“Assesment of the detection distance of an autonomous recording unit in the cloud forest”

Amauri Sarmiento-Rojas, Miguel Equihua, Octavio Pérez-Maqueo, Brian Napoletano

septiembre 12, 2019

Contents

List of Tables

List of Figures

ABSTRACT

Passive acoustic monitoring is an efficient and non-intrusive fundamental tool to provide information on the dynamics of spatial and temporal activity of the animals that produce sound. For designing research in the emerging field of Ecoacoustics, it is relevant to identify the detection space of recording devices. The evaluation of this range distance is a rather complex task, given that in the sound transmission there are multiple factors related to: acoustic attributes of the signal of interest, characteristics and configuration of the recording equipment, as well as some elements of the habitat and the environment (humidity, temperature, wind, precipitation, vegetation, topography, etc.). In the present project, using an experimental approach, we evaluated the range of scope of the omnidirectional microphone integrated in an automated recorder. Particularly, we identified the maximum distance at which the animals sounds, contrasting in frequency and call structure, are captured. Additionally, we analyzed the effect of distance, terrain slope, tree density and canopy cover on the loss of signals.

Keywords: Acoustic monitoring, Detection space, Sound attenuation, Ecoacoustics.

1 INTRODUCTION

Acoustic monitoring offers an efficient and effective method to assess biodiversity (**???**). Automated Recording Digital Systems (ADRS) constitute the fundamental equipment to record the sound environment at a specific site (**???**). Although there is a variety of acoustic sensors, it is necessary to improve the technique to achieve a greater representation of biodiversity and to know the resolution of the study, useful to predict and spatialize the patterns of acoustic activity. The probability of detecting an animal typically depends on its distance to the observer or the sensor (**???**). However, few studies have mentioned about the maximum range or the area covered by the recording devices (**???**). It is relevant to consider that the reaching distance of the devices delimits the *detection space* of the soundscape or the acoustic community of interest. Sound energy, measured in decibels (dB) as amplitude, and that is commonly understood as sound intensity, decreases or attenuates when sound waves propagate in the medium. The sound attenuation phenomenon is due to three main factors: distance spreading, absorption of the medium (heat conduction, viscosity or losses due to molecular relaxation), and other phenomena of wave dispersion (reflection, refraction, diffraction and absorption by changes in the impedance of the medium) (**???**). The absorption of the medium and the dispersion phenomena are difficult to model since they depend on several parameters such as frequency, humidity, temperature, pressure and physical properties of the obstacles that generate dispersion; on the contrary, spreading losses are easier to predict if there is a reference intensity (*iref*) and a reference distance (*dref*) (**???**).

The amplitude of the signal at the source (*source level*) can be extremely different between species and cause marked differences in detection distances (**???**). In addition, the sound loses power according to its frequency (measured in Hz); high-pitched tones (higher frequency) fade faster with distance and in contrast low-pitched tones (lower frequency) can travel longer (**???**). The structure and density of vegetation, topography and climatic variables (such as precipitation, wind speed, air temperature and ambient humidity), are some of the attributes of the site that can affect the transmission of sounds in the environment (**???**; **???**). On the other hand, among the characteristics of the microphone of the recorder that can intervene in the reception of the signal of interest are: the height above ground level, the orientation and/or the detection angle, as well as the microphone gain or level of recording.

Therefore, the evaluation of the recording range is a fairly complex task, since many factors are involved in the transmission of the sounds, from the acoustic nature of the signal of interest and the geophysical attributes of the site, to the characteristics and configuration of the recording equipment. This study has applications in the field of Ecoacoustics research, which studies the ecological relevance of the wildlife sounds.

In this project, we aimed to evaluate through an experimental approach, the detection range of the omnidirectional microphone integrated into the automatic recorder *SWIFT*. In particular, we identified the maximum distance at which all the sounds of animals of different frequencies are captured. We studied the transmission of each signal of interest according to its frequency category and its expected attenuation. We analyzed the effect of the distance, the terrain slope, the canopy cover and the density of arboreal vegetation on the loss of the signals. Since the intensity of the sounds decreases with distance and this attenuation is favoured in the presence of barriers such as vegetation, we expected a greater loss of amplitude occurring in closer distances and in sites with higher canopy coverage and tree density. On the other hand, given the inverse relationship between the distance and the frequency of the signal, we expect that the sounds with high dominant frequency will be attenuated in closer distances.

2 METHODS

2.1 *Study area*

The experiment was conducted in the Francisco Javier Clavijero Natural Protected Area, which presents secondary vegetation of cloud forest, located at southwest of the city of Xalapa, Veracruz. We chose six transects contrasting in tree density, physiographic form and terrain slope; one of these (transect 6) can approach a control site because of the flat terrain (less than 10° of inclination) and low tree density, located in the Clavijero Botanical Garden.

The fieldwork was carried out on May 8, 2018 from 11:00 a.m. to 5:00 p.m.; this schedule with the purpose of avoiding the peaks of activity of the local fauna that as background noise could cause masking of the signal of interest. During this period, the weather was with was abundant cloudiness, without precipitation, and no gusts of wind. The air temperature varied between 19.7 and 22.2 ° C, while the relative humidity changed between 92.3 and 99.9%; These variables were recorded with a portable meteorological microstation *Kestrell 4500*.

2.2 *Characterization of site*

We estimated the tree density along each the transect, a circular plot of 5m radius was drawn at each test point and within this area (78.5 m^2) we counted the number of trees with DAP> 10cm. We also shot photographs to estimate the percentage of canopy coverage using the *ImageJ* program. Finally, we calculated the average slope of the terrain (°) using a laser hypsometer *Nikon Forestry Pro*. This topographic variable was recorded pointing at a distance of 15m from the speaker point to the four cardinal points. This process was repeated in the six points of each transect (Figure**??**).

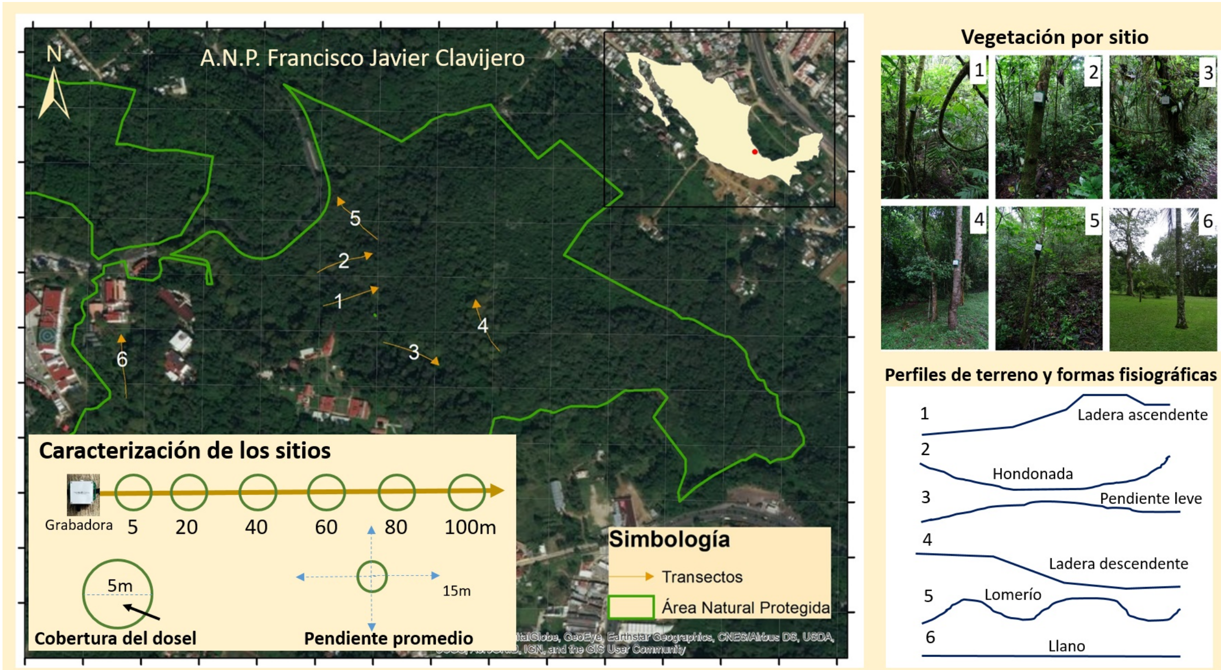


Figure 1: Study area and experimental design indicating the location of the six transects, some representative photographs of the vegetation, as well as the physiographic forms according to each terrain profile.

2.3 *Experimental design*

We evaluated the automatic recorder *SWIFT* which comes with a PUI Audio integrated microphone with an omnidirectional polar pattern (360° as detection angle) and a frequency response of 50 Hz to 16 KHz (**???**). We configured the device to record audio continuously, at a recording rate of 48 kHz and with a microphone gain set at 35 dB (default value).

We carried an experiment to know the maximum recording distance (m), this consisted of reproducing a and re-recording a soundtrack containing prerecorded animals contrasting in their dominant frequency (that one with the highest energy). The detection space was considered as the reach distance from the signal source, in which its amplitude remains above a minimum detection threshold (**???**).

2.4 *Animal sounds used for tests*

We chose representatives of different taxonomic groups with vocalizations in different categories of dominant frequency: low, <2000 Hz; medium,> 2000 and <3000 Hz; and high, > 3000 Hz. The chosen sounds belong to ten species of vertebrate animals (three amphibians, one reptile, five birds and one mammal) (Figure**??**). These audios were reproduced in each transect at six distances (5, 20, 40, 60, 80 and 100 m) from the evaluated microphone. In the original audios, we measured its dominant frequency (Hz) and its reference amplitude (*iref*), measured in dB at a reference distance of 1m (*dref*); these were the base parameters to compare with the outputs from the analysis of the audios rewritten by the *SWIFT* device. In addition, to take into account the spectral complexity of the sound, we estimated the acoustic diversity index (ADI), which measures the signal entropy by measuring the acoustic activity occuring in 500 Hz-frequency bands (**???**). This variable was calculated using ´r "soundecology" ´, an R library designed for acoustic analysis (**???**)' (Table1).

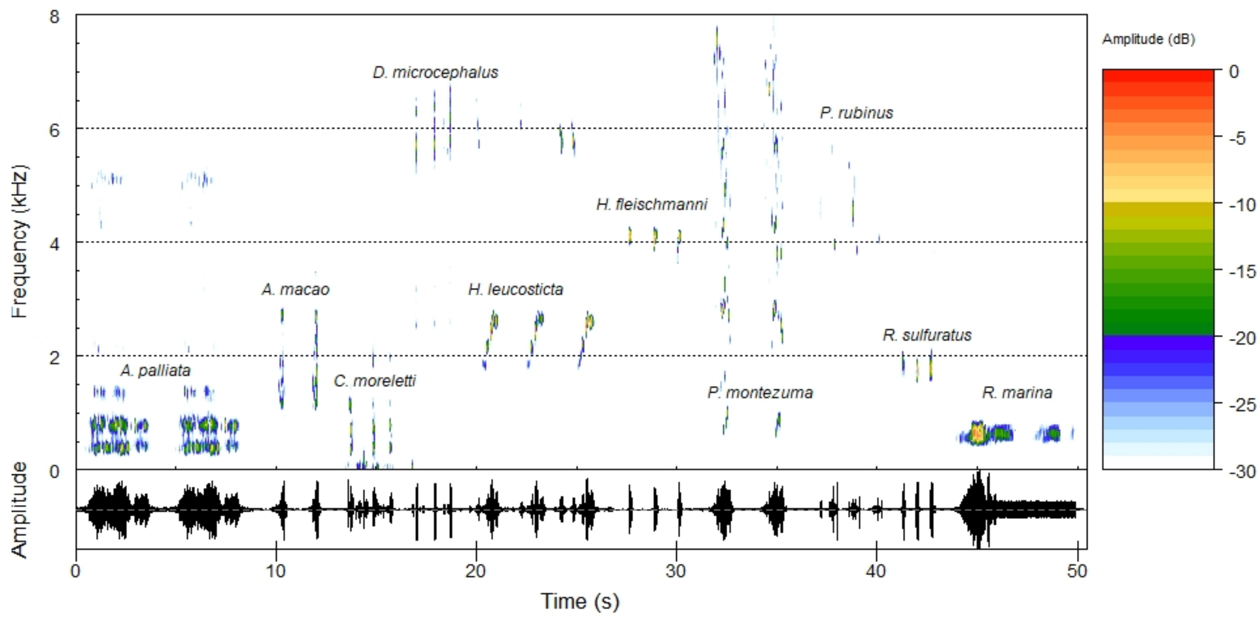


Figure 2: Spectrogram of the selected audios for the experiment, belonging to the ten species of vertebrate animals.

Table 1: Description of animal sounds used for tests.

Sp.	Group	Common name	*Scientific name*	Sound content	Author of recording	**Duration (s)**	Amplitude (dB)	Frecuencia (Hz)	Frequency category	ADI value
1	Reptiles	Morelet's Crocodile	*Crocodylus morelletti*	3 calls	SKPC	**2.5**	-28.0	387	low	4.76
2	Amphibians	Cane Toad	*Rhinella marina*	1 trill	ASR	**9.0**	-3.5	657	low	4.85
3	Mammals	Mantled Howler Monkey	*Allouata palliata*	2 calls	ASR	**10.0**	-16.8	779	low	4.97
4	Birds	Keel-billed Toucan	*Ramphastos sulfuratus*	3 songs	ASR	**2.0**	-16.1	1721	low	4.66
5	Birds	White-breasted Wood-wren	*Henicorhina leucosticta*	3 songs	FGG	**8.0**	-22.6	2507	medium	4.03
6	Birds	Scarlet Macaw	*Ara macao*	2 calls	ASR	**5.0**	-24.6	2701	medium	2.93
7	Birds	Montezuma Oropendola	*Psarocolius montezuma*	2 songs	ASR	**8.0**	-22.5	2809	medium	4.97
8	Amphibians	Fleischmann's Glass Frog	*Hyalinobatrachium fleischmanni*	3 calls	ASR	**3.0**	-21.4	4062	high	4.92
9	Birds	Common Vermilion Flycatcher	*Pyrocephalus rubinus*	3 songs	ASR	**3.5**	-36.4	5057	high	4.31
10	Amphibians	Small-headed Treefrog	*Dendropsophus microcephalus*	3 calls	ASR	**2.0**	-30.3	6231	high	2.67

To standardize the intensity of the sounds, these were normalized to -4 dB using the free-use software *Audacity*. The recorder *SWIFT* was placed at a height of 2m above ground level. To play the audios we used a portable loudspeaker *XP8000RD Power&Co* that has a power of 4200 W. The volume was calibrated at an average intensity of 55 dB measured at 1m distance, as reference distance (*dref*), and at a height of 1m above the ground.

2.5 *Assessment of the detection space*

In each recording obtained and for the ten signals of interest, the spectrum analysis tool *Plot Spectrum* was used in the *Audacity* program to measure the dominant frequency measured in number of cycles per second or Hertz (Hz), as well as its amplitude in decibels at full scale (dBFS). Then, for each distance and for each signal of interest the amplitude values were averaged taking into account the logarithmic nature of this variable, using the formula: `10 ^ (obs_amplitude * -1) / 10`. These values were added and divided by the number of observations and again transformed into digital amplitude in dBFS. From the reference amplitude value, the acoustic extinction curves were constructed for each distance. The detection threshold occurs when a loss of the signal of interest is identified; that is, when it is no longer displayed on the spectrogram; in this case, we assigned a symbolic value of -100 dBFS.

2.6 *Attenuation analysis by animal sound type*

To study the observed attenuation with respect to distance for each species, and according to its dominant frequency category; the expected attenuation curve was generated according to the theory of sound propagation. The following formula was used to calculate these values: $ SPL_expected = I_(ref)-20*log(d/dref) $; where the expected amplitude (*exp_amp*) is obtained with the reference amplitude (*iref*), the distance of interest (*d*) and the reference distance (*dref*). [Distance attenuation calculator] (https://www.omnicalculator.com/physics/distance-attenuation#inverse-square-law)

2.7 *Effects of topography and vegetation*

To study the possible effect of topography and vegetation on signal reception, **for each species**, we made **linear models** of the measurements of **amplitude observed in full scale (dBFS)** in function of: the **expected amplitude (dbFS)**, the **recording distance (m)**, the **average slope of the site (°)**, the **density of tree stems with DAP> 10cm** and the **tree cover percentage**). We used the “glmulti” function to find the most appropriate model based on the corrected Akaike Information Criteria (AICc).

3 RESULTS

3.1 *Detection space of tested recorder*

We present the acoustic extinction curves generated for each site (Figure3) and for each species (Figure4) based on their average amplitude values, in decibels at full scale (dBFS), recorded for each distance.

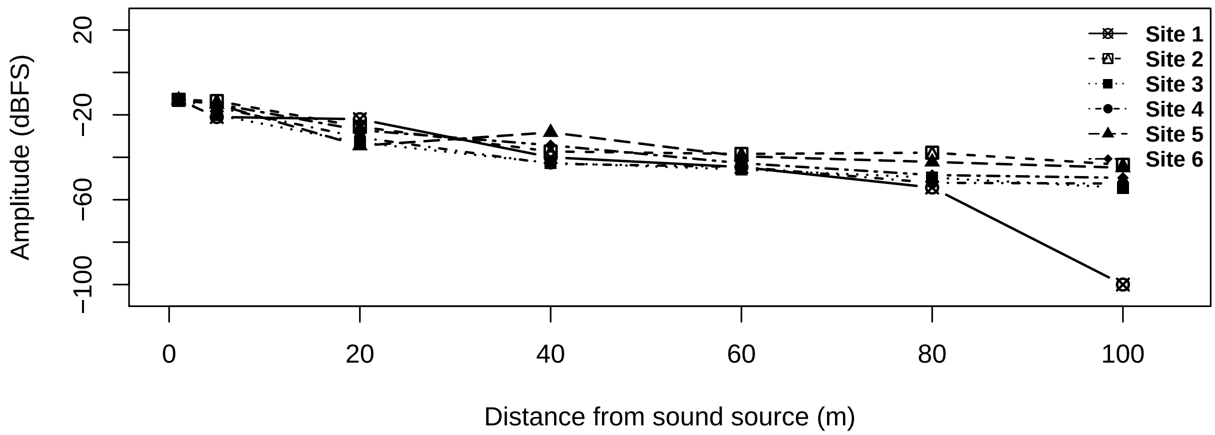


Figure 3: Acoustic extinction curves by site with amplitude measured at six distances.

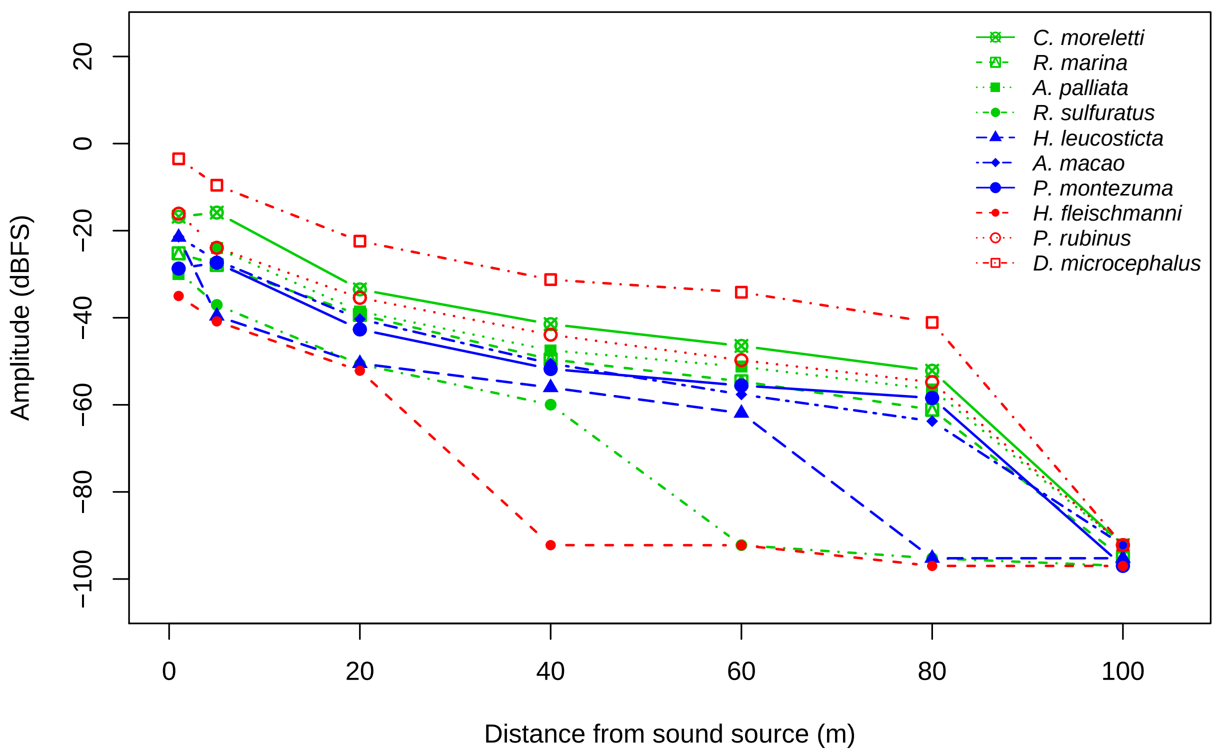


Figure 4: Acoustic extinction curves by sound type, with amplitude evaluated at six distances. Colors indicate the corresponding peak frequency category that each animal sound: red (high-pitched), blue (medium), green (low-pitched).

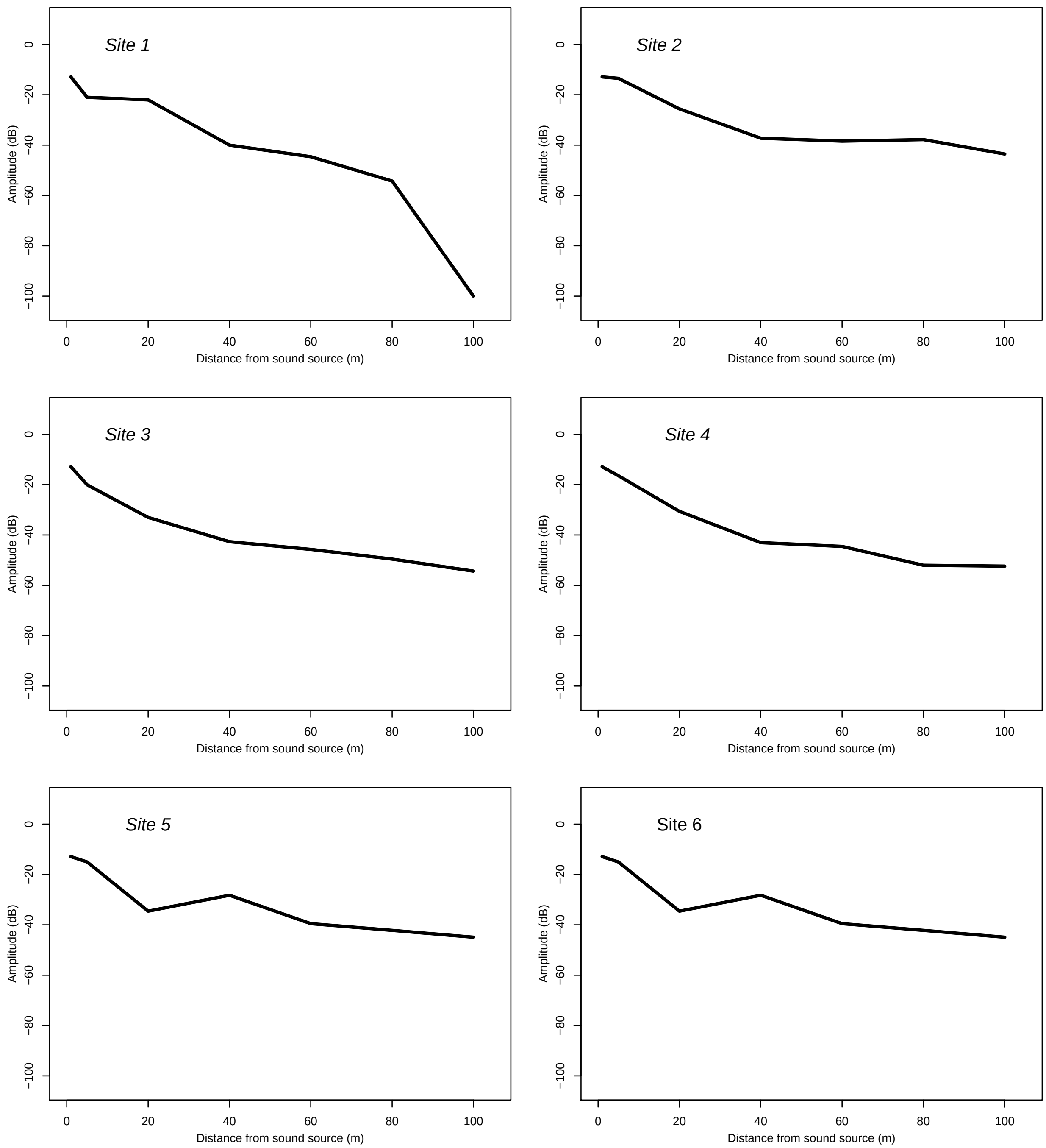


Figure 5: Attenuation curves with amplitude evaluated at six distances for six sites.

3.2 *Atenuattion by animal sound type*

The loss of signal by soundtype or species depending on the expected attenuation was very variable among the different types of sounds. In most species, the attenuation observed was greater than the expected curve in the distances closest to the sound source (Figure6).

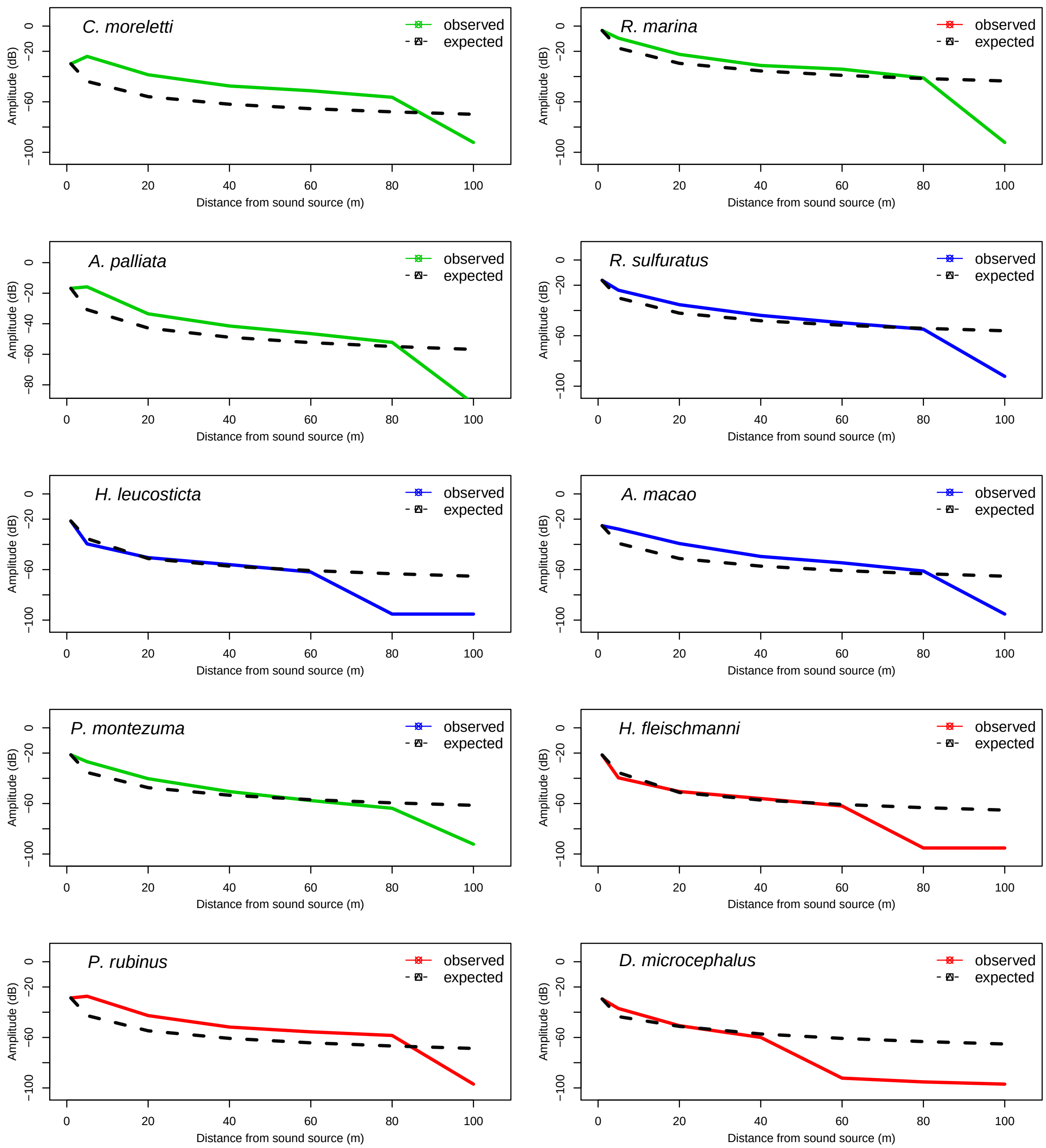
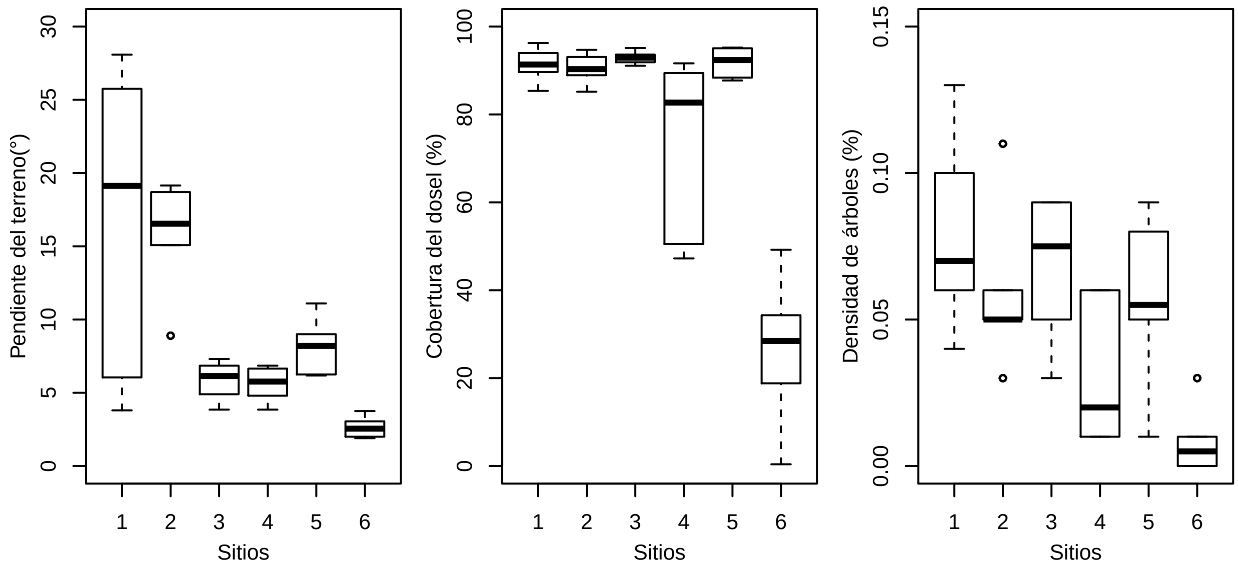
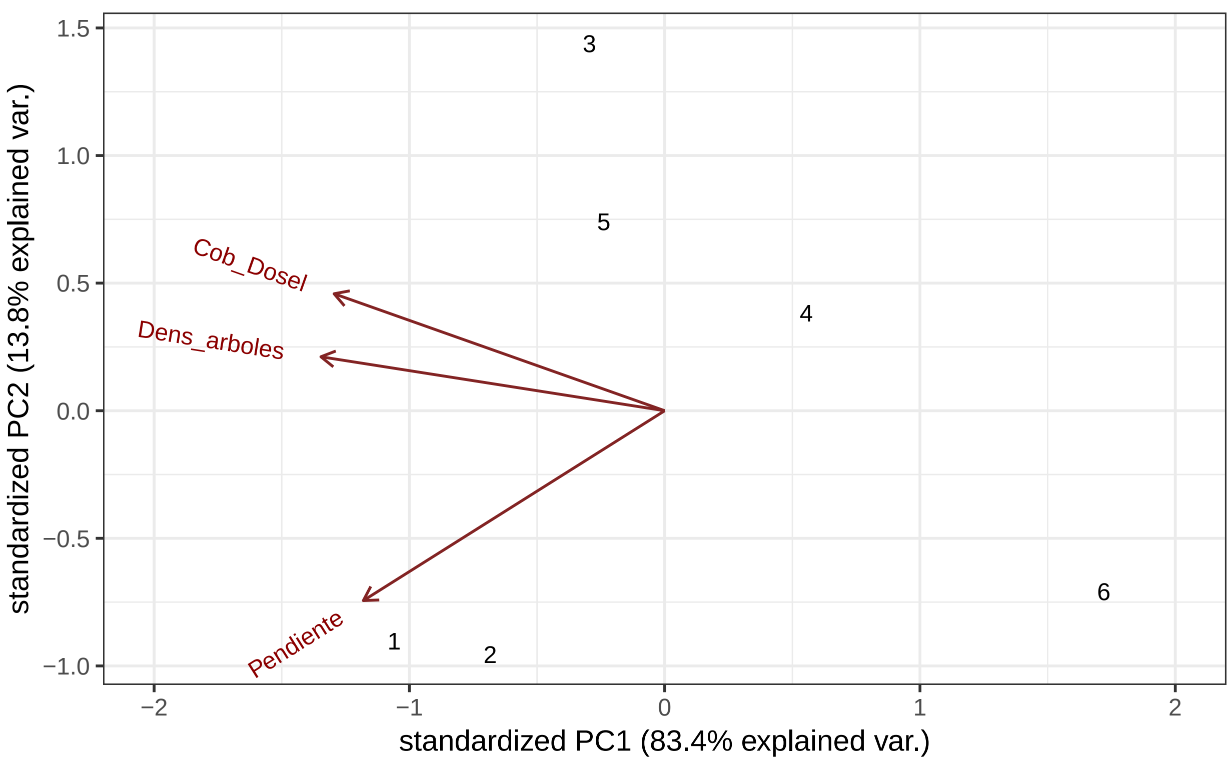
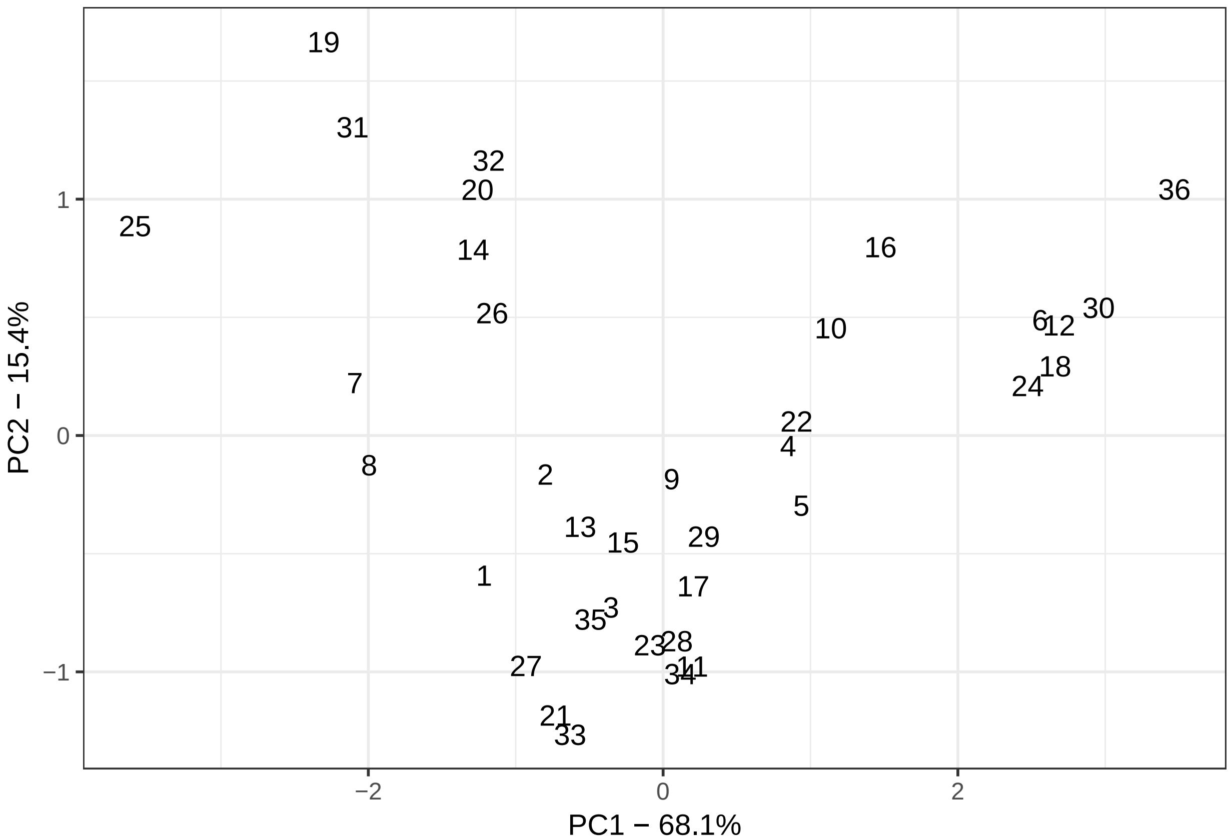


Figure 6: Observed vs expected attenuation curves of the ten animal sounds, with amplitude measured at six distances. Colors indicate the corresponding category of peak frequency: green for low-, blue for medium- and red for high-pitched sounds.

3.3 *Effects of topography and vegetation*







Linear Model

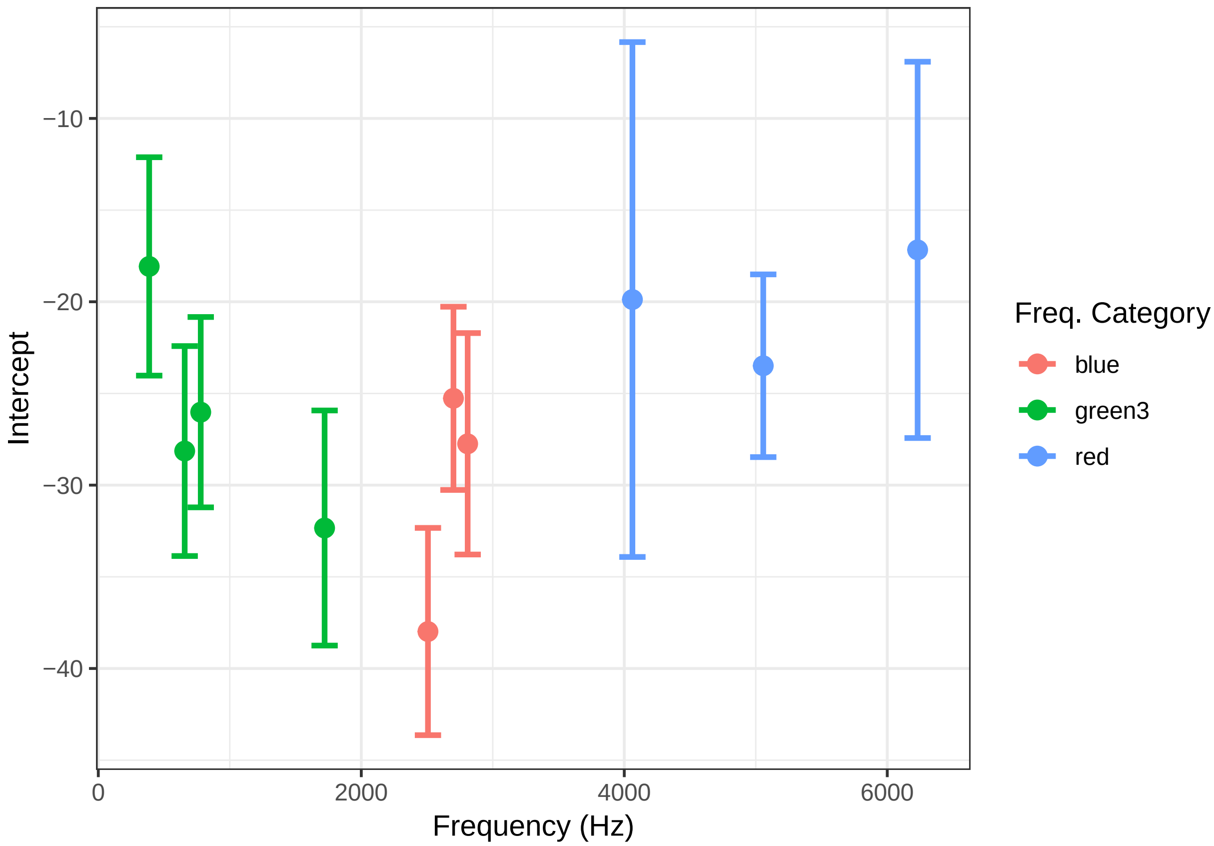
For each one of the species, we present the linear models that were selected using the “glmulti” function (Table2).

Table 2: Linear model results

Sp.	*Common name*	Frequency (Hz)	r^2	Model	α	σ_α
1	*Morelet's Crocodile*	387	0.671	$\alpha + Distancia$	-18.072	3.054
2	*Cane Toad*	657	0.710	$\alpha + Distancia + Dens_{arboles} : Distancia$	-28.141	2.936
3	*Mantled Howler Monkey*	779	0.690	$\alpha + Distancia$	-26.021	2.662
4	*Keel-billed Toucan*	1721	0.793	$\alpha + Distancia + Cob_{Dosel} : Distancia + Pendiente : Dens_{arboles}$	-32.339	3.288
5	*White-breasted Wood-wren*	2507	0.750	$\alpha + Distancia + Dens_{arboles} : Distancia$	-37.984	2.899
6	*Scarlet Macaw*	2701	0.804	$\alpha + Distancia + Pendiente : Cob_{Dosel}$	-25.266	2.562
7	*Montezuma Oropendola*	2809	0.724	$\alpha + Distancia + Cob_{Dosel} : Distancia$	-27.746	3.096
8	*Fleischmann's Glass Frog*	4062	0.718	$\alpha + Distancia + Cob_{Dosel}$	-19.877	7.200
9	*Common Vermilion Flycatcher*	5057	0.740	$\alpha + Distancia + Pendiente : Distancia$	-23.489	2.555
10	*Small-headed Treefrog*	6231	0.668	$\alpha + Distancia + Pendiente : Distancia + Pendiente : Cob_{Dosel}$	-17.170	5.262

3.4 *Model selection and fitting: theoretical vs empirical model*

The main signal is catched by the *offset* term; the intercept, which contains the *offset*, is clearly different from zero. In order to know the *offset* effects, we plotted the intercept with its confidence intervals at 95%.



It is clear that, there is a certain common arrangement for the attenuation of all calls, and the onlyone that separates the most is that one with dominant frequency of 2500 Hz, which is attenuated apparently more than everyone.

In all cases, we found a small effect of distance with the same sign as the offset, so we could actually add it to the previous estimate. Then, there are the secondary effects of tree density, terrain slope and canopy coverage, which in variable form also have small effects compared to the size of the *offset*.

3.4.1 *Model contrast approach*

We proposed a *complete model* as reference, which contains theoretical attenuation as a term plus an "empirical" component constructed with the main effects of distance and of site conditions including its first-order interactions. From this reference model, the non-significant terms are removed to get a "minimum adequate model". Based on the estimates of the "additive explanatory" effect of the "empirical" components, we assesed the improvement that the empirical model can bring to the theoretical model (Table3). We see no significant improvements, except in the case of *White-breasted Saltapared* and perhaps marginally the *Yellow Tree Frog*.

Table 3: Contrast of the theoretical vs empirical model

Sp.	*Common name*	Frequency (Hz)	Model	$r^2_{theoretical}$	df residual	df model	F	P
1	*Morelet's Crocodile*	387	theoretical vs empirical	0.754	27	7	1.103	0.389
2	*Cane Toad*	657	theoretical vs empirical	0.724	27	7	1.222	0.325
3	*Mantled Howler Monkey*	779	theoretical vs empirical	0.770	27	7	1.187	0.343
4	*Keel-billed Toucan*	1721	theoretical vs empirical	0.810	27	7	2.287	0.058
5	*White-breasted Wood-wren*	2507	theoretical vs empirical	0.787	27	7	5.224	0.001
6	*Scarlet Macaw*	2701	theoretical vs empirical	0.845	27	7	1.814	0.125
7	*Montezuma Oropendola*	2809	theoretical vs empirical	0.734	27	7	1.647	0.165
8	*Fleischmann's Glass Frog*	4062	theoretical vs empirical	0.758	27	7	1.847	0.119
9	*Common Vermilion Flycatcher*	5057	theoretical vs empirical	0.780	27	7	1.772	0.134
10	*Small-headed Treefrog*	6231	theoretical vs empirical	0.710	27	7	1.851	0.118

We can also explore the convenience of adding some of the site characterization variables or an additional distance effect. The principal effects of these variables plus the term of *theoretical attenuation*. Using the *stepwise* strategy but without incorporating any interaction in order to make slight improvements that may more clearly have the contextual effect of the site's characteristics on the sound behavior.

The issue of "identifiability of the call" is pending, in the sense how much distortion occurs to degrade the characteristics that allow differentiating the animals studied.

3.4.2 *Do all calls fade in the same way: does the same model apply to all?*

We adjusted a model including theoretical attenuation in interaction with the species and of course, the main effects of both. For convenience the type of contrast used in R is *treatment*, which means that one of the conditions is chosen as a reference and all others are then expressed as the difference from that reference. Usually, the first treatment is taken as a reference, but anyone that interests may be chosen.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	9.638	12.653	0.762	0.447
Amplitud_esp	0.802	0.342	2.347	0.020
sppSp10	-3.689	12.044	-0.306	0.760
sppSp2	-9.956	15.250	-0.653	0.514
sppSp3	-11.639	17.145	-0.679	0.498
sppSp4	13.973	16.874	0.828	0.408
sppSp5	-26.438	14.452	-1.829	0.068
sppSp6	-5.931	14.245	-0.416	0.677
sppSp7	-5.097	16.582	-0.307	0.759
sppSp8	7.360	20.210	0.364	0.716
sppSp9	-9.971	13.365	-0.746	0.456
Distancia	-0.029	0.359	-0.080	0.936
Amplitud_esp:sppSp10	-0.009	0.360	-0.024	0.981
Amplitud_esp:sppSp2	-0.148	0.313	-0.472	0.637
Amplitud_esp:sppSp3	-0.303	0.358	-0.844	0.399
Amplitud_esp:sppSp4	0.487	0.330	1.475	0.141
Amplitud_esp:sppSp5	-0.285	0.306	-0.930	0.353
Amplitud_esp:sppSp6	0.000	0.288	-0.001	1.000
Amplitud_esp:sppSp7	-0.080	0.345	-0.233	0.816
Amplitud_esp:sppSp8	0.233	0.420	0.555	0.579
Amplitud_esp:sppSp9	-0.115	0.277	-0.414	0.679
Amplitud_esp:Distancia	0.003	0.005	0.687	0.493

Almost all species could be modeled similarly, except for the sound of species 5 *(Henicorhina leucosticta)*.

This model shows that there is no statistically significant change in relation to the *original complete_model*. All species behaved similarly to each other, in terms of attenuation in relation to distance. The species differ in the initial condition from which the attenuation process begins.

This simplified model seems to account for the data almost as well as the original "complete model", so, in spite of everything, in the case tested we could even simplify the model a little more, since several species seem not to differ either when initial condition: Sp1 == Sp3 == Sp7 == Sp10. When making this change, explanatory capacity of around 0.5% is lost.

Now it would be interesting to graph the results. I hope that the anomaly you had in your first graphics does not occur. Use the `predict` function with the model you consider most appropriate and make the corresponding graphs. Let's see how they turn out. It will be nice to make them with the esteemed trust bands.

4 DISCUSSION

The maximum average distance at which most of the animal sounds of different frequencies are detected is 80 m, some sounds are attenuated and lost at 40m. As we expected, the high-frequency signals resulted in greater loss as the distance increases, these signals contain less pressure or less energy and tend to more easily degrade with obstacles.

The evaluated site variables of terrain slope and vegetation had no significant effect *per se* on attenuation. It would be interesting to study the effect of other topographic variables such as the terrain roughness, the orientation and the physiographic form of the site.

The attenuation estimated by theory, than of vegetation in the detection of sounds.

The main purpose of this project was to estimate the detection distance of the recorder which is especially relevant for studies in which it is intended to record the sound remotely and autonomously. On the contrary, it was not the objective of this project to evaluate the transmission of sounds, which could require another type of experimental design.

In the wildlife, animals emit vocalizations at different heights and some of them moves or change orientation while there are calling.

Puntos a considerar:

The detection space may vary according to weather conditions such as temperature, humidity, wind and precipitation, in the field is not possible to control this environmental variables.

There is no reference control signal (pure tone of 1kHz at 94 dB SPL which is the pressure of 1 Pascal), based on this normalization would be performed.

Review the frequency response of the horn, you may amplify certain frequencies further.

Consider the sensitivity of the microphone (frequency response and gain).

5 CONCLUSIONS

6 ACKNOWLEDGEMENTS

To Esau Toaki Villareal Olvera for orientation on acoustic transmission issues. To Fernando González García (FGG) and Sofía Karen Pérez Cruz (SKPC) for contributing with some audio files used in this project.

7 REFERENCES