actual discussion (Anhalt et al. 2014; Brennan et al. 2013). Further may howl stimulation lead to negative reactions in local human population, especially in area where predators have been absent for a long time. In areas with high density of human occupancy there are also domestic dogs. Although further studies are needed to investigate the differences between domestic dog and wolf howls, dog localizations are generally well known (houses, farms, kennels), and misinterpretation of results could be avoided with this information.

The use of passive field recorders and the development of optimized field designs for recording as well as enhanced data analysis may provide a powerful non-invasive tool for future wolf monitoring and thus help to establish sustainable management plans for this species and other canids with similar vocal behaviour.

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Disclosure statement

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