Mining noise affects loud call structures and emission patterns of wild black-fronted titi monkeys

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Short title: Noise affects titi monkeys' loud calls

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Abstract

Human activity has resulted in increased anthropogenic noise on soundscapes. Noise pollution can constrain acoustic communication and prevent effective animal communication. Our aim was to investigate how the black-fronted titi monkey (*Callicebus nigrifrons*) is affected by noise produced by mining activity in a fragment of Atlantic forest in Brazil. We installed two passive acoustic monitoring devices to record 24h/day, 7 days every two months, for a year, one unit close to an opencast mine and the other 2.5km away. Both sites presented similar habitat structures and were inhabited by groups of *C. nigrifrons*. Sound pressure levels measurements were undertaken six times for 20 minutes on different days at both sites. The number of *Callicebus* loud calls was quantified at both sites by analyzing the recorded files. The site close to the mine presented higher noise levels than the one further away. More black-fronted titi loud calls were detected at the far site and many vocalisations (20.32%) from the site close to the mine were masked by noise. Duration of loud calls was longer at the site far from the mine and the diel pattern of vocalisations was different between the two sites. Our results indicate that mining noise can constrain *Callicebus* long distance vocal activity, probably, because their loud calls occupy a similar frequency band of the noise. Given that vocalisations are important regulators of social behavior in primates, consideration should be given to the impact of mining noise on their behavior in impact evaluations and mitigation recommendations.

Keywords: Animal communication, anthropogenic activity, primates, social behavior, sound masking

Introduction

Acoustic communication is essential in the lives of many species as they use such signals to transmit biologically relevant information; for example, to find reproductive partners (Brumm et al. 2009), to escape from predators (Chan et al. 2010) and defend resources (Zuberbuehler et al. 1997). However, the sound produced by human activities (anthropogenic noise) has become a common impact on animal communication systems (Slabbekoorn and Ripmeester 2008; Barber et al. 2009; Laiolo 2010). Noise can interfere with the propagation and detection of signals by masking animal sounds and thus, preventing effective species communication (Foote et al. 2004; Bee and Swanson 2007). Noise pollution can also affect the behaviour of many species. Studies have shown that animals avoid foraging in noisy areas (Schaub et al. 2008), increase their vigilance behaviour in presence of noise (Delaney et al. 1999; Karp and Root 2009), select quiet areas to perform their daily activities (Sousa-Lima and Clark 2009, Duarte et al. 2011) and can be distracted by noise, thereby increasing the risk of predation (Chan et al. 2010). Noise can also cause physiological stress (Campo et al. 2005, Kight and Swaddle 2011) and impact on ecological aspects of animals lives such as population distribution (Reijen et al. 1998; Bejder et al. 2006), species abundance (Bayne et al. 2008) and diversity (Proppe et al. 2013).

Animal survival can be severely impaired by anthropogenic noise and many studies have documented a range of adaptive responses to minimize the immediate impact of noise of communication systems including: changes in frequency (Slabbekoorn and Peet 2003; Parks et al. 2007; Nemeth and Brumm 2009), amplitude (Brumm 2004; Brumm et al. 2009; Hage et al. 2013), calling rate (Sun and Narins 2005) number of notes (Slabbekoorn and Boer-Visser 2006), timing (Fuller et al. 2007) and duration of the calls (Brumm et al. 2004). The direct impact of noise on animal behaviour and ecology, and incidental costs of maintaining an efficient communication system through compensatory mechanisms can impose fitness costs on affected individuals (senders and receivers) and consequently on their survival and reproduction (Chan et al. 2010; Schroeder et al. 2012), and lead to population-level changes.

Beyond the effect of deforestation caused by mining, one less obvious impact on wildlife is the noise produced by such activity. Mining noise, especially if produced at the same frequencies that animals use in their vocalisations can mask important calls and, consequently, greatly reduce the efficiency of animal communication (Bee and Swanson 2007, Alvarez-Berríos and Aide 2015; Duarte et al. 2015) . However, the effects of mining noise on animals have been poorly documented, especially in the

Neotropical region. Smith et al. (2005) showed that diamond mines affect tundra birds by lowering breeding bird densities. In India, stone mining and crushing affected bird species diversity and population density in the areas adjacent to crushers (Saha and Padhy 2011). Thus, studies involving mining noise impact in terrestrial mammals and their communication systems are still lacking, and the noise effects on this group must be better understood, in particular with respect to the primates that use acoustic communication for a variety of vital processes.

Species of titi monkeys (genus *Callicebus*) exchange loud calls (duets) to either defend territories or food resources in their home-ranges; thus, these vocalisations are important regulators of their social behaviour (Robinson 1979, 1981; Kinsey and Robinson 1983; Price and Piedade 2001; Caselli et al. 2014). Primates of the genus *Callicebus* live in monogamous family groups, consisting of a reproductive pair and up to four generations of offspring (Kinzey and Becker 1983; Mendoza and Mason 1986; Valeggia et al. 1999). Titi monkeys are morphologically cryptic primates, which hinders surveying them using traditional methods such as linear transects (Aldrich et al. 2008). Mated pairs of *Callicebus* species regularly emit loud and coordinated calls (duets), which permit researchers to use an alternative and potentially more accurate method to monitor populations based in call surveys (Melo and Mendes 2000; Aldrich et al. 2008). Duetting is commonly used by many bird and primate species for both within and between group communication (Hall 2004; Oliveira and Ades 2004). Studies of *Callicebus* species show that their duets have a role in group location and avoidance of intergroup aggressive encounters (*C. lucifer*, previously *C. torquatus*, Kinzey and Robinson 1983; *C. personatus*, Kinzey and Becker 1983; Price and Piedade 2001), in territory establishment and probably mate defense (*C. ornatus*, previously *C. moloch*, Mason 1968; Robinson 1979, 1981). Black-fronted titi monkeys (*C. nigrifrons*) loud calls are used during intergroup communication to regulate access to important food resources, such as fruits. There is also some evidence that loud calls are used for mate defense (Caselli et al. 2014).

Typically, titi monkeys vocalise mostly at dawn, but also during the day when another group is sighted or heard (Kinzey et al. 1977; Kinzey and Robinson 1983; Melo and Mendes 2000). For *C. nigrifrons* mostly loud calls are emitted more often from their core area or near from important food resources in their home range that usually is around 8 ha in Atlantic forest (Santos 2008, Caselli 2008, Santos 2012). Large areas demand more time and energy to patrol (Schoener 1987), and black-fronted titi monkeys advertise the occupancy of its territory via loud call emissions and do not use patrol and mark range boundaries (Santos 2012; Caselli 2013).

Many of the forests in South America, where titi monkeys live suffer from large scale mining (Estrada 2009). In the state of Minas Gerais, Brazil, mining is an important economic activity and is commonly conducted close to Atlantic forest, one of the world's richest biodiversity hotspots (Myers et al. 2000). The Atlantic forest is one of the most impacted habitats of the world retaining only 7% of its primary vegetation (Myers et al. 2000) and is home to the black-fronted titi monkey (*Callicebus nigrifrons*); an endemic primate classified as Near Threatened on the IUCN's Red List (Veiga et al. 2008).

Black-fronted titi monkey loud calls are characterized by different syllables composed by components of high frequencies that ranges from 3 to 12 kHz and of low frequency that is near to 1 kHz (Caselli et al., 2014). Due to spectral characteristics of titi monkey loud calls such as high amplitude and low frequency, these calls can be heard over long distances (Melo and Mendes 2000; Caselli et al. 2014). Unfortunately, the same acoustic characteristics that were adaptive for long distance communication are now bringing these sounds into competition with mining noise.

In this study, we investigated how the noise produced by one of the largest opencast mines of the world affects acoustic communication of *C. nigrifrons* in an Atlantic forest fragment in Southeast Brazil. Here we tested the following hypotheses: (1) noise levels are different in the sites close and far from the mine; (2) emission rate, duration and diel pattern of titi monkey loud vocalisations would change between the areas due to noise exposure.

Methods

Study area

This study was conducted at Peti environmental station, which is located in an Atlantic forest fragment of approximately 605 hectares. The reserve is located in the upper Rio Doce Basin (altitude range: 630-806m) in the municipalities of São Gonçalo do Rio Abaixo and Santa Bárbara, Minas Gerais state, Brazil (19°53'57''S and 43°22'07''W), one of the most fragmented Atlantic forest regions of Brazil (Machado and Fonseca 2000). Peti environmental station harbors approximately 46 species of mammals (Paglia et al. 2005), 231 species of birds (Faria et al. 2006) and 29 species of anurans (Bertoluci et al. 2009).

A large part of the reserve is covered by secondary arboreal vegetation, and is surrounded by a matrix mainly composed by *Eucalyptus*, small farms and areas of exposed soil due to the activities of the Brucutu mine. Mining activity occupies an area of approximately 8km^2 and produces noise through road traffic, heavy machinery, sirens and explosions during the day and night (Roberto 2010). Brucutu's iron ore extraction started in 1992 and to increase the capacity of iron production, expansion projects started in 2004 placing Brucutu among the largest opencast mines in the world (Roberto 2010).

Data collection

To record black-fronted titi monkey loud calls, two song meters (SM2, Wildlife Acoustics) were installed into the home range of two groups of titi monkeys. One group inhabited a forest fragment close to a mine site and the song meter was installed at a distance of 100m from the closest mining road (Fig.1). Another group inhabited a forest fragment 2,500m far from the mine and the song meter was installed 100m away from a low traffic ('quiet') road (to control for a potential border effect at both sites in the same Atlantic forest fragment). The positions of geographic barriers such as roads and a river that surround close and far sites suggest that the group which inhabit the close site is isolated from the group that inhabit the far site. Both sites were habitat matched; they presented similar floristic compositions and habitat structures.

The passive acoustic monitoring devices were programmed to record 24h/day during seven days every two months from October 2012 to August 2013, in a total of six sessions and 2,016 hours of recordings. Each SM2 was fixed on a tree 1.5m above the ground, leaving the two lateral microphones free from any surface that could be an obstacle to incoming sound waves. They were configured to record in wave format at a sampling rate of 44,100Hz, at 16 bits, and with a 36% microphone gain. Pilot studies had found that this configuration to be optimal for recording the soundscape of the Atlantic forest (Pieretti et al. 2015). The loud calls of titi monkeys can be detected up to 500 m away, with a 'critical distance' of about 250 m (Robinson, 1981).

The sound pressure levels at both sites were characterized by using B&K2270 (Denmark) sound level meter configured on the A curve to conduct six measurements of 20 minutes length in at both sites, from 0600 to 1800 hours on weekdays. This research adhered to the Brazilian legal requirements and to the American Society of Primatologists (ASP) Principles for the Ethical Treatment of Non Human Primates.

Data analyses

To test for a difference in noise levels between the sites close and far from the mine we extracted data from the sound level pressure measurements and analyzed them using BZ 5503 software (Bruel and Kjaer). To avoid bias in the measured levels we excluded all recordings, which included loud animal sounds (i.e., animals close to the microphone).

The rate of emission and the duration of black-fronted titi monkey loud calls were measured in both sites during seven days by session from 0500 to 1700 hours totalizing 1,092 analyzed hours. All sound files used for analyses had to be visually and aurally checked in Raven Pro 1.5, since we try to use the band limited energy detector but this resulted in a large number of false positives and misses. We also manually detected all the loud calls, which were partially masked by anthropogenic noise at the site close to the mine (Fig. 2).

To verify a possible association between the noise produced by mining truck traffic at the site close to the mine (the road of far site was not trafficked by mining trucks) and the occurrence of the loud calls, we quantified all trucks passing from 0500 to 1700 hours at the road in front of the sampling site. This procedure was done by audio and visual identification of the trucks' noise pattern in spectrograms. An FFT size of 1024 points was used for all analyses in Raven Pro 1.5.

We used a nonparametric statistical approach with our data analyses since data did not meet the requirements for parametric statistics even after data transformations. All the statistical analyses were performed in Statistica version.8.0.

Results

Sound pressure (noise) levels were significantly higher at the site close to the mine (Mann-Whitney U-test: U=1, Z=2.72, N=6, $p<0.01$), as expected (Table 1).

Black-fronted titi monkeys emitted more loud calls than expected at the site far from the mine (Chi-squared test: $X^2= 339.96$, df=1, P<0.001, $N_{close}=187$, $N_{far}=752$). A considerable part (20.32%) of the vocalisations found in the site close to the mine was partially masked by noise from mining activity (Fig. 2). Duration of loud calls were also significantly longer at the site far from the mine (Mann-Whitney U test: U= 29142.5, Z= 12.40, $N_{close}=187$, $N_{far}=752$, P<0.01; $Median_{close}=1.77$, $Median_{far}=16.33$). The temporal distribution pattern of the vocalisations was also different between the two sites (Fig. 3). At the site far from the mine, titi monkeys were more vocally active early in the morning (from 0600 to 1000 hours, with peak vocal activity around 0700 hours), while at the site close to the mine they presented a constant but very low activity from 0700 to 1000 hours with peak vocal activity occurring around 1300 hours.

The time period of highest truck passing activity coincided with the time period of the lower number of loud vocalisations at the site close to the mine and the peak of loud calls also occurred when there was a decrease in trucks passing (Fig 4). Despite this, a Spearman rank test showed no significant correlation between the number of trucks and number of vocalisations (r_s = -0.21, t= -0.71, P>0.05).

Discussion

Our results show that the emission rate, duration and diel pattern of loud calls emitted by black-fronted titi monkeys is different between sites close to and far from mining activity. These changes in vocal parameters of titi monkeys calls are similar to those exhibited by some animals to compensate the impact of anthropogenic noise or as a response to avoid noise interference on their communication (Brum et al. 2004; Sun and Narins, 2005; Egnor et al. 2007).

The higher rate of loud calls found at the far site could be explained by several non-exclusive hypotheses, such as: (1) more titi monkey groups are present at the far site; (2) more encounters between titi groups at the far site; (3) titi monkeys from the close site were reducing their emission of calls due to masking caused by mining noise; (4) call emissions masked by noise decreasing detection of vocal activity at the site close to the mine. However, field observations and habitat matching showed that there should be a very similar numbers of groups at both sites. The area monitored by the passive acoustic monitoring devices was the same at both sites. Thus, while there will be some differences between sites, these are unlikely to be the major factors affecting differences in the rate of loud call emissions. In addition, as observed for *C. personatus, and C. torquatus, C. nigrifrons* also do not call more often from their home range boundaries and encounters with neighbouring groups are not frequent (Kinzey et al. 1977; Price and Piedade 2001, Santos 2012, Caselli 2013), since the regularly loud call emissions from core area or from more valuable sites can be more economical strategy. Another noteworthy factor is the longer duration of calls at the far site. This fact supports the third hypothesis: as it demonstrates the probably impact of mining noise on titi monkey's loud vocalisations.

A decrease of animal call rate in presence of noise has already been established in other studies and can be interpreted as a response to avoid interference from anthropogenic noise (Miksis-Olds and Tyack 2009; Sun and Narins 2005; Parks et al. 2007; Sousa-Lima and Clark 2008). This pattern may indicate that animals wait until it is quiet to vocalize, exhibiting only minimal vocalisation effort during periods of masking noise (Miksis-Olds and Tyack 2009; Sousa-Lima and Clark 2008). In this study, at the close site many loud calls (20%) were partially masked by noise, thereby potentially disturbing the exchange of acoustic information and preventing titi monkeys from communicating effectively (Lohr et al. 2003; Foote et al. 2004; Bee and Swanson 2007). One particularly important factor driving vocalisation effort is the range over which the signaller and receiver must effectively communicate (Miksis-Olds and Tyack 2009). In this context, when noise masks the vocalisations there is a decrease in the acoustic space over which the information can reach.

The longer duration of titi monkey loud calls at the far site is further evidence of the noise impact from mining. Research has already documented that some species adjust their vocal behaviour to compensate for anthropogenic noise by increasing or decreasing the duration of the calls. Studies with *Saguinus oedipus* showed a decrease in the average call duration to avoid masking noise (Egnor et al. 2007). However, common marmosets *Callithrix jaccus* increase the duration of their calls in presence of noise and they use higher vocal frequencies (Brumm et al. 2004). Our results, suggest that there is more available acoustic space at the far site, especially in the lower frequencies, which are naturally used by titi monkeys. At the close site, noise from the mine overlap the titi monkeys' loud calls and could be excluding them from an acoustic niche. Thus, they probably are emitting calls with shorter duration to communicate more effectively and/or to save energy since acoustic communication is an energetically expensive behaviour and vocalisation effort is increased by increasing call duration (Miksis-Olds and Tyack 2008).

The difference in the diel pattern of loud calls between the two sites can be also a consequence of the mining noise disturbance on titi monkeys' vocal behaviour. As observed in other primate species such as Indris (Geissmann and Mütschler, 2006) and gibbons (Mitani, 1985), *C. nigrifrons* are vocally active mainly during the first hours of the day (outside encounters) (Melo and Mendes 2000, Caselli 2013). Because of the higher humidity and lower temperatures in the first hours of the morning, these primates concentrate the emission of loud calls in this period of the day, when transmission of sound presumed to be more efficient (Mitani 1985; Wiley and Richards 1978). In our study, this natural pattern was observed only at the far site. At the site close to the mine, animals displayed very low vocal activity in the first hours of the day and peak of activity at 1300 hours. Many mammals affected by anthropogenic noise have limited developmental capacity to change the acoustic parameters of their calls to avoid the masking by noise such as some birds can do (Weiss et al. 2014). On the other hand, mammals may avoid noise with other behavioural modifications, such as vocalizing during periods of low noise (Rabin et al. 2003) or moving to quieter areas (Duarte et al. 2011).

Loud vocalisations are key factors involved in the regulation of titi monkey social behavior (Caselli et al 2014). One consequence of the masking of such calls can be increased territory invasion by neighboring group and consequently increased rates of inter-group agonistic encounters. Such changes could impact on the survival and reproductive success of the affected individuals, and result in disruptions with potential population-level consequences. In addition, studies with birds show that species with lower frequencies calls are more likely to avoid roads than those that emit calls at higher frequency, indicating how noise may change the organization of avian communities (Rheindt 2003; Francis et al. 2009). Similar effect could happen to titi monkeys communities that can prevent to use suitable habitats to avoid overlap of noise. Considering that *C. nigrifrons* is a "Near Threatened" endemic primate (Veiga et al. 2008), this effect is very concern for species conservation in long term.

Lastly, our results suggest that, apparently, there is no noise effect on titi monkeys loud calls at site that is 2,500m distant from the opencast mine. This information provide insight that can help into developing distance regulations for areas of environmental compensation and/or biologically important, and highlight the importance of considering noise pollution when determining reserve locations (Madliger 2012).

Finally, here, we have shown for the first time how a noise disturbance can affects black-fronted-titi monkey communication. Our results provide important information to be considered during the elaboration of conservation strategies in natural areas affected by mining activity. Furthermore, we suggest that noise monitoring plans for wildlife should be part of the process of licensing large scale anthropogenic activities such as mining.

Acknowledgements

We thank all of the staff at the environmental station of Peti, especially Leotacílio da Fonseca. We are also grateful to Marina Scarpelli and Renan Duarte for their help during data acquisition and the engineer Krisdany Cavalcante for help with the noise level measurements. Grateful for Martin Fisher and anonymous reviewers for comments on the manuscript. MHLD and MCK were supported by a Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) postgraduate and technical scholarship respectively. MR, RJY and RSL received financial support from FAPEMIG and Conselho Nacional de Pesquisa (CNPq).

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Table 1. Equivalent sound pressure levels (Leq) at sites close to and far from an opencast mine site near Peti environmental station, southeast Brazil.

Measurement	Close Leq dB(A)	Far Leq dB(A)
1	42.6	33.8
2	38.7	30.3
3	42.0	30.1
4	60.9	37.2
5	42.9	38.8
6	41.2	33.3

Fig. 1 Sites close to and far from the Brucutu mine at Peti Environmental station, southeast Brazil. Red lines represent the geographic barriers between the sites

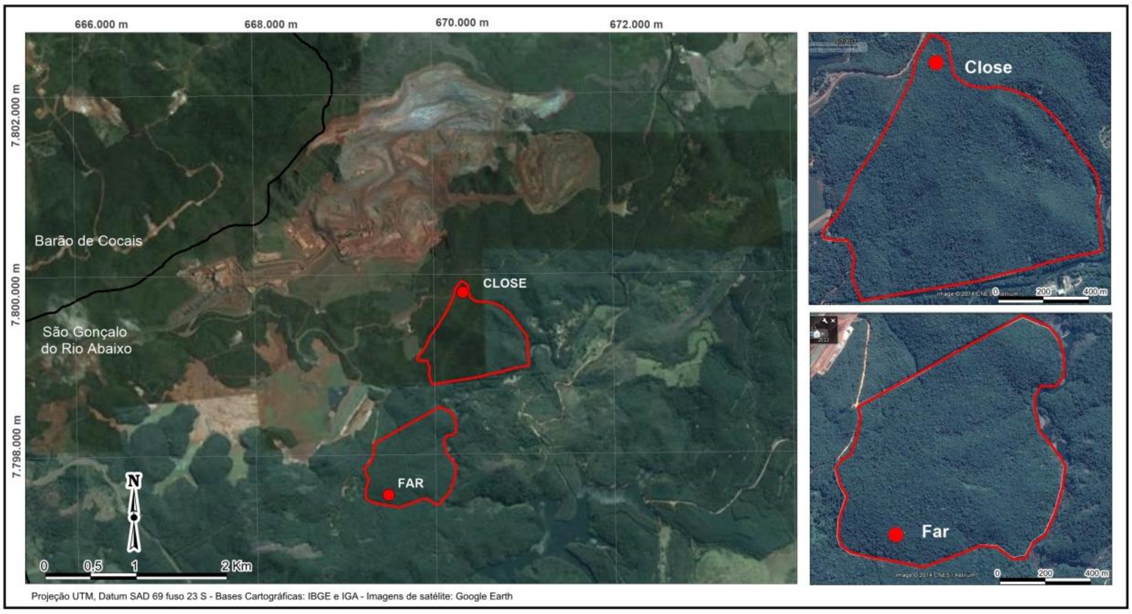

Fig. 2 Sound spectrograms of black-fronted titi monkey loud call, at Peti Environmental Station southeast Brazil, showing masking by noise mining activities (top) at a location close to a mine site, and non masked call (bottom) far from a mine site

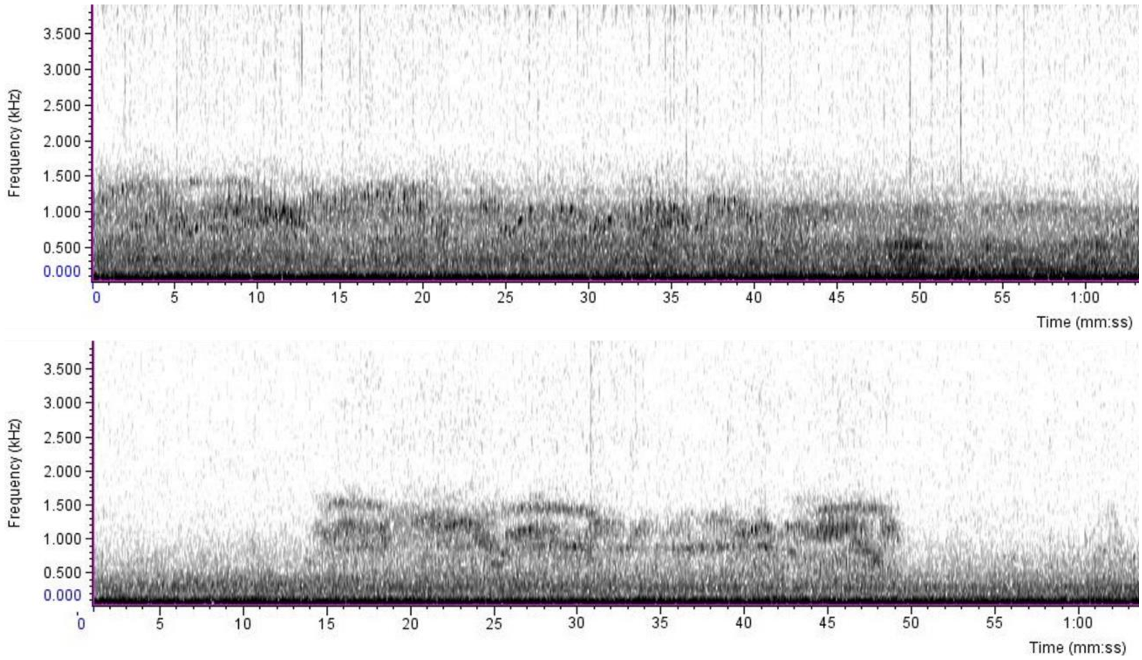

Fig. 3 Daily distribution of the mean (±SD) number of loud calls emitted by black-fronted titi monkeys at sites close to and far from an opencast mine site near Peti environmental station, southeast, Brazil

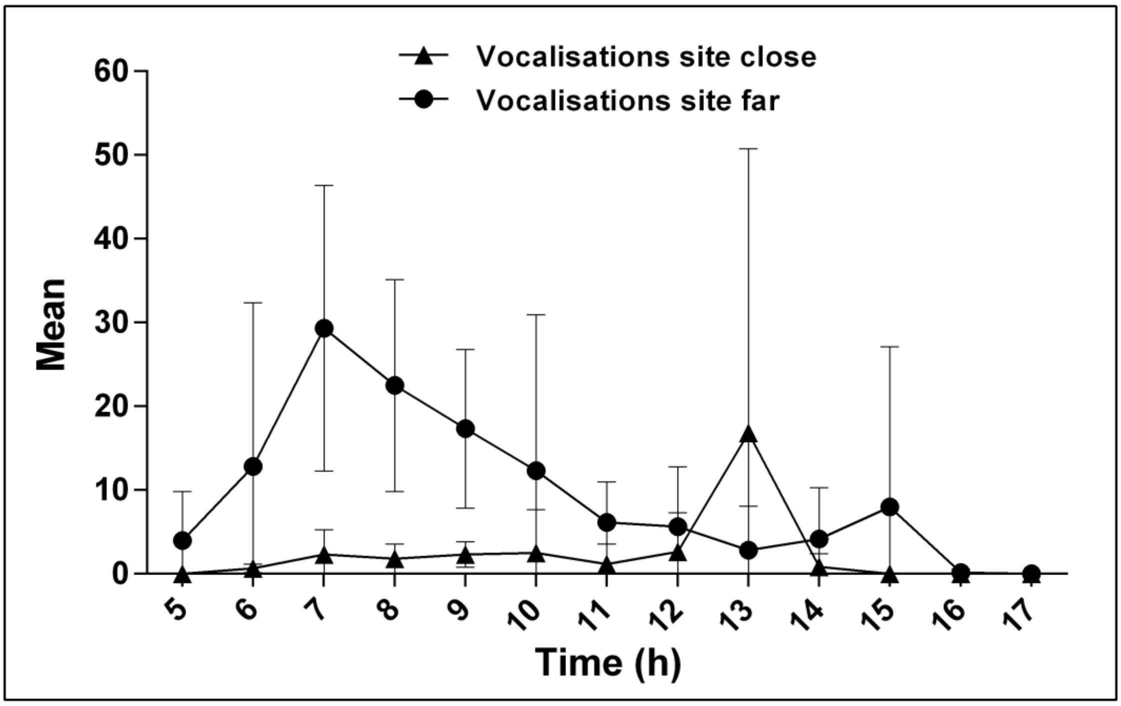

Fig. 4 Daily distribution of mean mining truck activity (number passing a fixed point) and mean frequency of loud calls of black-fronted titi monkey close to an opencast mine site near Peti Environmental station, southeast Brazil