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The effect of anthropogenic noise and weather conditions on male calls in the bladder grasshopper *Bullacris unicolor*

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ABSTRACT

Acoustic communication in animals relies upon specific contexts and environments for effective signal transmission. Increasing anthropogenic noise pollution and different weather conditions can disrupt acoustic communication. In this study, we investigated call parameter differences in the bladder grasshopper *Bullacris unicolor* inhabiting two sites in close proximity to each other that differed in their noise levels. Calling activity was monitored via passive acoustic recorders. Weather conditions, including wind speed, temperature and humidity, were also recorded. We found that the interval between successive calls increased with higher noise levels at both sites, and the peak frequency became lower. The total number of calls detected also decreased with anthropogenic noise, but this relationship was only evident at the noisier site. In addition, grasshoppers shifted the timing of their calls to later in the night at the noisier site, possibly to take advantage of relatively lower noise levels. We also found that weather conditions, particularly temperature, had a significant influence on call parameters. Further studies are thus needed to disentangle the effects of anthropogenic noise and environmental variables on calling activity in this species. Our results lend support to the growing concern regarding the effects of noise pollution on animal acoustic signalling systems and also highlight the complexity of factors which affect sound signalling in natural environments.

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Introduction

Increases in anthropogenic noise as a result of urban development and transportation networks affect acoustic communication in animal species in their natural habitats (Slabbekoorn and Peet 2003; Ey and Fischer 2009; Halfwerk et al. 2011; Parks et al. 2011; Rosa and Koper 2018). Anthropogenic noises are very different compared to the sounds emitted from biotic and abiotic sources (Hildebrand 2009) and have the potential to degrade and mask acoustic signals, and thus, affect intraspecific acoustic communication of many different species (Barber et al. 2010; Halfwerk et al. 2011).

Rapidly burgeoning research has identified various impacts of anthropogenic noise on acoustic communication signals. To date, however, these studies have mostly focused on the effect of noise on amphibians and birds (Parris et al. 2009; Cunningham and Fahrig 2010). Studies on anurans have demonstrated that frogs may call at times when ambient

noise is lower, and stop calling when it increases, whereas some species call more frequently under noisy conditions (Sun and Narins 2005). Furthermore, frogs exposed to traffic noise may alter the pitch of their calls, the length of calling periods or the timing of their signals (Parris et al. 2009; Kaiser et al. 2011). Birds inhabiting urban areas also shift their songs to higher frequencies compared to conspecifics from rural habitats (Dowling et al. 2012).

Insects produce sounds or vibrations for a variety of reasons: for example, aggression, mate location, attraction and courtship, predator avoidance, and social communication (Owings and Morton 1998; Morley et al. 2014). Increased urbanisation gives rise to noisy environments that can have detrimental effects on insect communication through acoustic masking of signals. For instance, female response rate to male courtship songs in *Drosophila montana* has decreased in the presence of background noise (Samarra et al. 2009). Einhaupl et al. (2011) found that females were more attracted by the courtship songs of male grasshoppers, *Chorthippus biguttulus*, which were more robust against broadband white noise. This process of masking interference of acoustic signals could negatively affect insect populations by reducing reproductive success, decreasing the chances of mating, or increasing predation risk (Kaiser and Hammers 2009; Vargas-Salinas and Amézquita 2013). Hence, the effectiveness of insect communication and ultimately breeding success depend on the recognition of signals against background noise. Thus, interference of road traffic noise has developed as a field of interest and concern in many taxa, including insects (Morley et al. 2014).

Despite their central role in food webs and fulfilling ecosystem services, surprisingly little research has been conducted on the effects of anthropogenic noise on invertebrates. However, these studies have shown that traffic noise can have a significant effect on call composition and calling behaviour (Morley et al. 2014). For example, grasshoppers from roadside habitats produce significantly higher frequency songs compared to conspecifics from quiet habitats (Lampe et al. 2012). Cicadas may likewise shift the energy distribution of calling songs to higher frequencies in the presence of higher noise levels (Shieh et al. 2012). In contrast, a study on tree crickets revealed that males do not alter the fundamental frequency of their songs in response to traffic noise, but rather reduce their calling effort, with shorter calls and more frequent pauses (Orci et al. 2016). While the exact mechanisms by which insects are able to modify frequency components of their call in response to noisy environments are unclear, developmental plasticity has been shown to be one such mechanism (Lampe et al. 2014). However, other mechanisms, such as natural selection, are also likely to occur.

In addition to anthropogenic noise, natural abiotic and biotic sound sources, such as wind, rain and the choruses of other animals, can also make the environment noisy. Animals that communicate acoustically may counteract masking interference by means of evolutionary adaptations or behavioural adjustments (Brumm and Slabbekoorn 2005). Populations may change communication traits in the long term, and senders may modify call intensity, rate, duration and frequency in the short term (see Vargas-Salinas and Amézquita 2013). For example, the cricket *Paroecanthus podagrosus* modifies its auditory tuning to conspecific songs in noisy rainforests with high levels of acoustic competition (Schmidt et al. 2011). Similarly, the Australian bush cricket (*Sciarasaga quadrata*) tunes in to lower frequencies of singing conspecific males to filter out noise generated by hetero-specifics (Römer and Bailey 1998). In insect assemblages, cricket and katydid species also

have calls with a reduced spectral overlap in the frequency domain, thus further avoiding masking (Schmidt et al. 2013; Jain et al. 2014). Several bird species have been shown to time their calls to avoid overlap with biotic and abiotic noise (Brumm 2006; Stanley et al. 2016; Wilson et al. 2016), while tawny owls (*Strix aluco*) reduce calling effort in rainy weather (Lengagne and Slater 2002).

Environmental factors, such as temperature, wind speed and moisture, may impact acoustically signalling animals in various ways, and should thus be additionally considered in field studies. Both the acoustic features of calling songs (Castellano et al. 2002) and calling activity (Oseen and Wassersug 2002; Franklin et al. 2009; Ospina et al. 2013) may be influenced by environmental conditions. For example, temperature is known to correlate with several song elements in crickets, including peak frequency and temporal aspects (Walker 1962; Martin et al. 2000). Moreover, in addition to environmental influences on patterns of acoustic signal differences (Goutte et al. 2018; Velásquez et al. 2018), the environment may also influence population dynamics (Combes et al. 2018). For example, annual temperature and rainfall fluctuations have been shown to affect breeding success in the agile frog (Combes et al. 2018).

In bladder grasshoppers, acoustic communication plays a major role in mate location (van Staaden and Römer 1997; Römer and Bailey 1998; van Staaden et al. 2003; Couldridge and van Staaden 2004, 2006). To attract females, males produce a loud advertisement call by rubbing a line of ridges on their hind-femur against a crescent-shaped ridge on the side of the inflated abdominal bladder, functioning as an acoustic resonator. A female responds to male calls with short, low-frequency acoustic signals and this response depends upon the attractiveness of call characteristics (Couldridge and van Staaden 2006). Males orient and fly to receptive females to mate with them. The advertisement calls of males possess species specificity, with variation in both temporal and frequency properties both between and within species (Couldridge and van Staaden 2004; Sathyan et al. 2017). A previous study found some association between habitat and signal characteristics in bladder grasshoppers (Couldridge and van Staaden 2004). Hence, the effect of weather conditions and noise on bladder grasshoppers that rely on acoustic communication need to be better studied to understand their impact on acoustic behaviour and ecology.

This study uses acoustic monitoring to describe the call characteristics of the bladder grasshopper *Bullacris unicolor* at two nearby sites that differ in their levels of road noise, and to evaluate the effects of road noise, as well as natural abiotic factors, on the call characteristics and calling activity of this species. Very few studies have examined the effects of traffic noise on the call composition and behaviour of invertebrates (reviewed by Morley et al. 2014), and more studies conducted on a wider variety of species are thus urgently needed.

Materials and methods

Study area

Two nature reserves that differ in their levels of background noise were selected as study sites. These sites were chosen due to their proximity to each other and the confirmed presence of the study species at both locations. The two reserves were the 30 ha Cape Flats Nature Reserve (CFNR) (33.9333°S, 18.6277°E), situated adjacent to a major road and

a railway line, and the 388 ha Tygerberg Nature Reserve (TNR) (33.8775° S, 18.6041° E), a reference site with less noise. Both nature reserves are located in Bellville, in the northern suburbs of Cape Town, approximately 6 km apart. The study was conducted during October and November 2016, at the beginning of summer, coinciding with the peak calling season of *B. unicolor* in this area.

The predominant vegetation in the CFNR is the endangered Cape Flats Dune Strandveld, and in Tygerberg Nature Reserve is the Swartland Shale Renosterveld; both are endemic to the Western Cape. Various species of birds, reptiles, frogs, insects and mammals are found in both reserves. Another bladder grasshopper species, *Physemacris variolosus*, is also present in both nature reserves. Despite their close proximity, the climate differs somewhat between the reserves, as TNR stands on a series of hills (elevation 237 m) with 360 degree views over Cape Town. Most of the TNR is covered by natural vegetation, and it is surrounded by agricultural fields and some residential properties, while a large part of CFNR (elevation 80 m) is surrounded by industrial areas, as well as a university campus and residential houses. Commuter trains and road traffic also produce noise pollution during the day and night in this location (Figure 1).

Data collection and analysis

A passive acoustic recorder (SM3, Wildlife Acoustics), equipped with two omnidirectional weatherproof acoustic microphones (SM3-A1), was installed at each of the two sites. The recorders were programmed to record from sunset to sunrise, over three consecutive weeks at each site, at a 96 kHz sampling rate (68 dB signal-to-noise ratio). Sounds were recorded digitally in 16-bit wave format. While the 3-week sampling period was not concurrent at the two sites, the entire study period fell within the peak time that the grasshoppers were active (pers. obs.), with no significant correlation between calling activity and date ($r = 0.125$; $df = 39$; $p = 0.418$) to suggest a tapering off of calls. Each recorder was placed approximately 2 m above the ground, leaving the two lateral microphones free from any interference. Recorders were moved to new positions (-200 m apart) each week to monitor different male calls and to prevent double sampling. Humidity, temperature and wind speed were continuously logged every 5 min by a weather meter (Kestrel 4000).

The level of anthropogenic noise was calculated based on 30 min sampling intervals between 19:00 and 05:00 hours, resulting in twenty 30-min intervals per night, for 21 nights per site. To quantify the disturbance from the road, we counted all instances of noise generated by passing vehicles for each 30 min period. Counts were done by visual and audio identification of broadband patterns in spectrograms generated in Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, NY).

The advertisement call of *B. unicolor* is a short- and high-intensity call produced by males (Figure 2). We used four call parameters to characterise and compare *B. unicolor* calling behaviour between sites: call duration (length of call from beginning to end of the call, s), peak frequency (frequency at which the call is of greatest intensity, kHz), inter-call interval (duration between two calls from the same individual, s), and call rate (total number of calls per 30-min period). Because of the large number of recordings generated during the study, call duration, call interval and peak frequency were measured from individual calls representing a sub-sample of 45 randomly selected 30-min intervals per

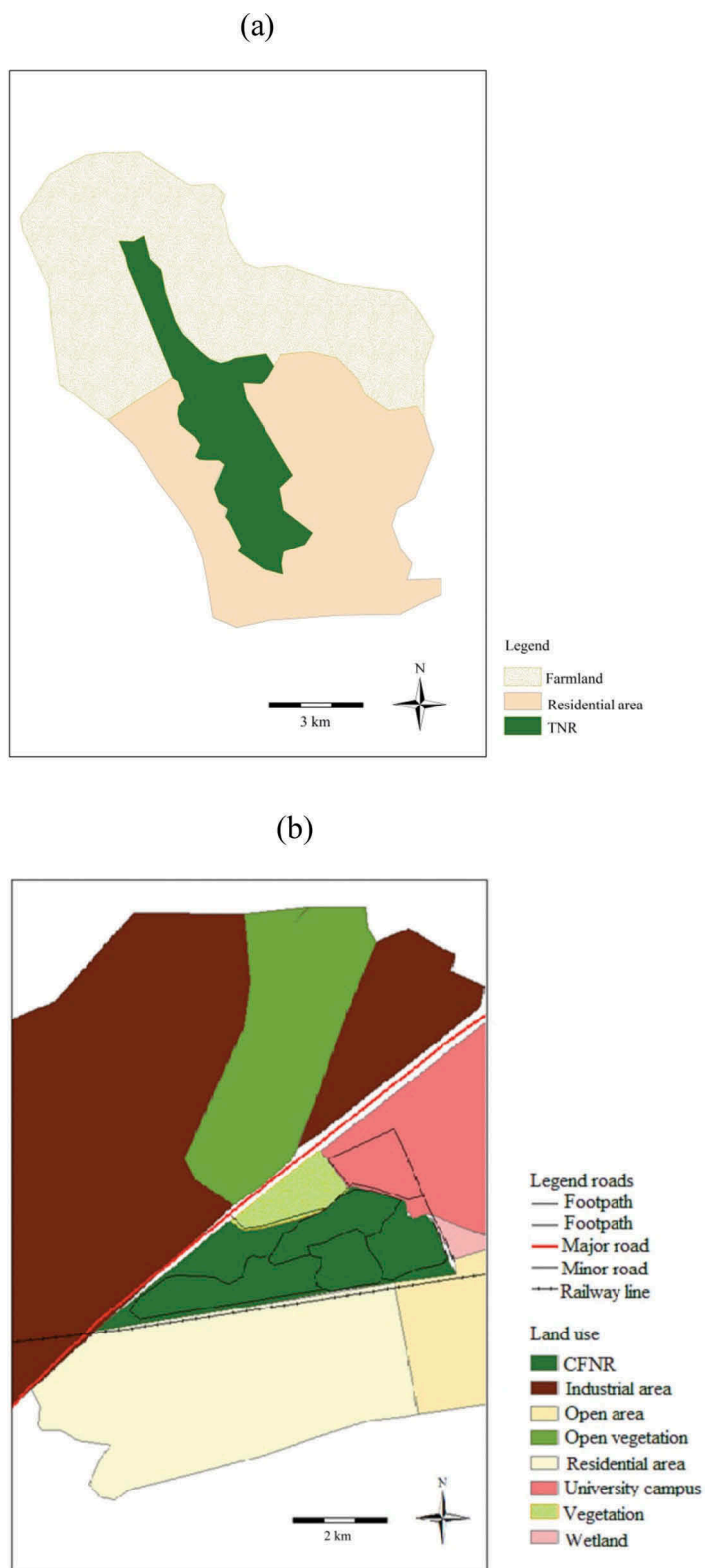


Figure 1. Land cover map of (a) TNR (Tygerberg Nature Reserve) and (b) CFNR (Cape Flats Nature Reserve).

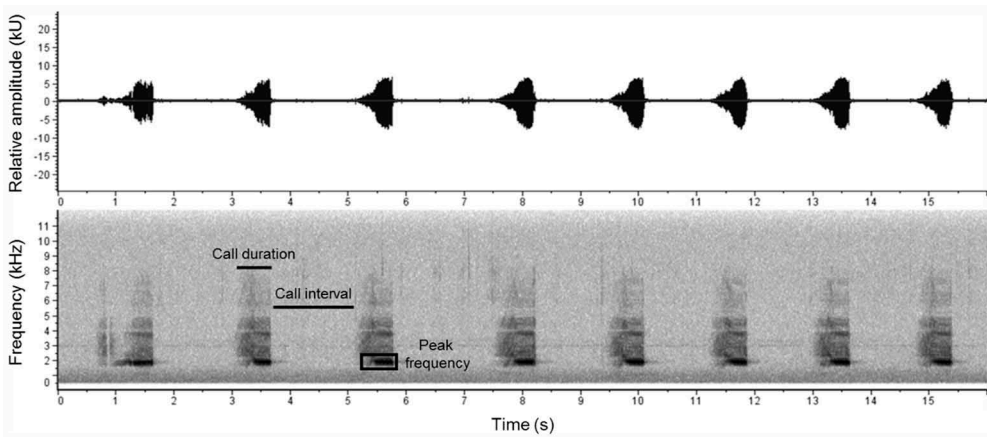


Figure 2. Example of advertisement calls of *Bullacris unicolor* recorded in the field with their respective oscillogram (above) and spectrogram (below).

site, throughout the study period. Values within each of these 30-min periods were averaged for further statistical analyses. In the case of inter-call interval, this was only measured when we could be sure that the same male had produced two consecutive calls (based on spectral properties). Call rate was calculated based on manual counts of the total number of *B. unicolor* calls detected per 30-min interval, using the same intervals as for the anthropogenic noise. All sound analyses were completed using Raven Pro (version 1.5).

Statistical analysis

For each site, anthropogenic noise, weather variables and call rates measured over 21 consecutive nights were averaged to create a time series of 23 half-hourly averages. Matched time interval Wilcoxon signed-rank tests were then used to compare these averaged values between the two sites, as data were found to be non-parametric when testing for normality using Shapiro-Wilk tests. Differences in call parameters between sites were tested with independent samples Mann–Whitney U-tests. We used Spearman correlations to test for relationships between measured call parameters (call duration, call interval and peak frequency) and anthropogenic noise and weather conditions. To test for relationships between call rate and anthropogenic noise and weather conditions, we used partial correlations, controlling for time. All statistical analyses were performed using SPSS 25.0.

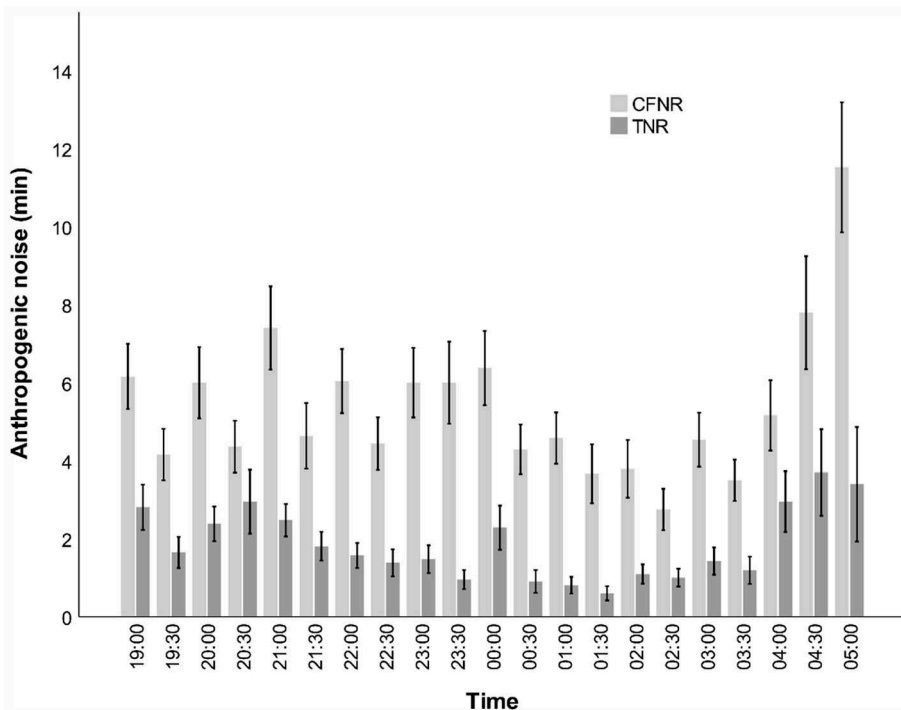
Results

The anthropogenic noise level in the CFNR was significantly greater than in the TNR (Table 1). Noise levels were consistently much higher at the CFNR at all time intervals throughout the night (Figure 3). At both sites, there was a slight dip in traffic noise after midnight, with levels increasing again from around 04h00.

Out of the four measured acoustic parameters, only peak frequency and call interval differed significantly between the two sites (Table 1). Peak frequency was lower, and the

Table 1. Differences in call parameters of *Bullacris unicolor*, weather conditions and anthropogenic noise between the two study sites (CFNR and TNR).

	CFNR Mean \pm SD	TNR Mean \pm SD	N	Standardised test statistic	p
Anthropogenic noise (min/30-min)	6.856 \pm 5.443	1.850 \pm 0.916	23	-4.015	<0.001*
Call parameters					
Call duration (sec)	1.323 \pm 0.440	1.180 \pm 0.518	90	-1.894	0.058
Call interval (sec)	11.817 \pm 6.634	9.019 \pm 5.414	90	-2.187	0.029*
Peak frequency (Hz)	1669.2 \pm 112.1	1782.2 \pm 118.0	90	4.768	<0.001*
Call rate (calls/30 min)	9.877 \pm 12.398	5.865 \pm 8.280	23	-1.459	0.145
Weather					
Temperature ($^{\circ}$ C)	11.902 \pm 1.566	15.317 \pm 0.547	23	4.197	<0.001*
Wind speed (m/sec)	0.509 \pm 0.208	1.562 \pm 0.191	23	4.197	<0.001*
Relative humidity (%)	90.870 \pm 9.620	82.074 \pm 2.020	23	-3.528	<0.001*

* $p < 0.05$ **Figure 3.** Anthropogenic noise levels in the CFNR and TNR measured over a period of 3 weeks in October and November 2016. Data are presented as averages for each 30-min interval during the night (mean \pm SD).

call interval was longer, at the noisier site (CFNR). Call rate was higher at the noisier site, indicating that more grasshoppers occurred there, but this difference was not significant, due to the large variability in call rate. Weather variables also differed significantly between sites, with the TNR experiencing warmer and windier conditions during the recording period, and the CFNR having a higher relative humidity (Table 1).

At both study sites, *Bullacris unicolor* started calling at around 21h00, reached a peak level at around midnight and continued until around 04h30 (Figure 4). However, the

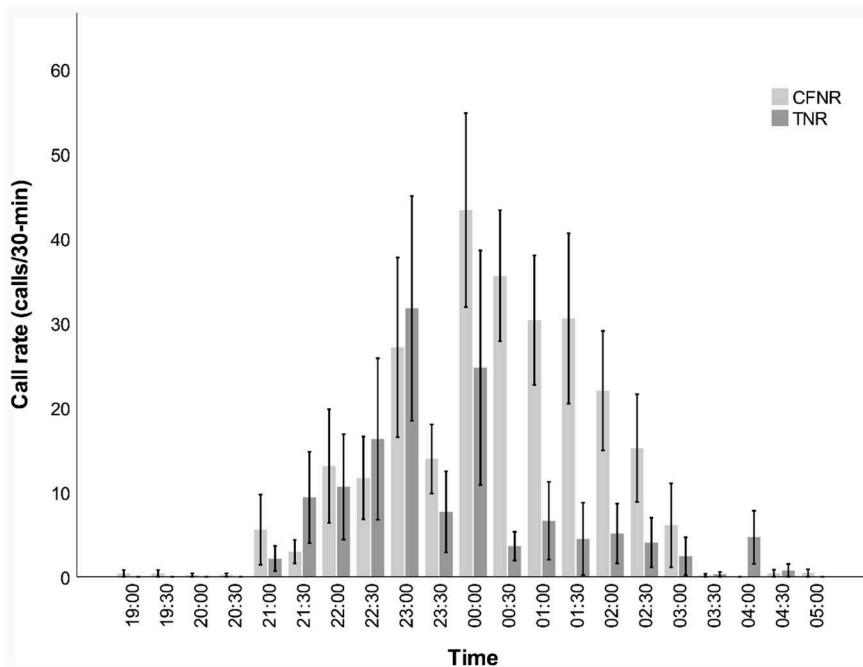


Figure 4. Call rates of *B. unicolor* measured over 30-min intervals. Values are means \pm SD.

pattern of distribution of calling activity during the night differed between the two sites. At the noisier site (CFNR), grasshoppers showed much greater levels of calling activity in the latter half of the night, with the bulk of calling activity occurring in the early hours of the morning. In contrast, at the site with less traffic noise (TNR), the bulk of calling activity occurred in the earlier half of the night and dropped off very sharply after midnight (Figure 4).

Correlations between anthropogenic noise and weather conditions showed that anthropogenic noise was positively correlated with call interval, and negatively correlated with peak frequency, at both sites (Table 2). Call rate was negatively correlated with noise, but only at the noisier site (CFNR) (Table 2). Call duration was not correlated with noise levels at either of the two sites.

There were significant relationships between acoustic parameters and weather conditions. Call duration was negatively correlated with temperature at both sites, and was also negatively correlated with wind speed, but at the CFNR only (Table 2). Call interval decreased with increasing temperature at both sites, and also decreased with wind speed at the TNR. Peak frequency increased with temperature at both sites, and was also correlated with wind speed and relative humidity at the TNR (Table 2). The number of calls detected (call rate) increased with temperature at both sites, decreased with wind speed and humidity at the TNR, and increased with humidity at the CFNR (Table 2).

Discussion

Our results show that as levels of anthropogenic noise increase, *B. unicolor* increases call interval (period between successive calls), decreases call rate, and calls at a lower peak

Table 2. Relationships between anthropogenic noise and weather conditions and the call parameters of *B. unicolor* at two different sites (CFNR and TNR).

	Call parameter	Anthropogenic noise (mins/30-min)	Wind speed (m/sec)	Temperature (°C)	Relative humidity (%)
CFNR	Call duration (sec)	0.056	-0.332*	-0.300*	0.014
	Call interval (sec)	0.380*	0.009	-0.269*	0.065
	Peak frequency (kHz)	-0.340*	0.097	0.557**	-0.086
	Call rate (calls/30-min)	-0.122**	-0.079	0.164**	0.132*
TNR	Call duration (sec)	0.117	-0.253	-0.526**	0.25
	Call interval (sec)	0.357*	-0.391*	-0.462**	0.175
	Peak frequency (kHz)	-0.264*	0.331*	0.647**	-0.438**
	Call rate (calls/30-min)	0.023	-0.131*	0.221**	-0.248**

* Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.

frequency. Thus, while there was a clear difference in noise levels between the two sites, the grasshoppers responded in similar ways to noise exposure.

In order to overcome anthropogenic noise, many animal taxa shift to higher frequencies to avoid signal degradation and masking. Studies on mammals (Duarte et al. 2018), birds (Narango and Rodewald 2018) and anurans (Kruger and Du Preez 2016; Goutte et al. 2018) have indicated frequency adjustments to cope with noise. However, our results differ from the findings of previous studies that showed invertebrates produce higher frequency calls in noisier habitats (Lampe et al. 2012). We found that peak frequency was negatively correlated with noise, indicating that males lowered the frequency of their calls during noisier periods. Furthermore, males from the CFNR (noisy area) produced calls with a significantly lower peak frequency compared to males from the TNR (quieter area) (also see Caorsi et al. 2017).

We found that the interval between calls increased, and the total number of calls decreased, with higher levels of traffic noise level, suggesting that grasshoppers additionally dealt with the potential masking effect of traffic noise by reducing calling effort during periods of high background traffic noise. The adjustment of calling activities to avoid interference from noise sources has been established in various animal taxa (Sun and Narins 2005; Parks et al. 2007; Sousa-Lima and Clark 2008; Slabbekoorn and Ripmeester 2008). This may help to conserve energy, as the production of advertisement calls is one of the most energetically expensive activities, and the cost of calling is substantial, as reported in insects, amphibians and birds (Ryan 2001; Ophir et al. 2010). Our results support this expectation by showing significant changes in call interval and call rate during high anthropogenic noise levels. Male *B. unicolor* from the noisier site (CFNR) also had a significantly longer call interval than males from the quieter site (TNR). However, there was no significant difference in call rate between the two sites. This is likely because call rate is dependent on the number of males active at the site, so even if individual males are spacing their calls more widely, there may still be more individuals active.

Additionally, we found that weather conditions correlate with the call parameters of *B. unicolor*. Thus, it is possible that the observed differences in male calls between the two sites were rather due to differences in environmental variables. Temperature was the environmental variable most strongly related to call parameters, being negatively correlated with call length and call interval, and positively correlated with call rate and peak frequency. These findings are in agreement with previous studies on other insect species, which have found similar relationships with temperature (e.g. Martin et al. 2000). Wind speed was

correlated with call parameters, but none of these relationships were significant at both sites, possibly because the CFNR experienced far less windy conditions than the TNR, making any effects more difficult to detect. Calls became shorter and more closely spaced under windier conditions, whereas peak frequency increased, and call rate decreased. This suggests that fewer males were active when it was windy, but those that were active produced shorter and more frequent calls. This behaviour may help grasshoppers to overcome the signal distortion and uncertain dispersal caused by wind. Humidity was negatively correlated with peak frequency, but only at the TNR, and was also correlated with call rate at both sites. This relationship with call rate may be linked to signal transmission, as differences in humidity can alter the efficiency of sound transmission (Campbell et al. 2010; Snell-Rood 2012).

There was a marked difference between the two sites in the times of night at which *B. unicolor* was most active. At the site with less noise (TNR), we observed much higher calling activity earlier in the night, with calls dropping off sharply after midnight (Figure 4). In contrast, at the noisier site (CFNR), males were less active earlier in the night and called at higher levels from midnight onwards. This activity pattern corresponds to levels of anthropogenic noise (Figure 3), which are lowest during the times when *B. unicolor* is most active, indicating that males at the noisy site are shifting their activity period later in the night to take advantage of relatively quieter conditions.

The biotic soundscape of both study sites was shaped by animal communities that were mainly composed of birds, mammals and insects. At both sites, calls of *Physemacris variolosa* (co-existing bladder grasshopper) were present, but at TNR the call rate of this species was much higher (average: CFNR = 0.14 and TNR = 3.14 calls/min), indicating that the species exists at higher numbers at the TNR. *Physemacris variolosa* calls at a higher peak frequency than *B. unicolor* (average: CFNR = 2.663 kHz and TNR = 2.887; N = 90 calls). These two species of grasshoppers occur in sympatry, thus creating competition in acoustic space (Parris et al. 2009). In bladder grasshoppers, females generally prefer conspecific calls and discriminate against heterospecifics (Couldridge and van Staaden 2006). Therefore, the observed higher peak frequency of *B. unicolor* calls at the TNR may possibly be due to acoustic competition with *P. variolosa*, which also has a relatively higher peak frequency than in the CFNR. Alternatively, both species may be adjusting their carrier frequency in the same direction at each site due to the same external conditions.

Studies on the impact of noise on insect call parameters have so far yielded inconsistent results, with some studies verifying an increase in the peak frequency of calls in noisy environments; however, others indicated a decrease or no change in peak frequency. For example, in the cicada *Cryptotympana takasagona*, males increased the dominant frequency of calls in response to traffic noise (Shieh et al. 2012). They were able to increase the resonant frequency of their calls by decreasing the volume of the abdominal cavity. In this study, we cannot rule out the possibility that factors other than noise and climate are associated with the observed differences (e.g. morphology). It is proposed that small-sized males produce higher frequency calls with smaller abdominal cavities and that large-sized male reduce the volume of the abdominal cavity to produce higher frequency calls in birds (Patricelli and Blickley 2006). While it is possible that the observed variation in calls at the two sites results from differences in body size, preliminary data does not suggest this (mean body length: CFNR = 40.4 mm; TNR = 39.6 mm; Mann-Whitney U = 24; N = 14; p = 1.000). Bladder

grasshoppers have stridulatory files on their abdomen that are rubbed by scrapers on their legs to produce calls (van Staaden and Römer 1997). We consider that alterations to these sound-producing structures, or to the speed of stridulation, could change the peak frequency of calls. Thus, the mechanism by which grasshoppers are able to shift their songs to higher frequencies requires further investigation.

Grasshoppers might also be adjusting the spectral and temporal characteristics of acoustic signals to reduce competition pressure or predation risk. Noise from traffic has been demonstrated to alter predator–prey relationships (Barber et al. 2010). Habitat features, such as vegetation height and background sound level, interfere with the ability of an animal to detect predators (Verdolin 2006). Few studies have documented the increase of vigilance behaviour under high noise levels (Quinn et al. 2006). The major predators in the study areas are birds and bats. It is likely that nocturnal predators (bats) rely heavily on acoustic cues to find their prey. This highlights the potential complexity of the relationship between noise exposure and predation risk. Studies incorporating predator–prey relationships and diel variation in signalling in different parts of the distribution of *B. unicolor* would be valuable.

Spectral and temporal properties of calls are essential in mate localisation and mate selection (Forrest 1994). We observed that *B. unicolor* modified their calling behaviour in response to anthropogenic noise, possibly to help reduce potential masking effects. However, the consequences of these changes to their acoustic signalling remain to be investigated. We found that *B. unicolor* is less likely to call under high noise conditions, and also adjusts the carrier frequency of the call. Since this species is highly dependant on acoustic communication for mate location, reduced calling effort is likely to negatively impact mating success. Changes to call parameters a noisy environment may also influence female mate choice decisions. Further playback experiments thus need to be conducted to investigate the potential effects of signal alterations on mating preferences. In addition, it has been shown in anurans that females decrease in their ability to decode a message from male calls in the presence of acoustic noise (Goutte et al. 2013). Therefore, females may be less likely to respond to male calls.

Our study is based on long-term exposure to traffic noise, and on individuals recorded in their own environment. Thus, we only assessed long-term effects caused by noise and cannot exclude the possibility of additional changes in call parameters, which might occur during short-term exposure. To assess this, controlled experiments are required to measure call parameters before and during exposure to noise. In addition, variable habitat quality imposed by high to low traffic noise with increasing distance from the road may also cause a spatial effect (Caorsi et al. 2017).

This study adds to the growing literature concerning the effects of anthropogenic noise on acoustic signals. It also highlights the interplay between call parameters and environmental variables and noise. Since different species are differently affected by anthropogenic noise, detailed studies and a clear understanding of the behaviour of individual organisms is required to understand the ecological and evolutionary consequences of increasing anthropogenic noise and changing signalling environments.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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