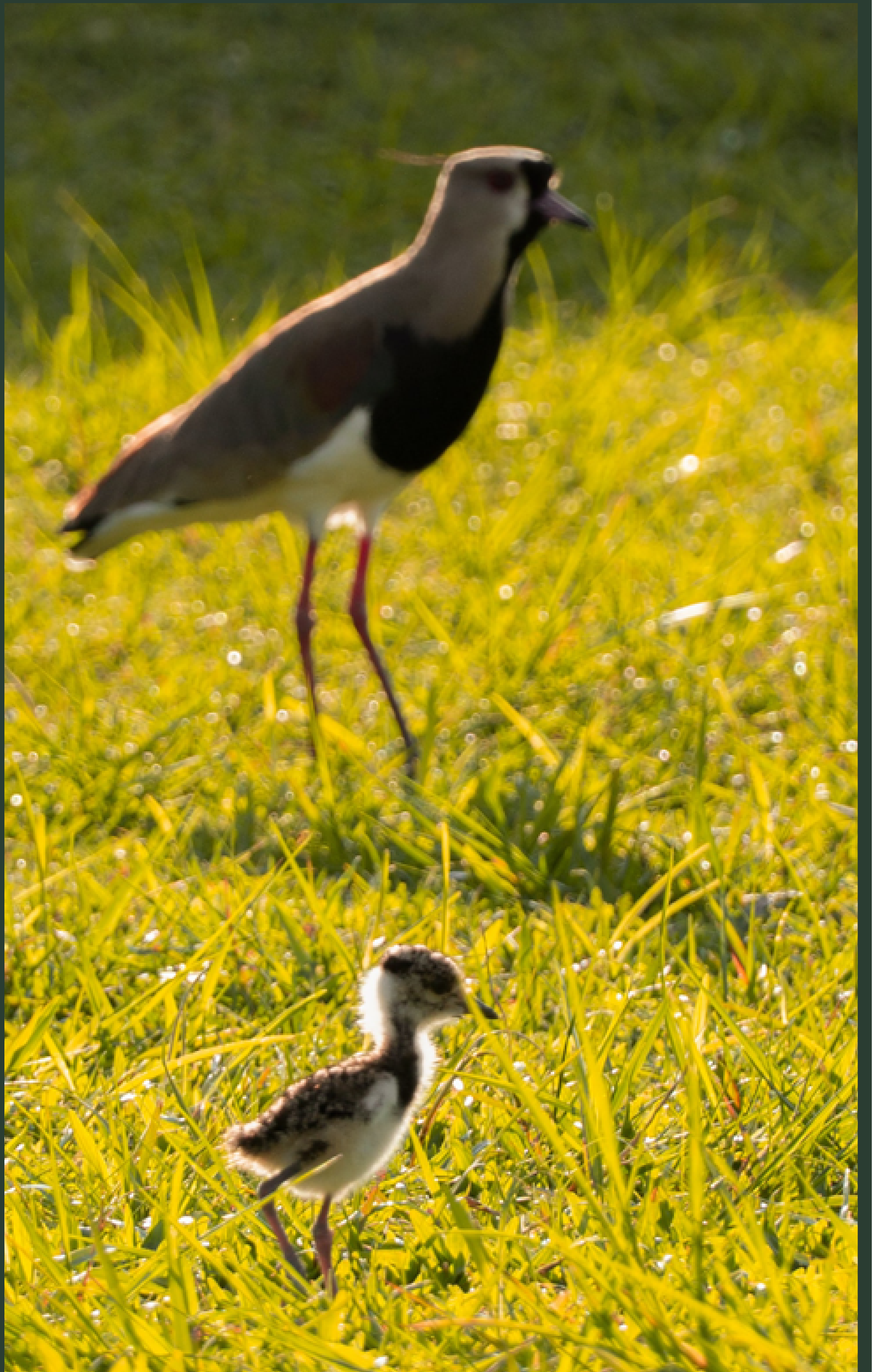
EXPLORING BIOACOUSTICS

FOR MEASURING ECOSYSTEM HEALTH OF REFORESTATION PROJECTS

Report by Yvo Hunink

IRACAMBI
Mata Atlântica - Brasil



Preface

About this project

This report is the result of a volunteer project by Yvo Hunink for and with Iracambi. The project took one month to complete. In conversations and e-mails between Yvo and the Iracambi staff, before traveling to Minas Gerais, several options of subjects for the volunteer project were discussed and mutual interest in the field of bioacoustics was determined for monitoring ecosystem health.

About Iracambi

Iracambi is a community of people around the world whose vision is to see the beautiful Brazilian Atlantic Forest restored, with prosperous communities living in a flourishing landscape. In our headquarters in Minas Gerais, the Iracambi Research Center spearheads our work in managing natural resources, educating for sustainability, and researching ecosystems and how we impact them. Over the last twenty years, Iracambi has planted over 160,000 trees in the remote mountains of the Serra do Brigadeiro and is accelerating its operations to plant thousands more.

About the Smart Forest Program

This exciting new program aims to build up a picture of ecosystem health in the neighboring forests – old growth, regenerated and restored – and provide a baseline standard for monitoring restoration projects in subtropical forest ecosystems, by developing scientifically validated, data-based reference conditions for forest restoration. Data to be collected will focus on vegetation, fauna, soils, and water, as well as weather and sounds. Bioacoustics can support these goals.

IRACAMBI
Mata Atlântica - Brasil

The Iracambi logo has a hidden meaning to it that puts the bird central at its conservation mission of saving forest and changing lives. It's based on a story that has been passed down through generations within indigenous communities in South-America.

"The forest is on fire, and all the animals are fleeing to safety. All except the humming bird. She is flying towards the fire with a drop of water in her beak. "Silly little bird," shouts the eagle, looking down at her. "Don't you see that you'll never put out the fire all by yourself?"

"You're right," says the humming bird.
"I'll never put it out all by myself. But I'm doing my part."

Summary

The main question central to this project concerns whether bioacoustics can be of value for monitoring forest ecosystems and explore how it can be applied in practice. Bioacoustics is the field where biology and sound interact, and contains a wide spectrum of different activities. Here the focus is mainly on using sound recording equipment to record and detect birds, and identify them by their songs and calls.

In the preparations, an exploration of possibilities was done, after which equipment was purchased for usage during a 1-month stay at Iracambi, and it was learned how to operate the hardware and software. Also, a list of potentially audible species was formed.

During the stay on location, the sound recorder was deployed in 5 different locations, generating over 200 hours of sound recordings, of which 25 hours have been analyzed for audible birds with the help of dedicated software tools. This resulted in 845 detections, of 35 different types of songs, of which 2 have identified to belong to a certain species of bird. These detections form a sound bank of data that can be used in future projects.

In the discussions is has come up that the current software tools do not yet adhere to all requirements and still require an immense amount of labor for complete ecosystem monitoring. Furthermore, the persistent background noise and variety of audible species, seems to create problems for the algorithms used to cluster and classify detected signals. Since this is inevitable, severe data processing would be required, or better algorithms that can see past the background noise.

Therefore, currently the most feasible application of bioacoustics is the monitoring of a single species, or few, as this gives less opportunities for false positives. That insight has been used as input for two grant proposals, one for bioacoustics equipment specifically, and one for a broader take on ecosystem monitoring of bioacoustics is merely a small part. The grant for bioacoustics equipment proposes to focus on the bare-throated bellbird (araponga) as and indicator for ecosystem health in reforested areas, as well as includes the monitoring of the recolonization of the woolly spider monkey (muriqui) in collaboration with the Muriqui Instituto de Biodiversidade.

Recent developments in artificial intelligence promise to change the limited application on single species monitoring towards a broad ecosystem monitoring as well because of improving neural networks that help to scale up data analysis and improve outcomes. Although no commercially available software for the requirements of Iracambi is available, expertise on this subject is growing and partners could be found to execute the technical process steps, or co-create new software with Iracambi in the role of pioneering practitioner.

Therefore the main advice to Iracambi is to appoint a bioacoustics coordinator, that can continue the activities, such as data collection, sound bank expansion, supervise volunteers and form partnerships on the side of technical expertise. This way bioacoustics can develop under the Smart Forest program as an integral part of the wider ecosystem monitoring system that is envisioned.

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1. Introduction

Deforestation

Deforestation of the Atlantic Forest in Brazil has been going on for many years, mostly because of mining activities, agriculture and the clearing of land for livestock.

Reforestation

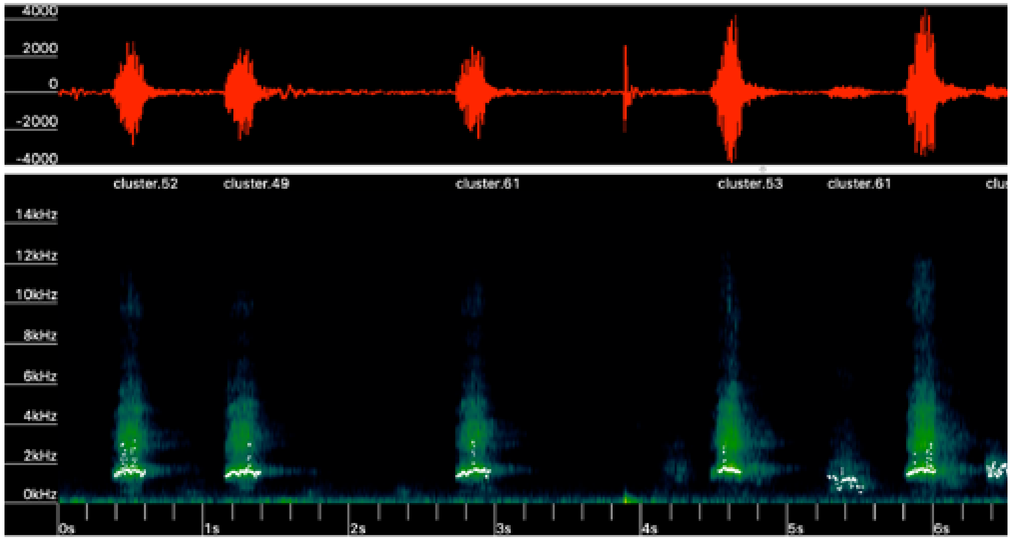
Projects like Iracambi help to replant forests in the in areas where deforestation has taken its toll. It does not only help to reach global goals on climate change by taking up CO2, but primarily aims to undo the negative impact of deforestation on the local biosphere, by restoring the ecosystem to its former glory.

Ecosystem Health

Reforestation, begins with a focus on flora, like trees and plants. However, a healthy ecosystem includes fauna as well. When animals return to newly grown forest, the objective of restoration is fully reached. This gives rise to the question: When is an ecosystem considered to be healthy and how can you measure this?

Bioacoustics

The field of bioacoustics combines biology and acoustics. The sounds of nature. As a scientific discipline, it dates back to the 1920s. Improvements in technology and analysis expanded the field from listening towards visual analysis, with the help of sound recording and sound analysis software. Recent advancement in machine learning techniques have given the field a boost, since patterns in and between sounds can now be analyzed with more precision, speed and ease. Recently bioacoustics has been proposed as a non-destructive method of estimating biodiversity in an area.



A sonogram of a Toco Toucan - Tucanuçu - Ramphastos toco
a beautiful but invasive species to the area of Iracambi

How to apply bioacoustics?

Applying bioacoustics in practice requires a set of tools, starting at using our ears. In general, however, for the objective of measuring biodiversity, one is interested in the identifying different species by sonograms, as seen in above image. These are visual representations of the sound into the frequency (in green) over time in Hertz, meaning the number of vibrations per second that the sound reaches. Sometimes also the amplitude (in red) is included. Animals often have very distinctive sonograms, meaning that they can be differentiated and identified by analyzing them. There many tools available to do such an analysis, but generally requires sound recorders, data storage and a software program. The main question of this report is, therefore: **What value can bioacoustics bring to monitoring forest ecosystems and how is it applied in practice?**

2. Project overview

At the end of November the decision was made to start the project containing the following structural elements:

- Preparation
- Data Collection
- Data Processing & Analysis
- Further Activities
- Reporting

Preparation

After choosing the project subject, an exploratory research was done on how to execute a bioacoustics project. Here the Wildlife Acoustics hardware and software was chosen and ordered in the Netherlands.

Data Collection

This phase concerns the placement of the sound recorder in the area of Iracambi for the generation of sound data of the environment.

Data Processing & Analysis

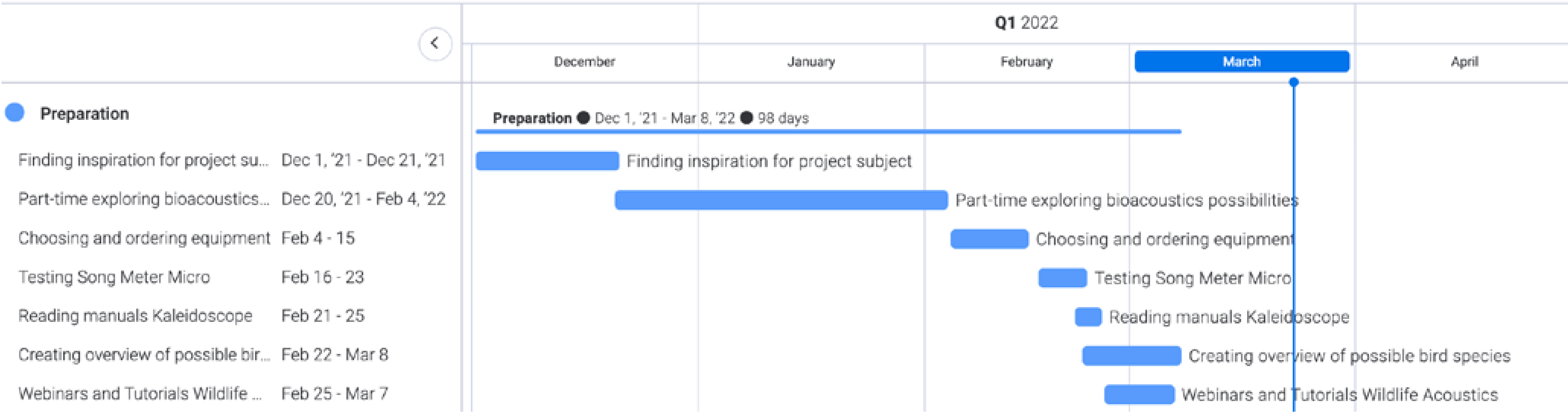
This phase concerns the loading of the data in the sound analysis software, isolating interesting detections in a sound database and identifying the audible species in the data.

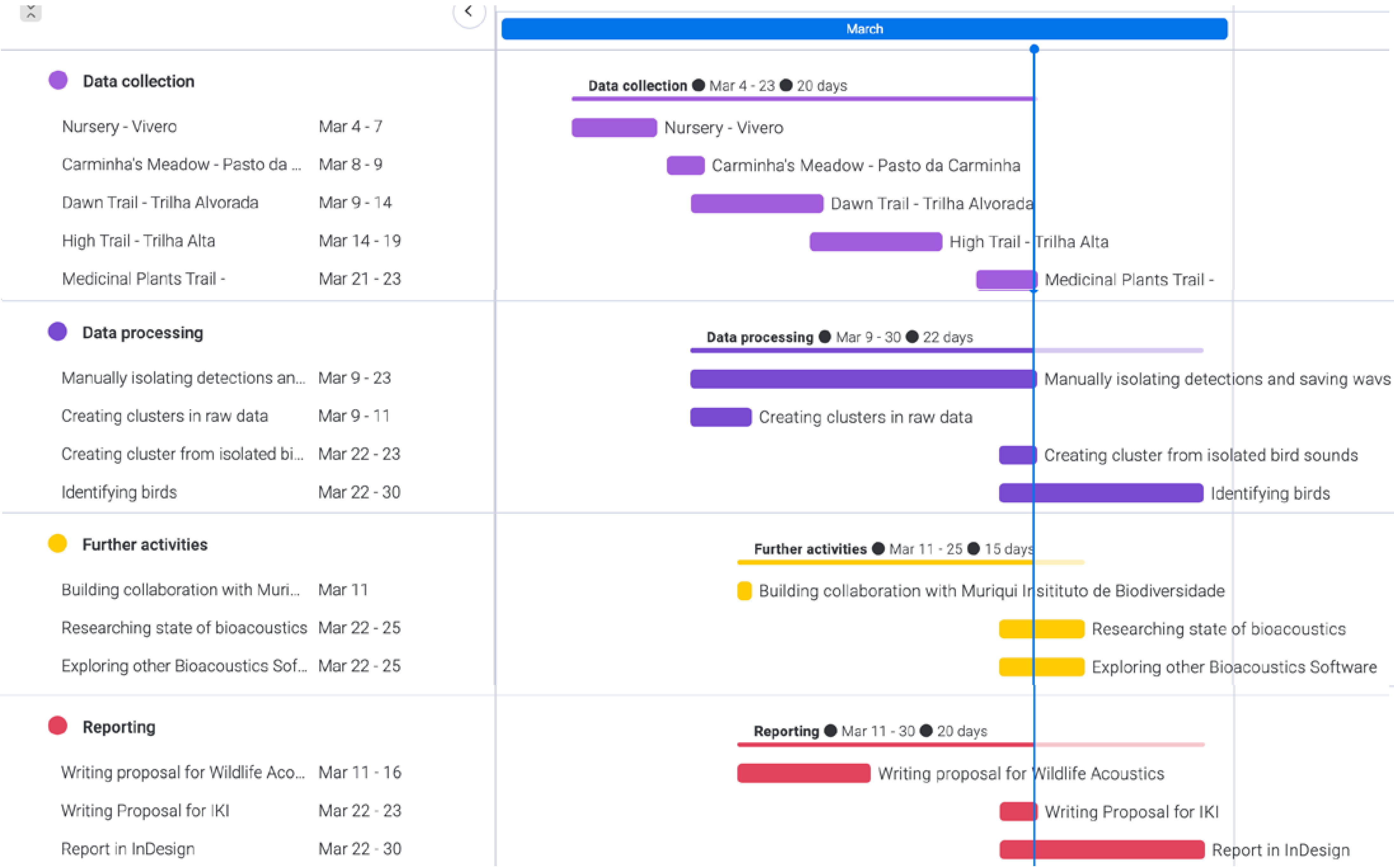
Further Activities

Some miscellaneous activities were performed. A collaboration was built with a local NGO on biodiversity and some further research was done on alternatives for bioacoustics software and the state of technology of bird identification through sound detection was evaluated.

Reporting

The final deliverables are a final report and two contributions to proposals for grants, namely for equipment for sound recording as well as a larger integrated ecosystem monitoring system.




March
Data collection
Nursery - Vivero Mar 4 - 7
Carminha's Meadow - Pasto da ... Mar 8 - 9
Dawn Trail - Trilha Alvorada Mar 9 - 14
High Trail - Trilha Alta Mar 14 - 19
Medicinal Plants Trail - Mar 21 - 23
Data collection ● Mar 4 - 23 ● 20 days
Nursery - Vivero
Carminha's Meadow - Pasto da Carminha
Dawn Trail - Trilha Alvorada
High Trail - Trilha Alta
Medicinal Plants Trail -
Data processing
Manually isolating detections an... Mar 9 - 23
Creating clusters in raw data Mar 9 - 11
Creating cluster from isolated bi... Mar 22 - 23
Identifying birds Mar 22 - 30
Data processing ● Mar 9 - 30 ● 22 days
Manually isolating detections and saving wavs
Creating clusters in raw data
Creating cluster from isolated bird sounds
Identifying birds
Further activities
Building collaboration with Muri... Mar 11
Researching state of bioacoustics Mar 22 - 25
Exploring other Bioacoustics Sof... Mar 22 - 25
Further activities ● Mar 11 - 25 ● 15 days
Building collaboration with Muriqui Insitituto de Biodiversidade
Researching state of bioacoustics
Exploring other Bioacoustics Software
Reporting
Writing proposal for Wildlife Aco... Mar 11 - 16
Writing Proposal for IKI Mar 22 - 23
Report in InDesign Mar 22 - 30
Reporting ● Mar 11 - 30 ● 20 days
Writing proposal for Wildlife Acoustics
Writing Proposal for IKI
Report in InDesign

3. Preparations

Since the time at Iracambi itself was limited to 4 weeks, the success of the project depended largely on a good preparation. This phase has the following components:

- Choosing the subject
- Exploring bioacoustics possibilities
- Choosing and ordering equipment
- Learning to work with the tools
- Overview of possible bird species

Choosing the subject

Whereas Yvo's professional skills lie in the Smart City and Digital Innovation domain (link), the link to Iracambi's Smart Forest program were quickly made. Three options came forward in the conversation, namely bioacoustics, the use of drones for planting trees and sustainable energy system for the Iracambi terrain. As the planting season was ending and the upfront cost of the planting drone were high, and the sustainable energy topic was not that urgent, those options were disregarded. The topic of bioacoustics seemed most suitable, because of feasibility of generating results with low costs, the desire of Yvo to learn something new and the existing plans regarding ecosystem monitoring in the Smart Forest program.

Exploring bioacoustics

With no previous knowledge on the subject of bioacoustics, several organizations were contacted for help. Of those, the Brazilian-based IPBio that is active in bioacoustics was contacted through phone and gave a significant amount of information regarding the type of recorders that they use, from Wildlife Acoustics.

Choosing and ordering equipment

Wildlife Acoustics is a established company in the field of bioacoustics. Apart from the advice of IPBio, and being the only company answering questions through email, Wildlife Acoustics also makes the Kaleidoscope software for sound analysis, which seemed like a good match. Moreover, since only little time was left before Yvo traveled, delivery times were of importance and with Veldshop.nl a Dutch seller of the Wildlife Acoustics hardware was found. After calling them, it was confirmed that the Song Meter Micro at €275 was sufficient in combination with two SD cards of €27,50 each, and they even helped by testing the recorder before shipping. The purchase was done by Yvo as a donation to Iracambi.

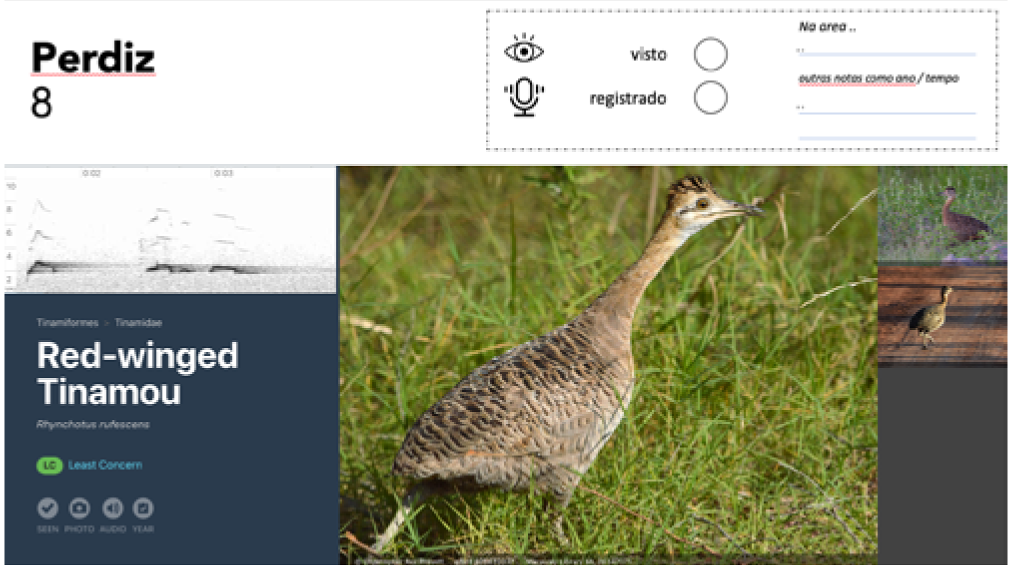
Learning to work with the tools

The installation of the SMM is straightforward and with the help of the user manual, the setup was tested in Sao Paulo, before traveling to Iracambi (see next chapter for the complete setup). Moreover, there is a bunch of video tutorials, webinars and online trainings available, for both the SMM (link) and the Kaleidoscope software (link), which were all used. For further questions, the support email of Wildlife Acoustics is very much open to communication and generally always answers questions coming up. Lastly, there is also a Facebook community where around 1600 users of the hard- and software can be questioned. (link)

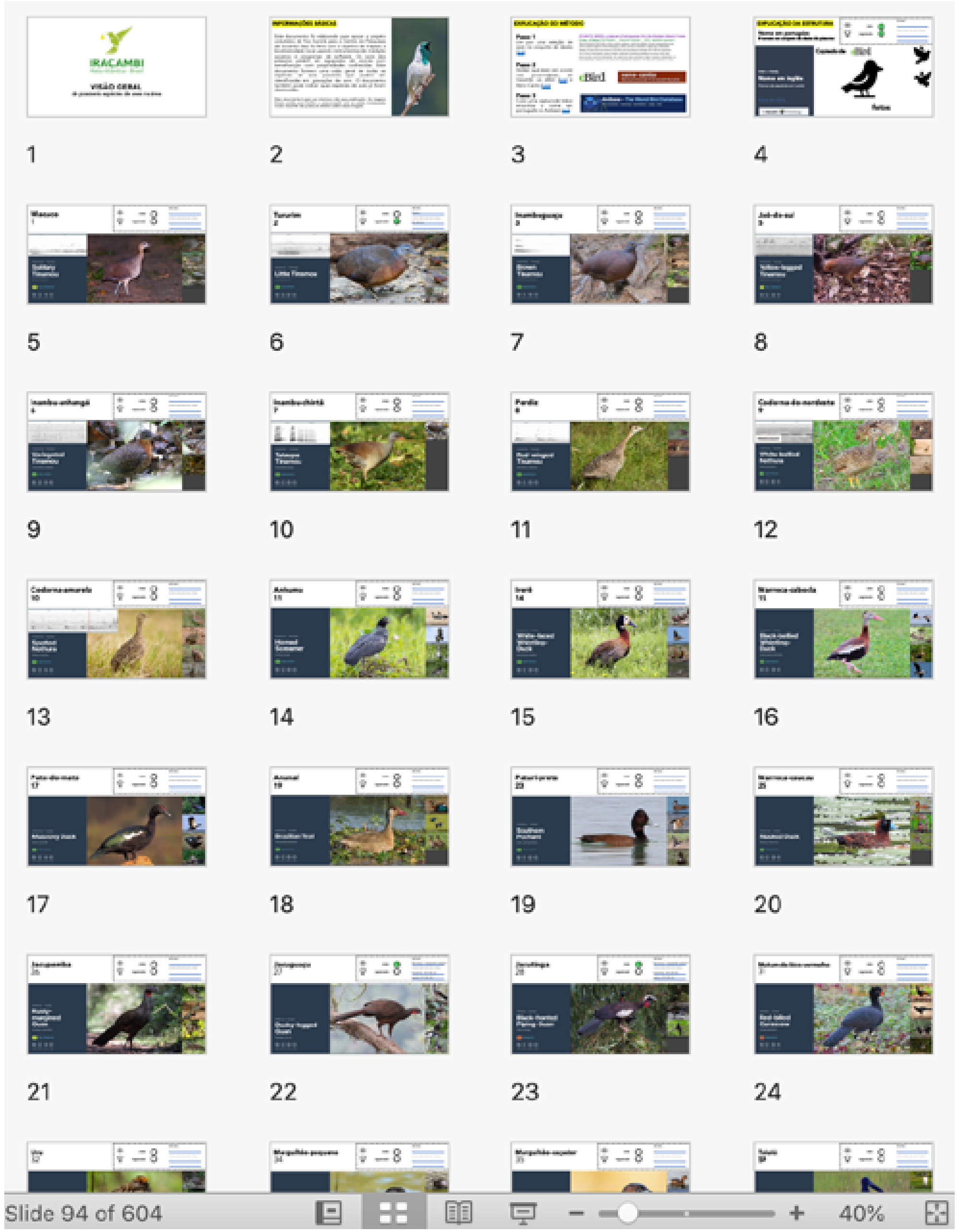
Overview of possible bird species

Recording sound is one thing, identifying the bird is next. The Kaleidoscope software is able to detect whether something is a detectable sound in the recording, and it can cluster similar sounds based on minimum, maximum and frequencies and some other patterns. However, Kaleidoscope 'does not know about birds', unless sufficient data can be fed to it and a classifier is made. In order to be able to identify which birds are audible in the recording, therefore, a baseline needed to be established of which birds are actually known, or likely, to be present in the area.

A research paper with a dataset of 830 bird species in the Brazilian Atlantic Rainforest (link) was used. With the help of the online databases of Ebird (link) and Xeno Canto (link), the likelihood of presence in the area by each species, or the possibility of migration due to reforestation, was determined. After adding it to the list upon confirmation, the Portuguese name was found with the help of Avibase (link). An internal list of spotted birds at Iracambi added 20 more species, which was given as feedback to the researchers who made the initial dataset. The list can be found in Appendix A.2. To further improve the usability of the results, a slide deck was made with basic information, images of the bird and its sonogram.



Screenshots from slide deck of 600 potentially detectable bird



4. Equipment Setup

For this exploration of bioacoustics at Iracambi, the decision was made to work with the most affordable sound recorder of Wildlife Acoustics, the Song Meter Micro (SMM) (link). The complete setup for installation becomes the following:

- Song Meter Micro
- Smart phone with Wildlife Acoustics configuration app
- 3x AA Batteries (for 120-170 hours of recording at 48kHz)
- 64GB SD card
- Attachment materials (rope / iron wire)

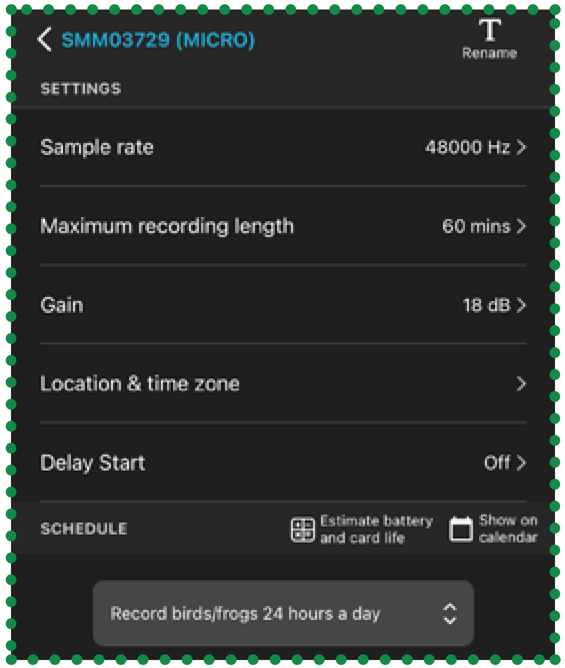
In the application, and on the website of Wildlife Acoustics, extensive and clear user manuals are available in several languages (link). The setup is straightforward and consists of using the pair button on the SMM to connect with the app on the phone. After loading in the configuration (see image on the right), and checking the SD card storage and battery status, the SMM has to unpaired again. Green blinking lights on the SMM indicate that SD card is active and that it is recording.

The equipment has been tried in 5 locations on the land of Iracambi, namely:

- The Nursery (Vivero) - 67 hours
- Carminha's Meadow (Pasto da Carminha) - 6 hours
- Dawn Trail (Trilha Alvorada) - 9 hours
- High Trail (Trilha Alta) - 112 hours
- Medicinal Plants Trail (Trilha Plantes Medicinas) - 14 hours
- **TOTAL - 208 hours**

WILDLIFE ACOUSTICS

Song Meter Micro



Configuration settings used

Things to consider

Location of the recorder

Some things have to be taken into account while installing. Firstly, try to minimize the background noise, such as windy areas, rivers or places with many insects. Secondly, find an area that is has open spaces for sound to travel, but prevent too open spaces so that there is not too much sound being picked, which can lead to more background noise or difficulty isolating sounds later. Also take into account what it is you want to measure, as some animals remain in the top of the trees, you might want to get higher up to catch the sounds.

Closing the lid

Make sure, when closing the SMM, that a click can be heard twice. The lid is, especially in the first few uses, a bit hard to close and when not done properly, this leads to the SMM not being waterproof.

SD slot fragility

The SD card holder in the SMM is very fragile. After forgetting that for removal it first needs a slight push, the SD card was forced just a bit and bend the ejection system just enough for the card not to click in anymore. A quick-fix was found by using a wooden stick to keep pushing the card in, which did the job, but the sustainability of this solution is questionable.

SD card formatting

The SD card does not seem to actually remove data when you delete the files and this has two times resulted in the card being full after only several hours of recording, while the recorder was out several days. It is recommended to format the SD card after each use.


Medicinal plants trail (click for map)


Dawn Trail (click for map)


Carminha’s Meadow (click for map)


IRACAMBI
Serra do Brigadeiro
Medicinal plants trail
Nursery
Carminha's Meadow
REC
REC
REC
REC
REC
High Trail
(oldest forest)
Dawn trail
Belisario
+-5km
500 ha
Legenda
rua
rios
Trilhas
canjiquiha
Jacaré
PlantasMed.
natureza
alvorada
vale
limite
eucalipto
alta
irland-esa
N
W
E
S
Rosário de Limeira
REC
Location of recording

5. Data Processing

For the data processing, the Wildife Acoustics software Kaleidoscope was used, for which a 30 day trial was unlocked during this project (normally $400,- per year). There are three main functions that Kaleidoscope offers which were used:

- **Detection of sound signals** **(Free version)**
- **Clustering detections in recording** **(Paid version)**
- **Using existing cluster on new data** **(Paid version)**

Detection of sound signals

With the sound recorder, depending on your settings, large sound files are generated. It is not practical to have to analyze the whole sound file second by second, as it would take large amounts of time. Therefore, this functionality helps to reduce workload, by extracting snippets of sound from the file, on which a potentially interesting sound can be heard. The settings allow for optimizing this.

When using this functionality, in the case of Iracambi recordings, between 6.000-12.000 detections are done within a 60-minute recording. These can be individually selected and visualized from a list, that is saved as an editable csv file. The detections can be sorted on a wide range of columns, such as min/max/mean frequency, and can also receive manual input per detection. Any detection can be extracted in a separate WAV file. On the next page, a screenshot is positioned of the windows of Kaleidoscope.

Not all detections are useful. Some might be solely background noise, partial bird songs or bad quality. This means that using this function leaves a lot of manual work left to do. And it does not yet provide any answers on which bird is detected how many times.

Clustering detections in recording

This functionality is the main selling point of the Kaleidoscope pro software. By using a statistical model called a 'Hidden Markov Model' the software compares the detected sounds for similarity and groups together the ones that are statistically similar in so called clusters. The biggest group of sounds is cluster 00, every next cluster is the group that looks most similar to the previous, meaning the last cluster is most statistically different from the first. The first sound in a cluster is the sound that is closest to the average of the cluster, and the last has the most distance. The settings allows for changing the thresholds of how many clusters are maximally formed, and what the maximum distance to the cluster center can be for sounds to be included. The found clusters can be saved in a classifier.

It is possible that detections that were audible in the former function of detecting sound signals, are not included in any cluster, because they do not have sufficient statistical significance to other sounds. This means that the cluster analysis will usually not show that one special bird that only made a single sound. It can also mean that calls of a single bird are audible in several clusters, because of slight differences in the file due to variations in the call or certain background noise.

Using existing cluster on new data

When the cluster analysis has good results, a classifier file can be generated that saves a mathematical representation of the found clusters. This cluster file can be used on new data, that will analyze the new sound recording for detections that are statistically similar to the pre-defined clusters from the earlier clustering on old data.

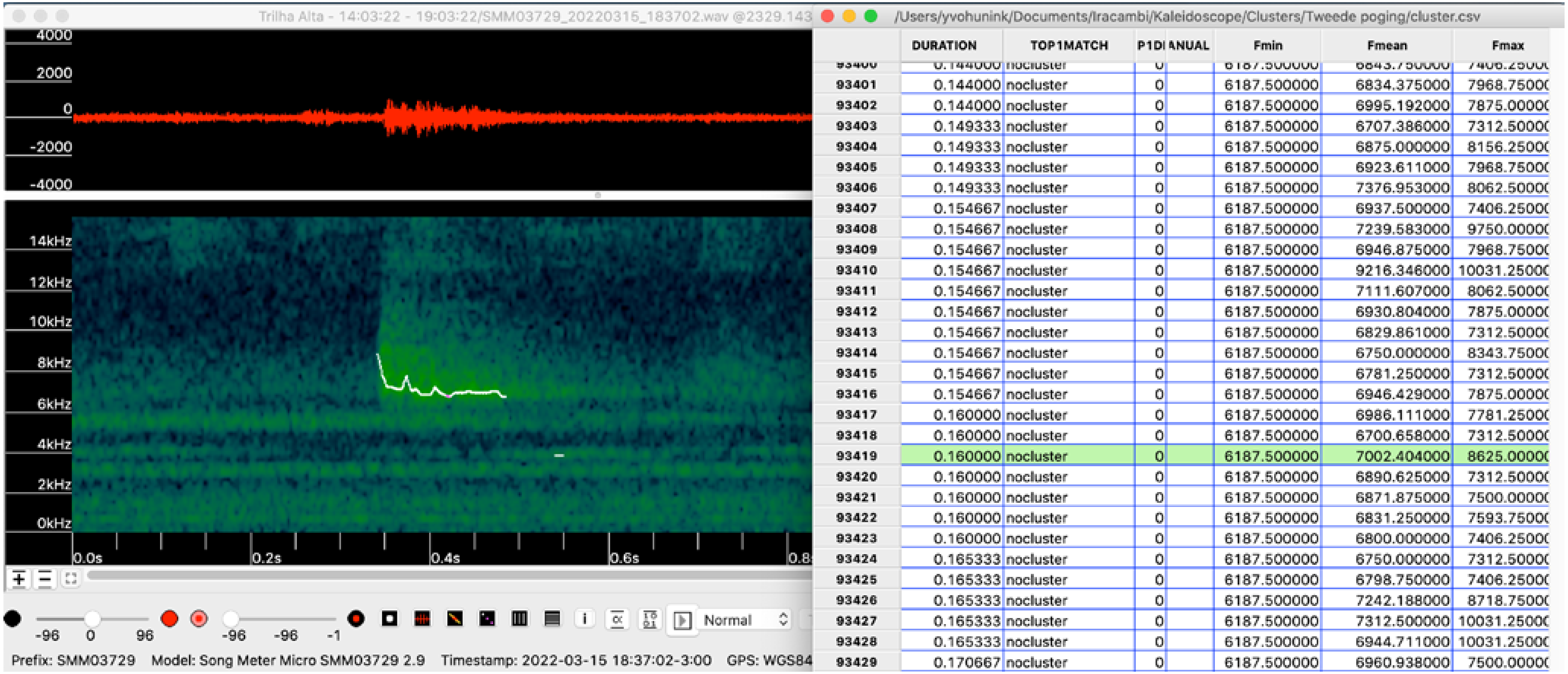
Using a cluster file will only analyze the data according to the clusters that are saved in the cluster file. Any detection that does not fall within the clusters will not show up, nor any new clusters that were not predefined.

When is Kaleidoscope useful?

From the gained experience and discussions with the support team and online groups, it has become clear that Kaleidoscope is mainly useful for tracking one or a few species of species. With sufficient training data a decent classifier could be built, which can be used to scan many GBs of data for those few cluster. A very inaccurate and general idea of present species might also come from doing multiple cluster analyses with different frequency bandwidth filters over recordings of a single location. The free function of detecting signals can also be useful for manually building a sound database

Kaleidscope is not practical to build a classifier suitable for reliably sorting hundreds, or even dozens, of species. Another issue is that the clusters become very unreliable with background noise, of which there is a lot at Iracambi, therefore still needing much manual work.

Screenshot from Kaleidoscope software after batch analysis of 54 sound files of each 60 min



	DURATION	TOP1MATCH	P1DI	ANUAL	Fmin	Fmean	Fmax
93400	0.144000	nocluster	0		6187.500000	6843.750000	7406.2500
93401	0.144000	nocluster	0		6187.500000	6834.375000	7968.7500
93402	0.144000	nocluster	0		6187.500000	6995.192000	7875.0000
93403	0.149333	nocluster	0		6187.500000	6707.386000	7312.5000
93404	0.149333	nocluster	0		6187.500000	6875.000000	8156.2500
93405	0.149333	nocluster	0		6187.500000	6923.611000	7968.7500
93406	0.149333	nocluster	0		6187.500000	7376.953000	8062.5000
93407	0.154667	nocluster	0		6187.500000	6937.500000	7406.2500
93408	0.154667	nocluster	0		6187.500000	7239.583000	9750.0000
93409	0.154667	nocluster	0		6187.500000	6946.875000	7968.7500
93410	0.154667	nocluster	0		6187.500000	9216.346000	10031.2500
93411	0.154667	nocluster	0		6187.500000	7111.607000	8062.5000
93412	0.154667	nocluster	0		6187.500000	6930.804000	7875.0000
93413	0.154667	nocluster	0		6187.500000	6829.861000	7312.5000
93414	0.154667	nocluster	0		6187.500000	6750.000000	8343.7500
93415	0.154667	nocluster	0		6187.500000	6781.250000	7312.5000
93416	0.154667	nocluster	0		6187.500000	6946.429000	7875.0000
93417	0.160000	nocluster	0		6187.500000	6986.111000	7781.2500
93418	0.160000	nocluster	0		6187.500000	6700.658000	7312.5000
93419	0.160000	nocluster	0		6187.500000	7002.404000	8625.0000
93420	0.160000	nocluster	0		6187.500000	6890.625000	7312.5000
93421	0.160000	nocluster	0		6187.500000	6871.875000	7500.0000
93422	0.160000	nocluster	0		6187.500000	6831.250000	7593.7500
93423	0.160000	nocluster	0		6187.500000	6800.000000	7406.2500
93424	0.165333	nocluster	0		6187.500000	6750.000000	7312.5000
93425	0.165333	nocluster	0		6187.500000	6798.750000	7406.2500
93426	0.165333	nocluster	0		6187.500000	7242.188000	8718.7500
93427	0.165333	nocluster	0		6187.500000	7312.500000	10031.2500
93428	0.165333	nocluster	0		6187.500000	6944.711000	10031.2500
93429	0.170667	nocluster	0		6187.500000	6960.938000	7500.0000

6. Data Analysis & Results

This project was mainly set up to determine the value of bioacoustics in forest monitoring and measuring biodiversity and ecosystem health. While Kaleidoscope does not fill all requirement that were defined, however, several steps of work have been done that did deliver results, namely:

1. The deployment of the recorder
2. Loading the sound files in Kaleidoscope
3. Manually analyzing detections in 25 hours of recordings
4. Separating files in folders dedicated to similar types of sounds
5. Using the WASIS software.
6. Comparing sounds with suggested birds on Xeno Canto and Ebird

This has led to the following results:

- **Identification of birds**
- **A sound bank of isolated sounds sorted on similarity**

Identification of birds

Since Kaleidoscope does not have a database for birds (as it does for bats), the identification of the corresponding birds with the different types of songs and calls that were found needs to be done through some other method. There are several potential strategies for further identification, each with its up- and downside.

1. Manual comparison of database with Xeno Canto/Ebird data
2. Analysis by WASIS software from UNICAMP
3. Consultation of an expert for specific identification
4. Upload to Xeno Canto for identification by the community
5. Share on social media for help from network

1. Manual comparison - This strategy it very time intensive, whereby each species in the dataset is found on Ebird and Xeno Canto, and the available sounds and sonograms are compared to the known types of songs and calls from the detections. It is less precise than statistical analysis, but might give better results, because the human ear is tuned to spot similarities that algorithms do not see, especially with background noise. One bird was identified this way. The call of the **Little Tinamou** or Tururim (Crypturellus Soui) (on the photo on the right) was recognized and after comparison it was confirmed that length and frequency of the Little Tinamou were equal of the found detections. The identified song was uploaded to Xeno Canto under the ID of XC710680 (link), to contribute to the community from which this project benefited greatly.

2. Brute Force Analysis in WASIS - Fortunately, the software program 'WASIS' (link) created by researchers from UNICAMP, a Brazilian public university in the city of Campinas, came to the attention after e-mail correspondence with them through a connection at IPBio. Here a sound file can be loaded in, a focus area selected and a so called 'brute force analysis' can be done to make a comparison with sounds from their database. When first trying the software it gave a good lead to the song of the **Rufous-Browed Peppershrike** or Pitiguari (Cyclarhis gujanensis), which was confirmed after applying the techniques of strategy 1. However, after trying out more sounds, the same birds keep on coming up as suggestions and even the Rufous-Browed Peppershrike was suggested in other detections. Furthermore, the software is only available for Windows OS and the manual is only available in Portuguese.

3. **Consultation of an expert** - Someone with knowledge about bird sounds might help to identify. No such person was yet found.

4. **Upload to Xeno Canto** - On this citizen science bird sound community, one can upload a sound and click the option 'ID unknown', for a post to be created on the forum. Up until now, six of those have been uploaded (link), however no responses have been received yet.

5. **Share on social media** - A video was created, with the software Adobe Premiere Rush, with some introductory text. At the end, one of the unidentified songs is presented, with the request to the community to help identifying it. Apart from creating engagement, which is the main objective of the video, this could result in surprising findings with the help of Iracambi's followers. If successful in creating engagement or identifying the bird, other mystery birds will be shared in the same setup, possibly with another shorter introduction.

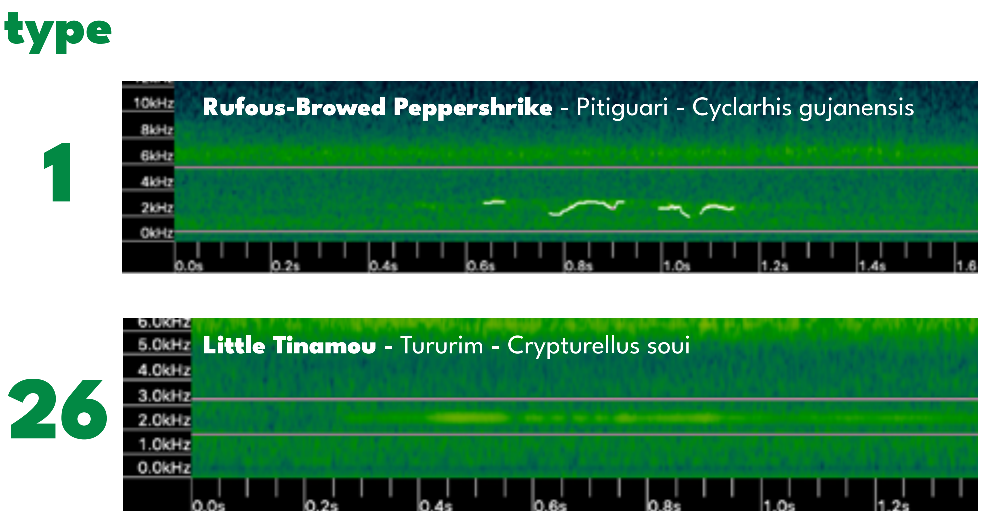
Screenshots from the video made for social media

Sound bank of isolated sounds

With the help of Kaleidoscope, it can be evaluated if sounds are similar. A total of 25 hours of recordings (all in the nursery) have been analyzed with the detections functionality of Kaleidoscope. In total, 845 sound files have been isolated, in which 35 song/call types have been found. Also several songs have been isolated that were only detected once, but were distinguishable enough to be added to the sound bank in a separate folder of single detections.

When the isolated detection is loaded in Kaleidoscope, the sonogram and other information such as the timestamp can be re-evaluated. In the below image, two of such sonograms (of frequency) are shown of the two birds that are identified. In Appendix A.1, the all the 35 types of sonograms with multiple detections have been placed. The sound bank is made available in a folder structure, containing all the wav files.

Sonograms of the identified birds



Little Tinamou - Tururim - Crypturellus soui
Song recorded on 05/03/22 at 08:03


Rufous-Browed Peppershrike - Pitiguari - Cyclarhis gujanensis
Song recorded on 04/03/22 at 17:10

7. Discussion

Some things discovered over the course of this project needs to be explored in greater detail. This section elaborates on some unresolved or unclear issues or gives input for potential future projects

Sound recorders

While the Song Meter Micro seems to have done the job, there can be a discussion on price, quality, usability. There are, for example cheaper recorders that could have the same quality as the SMM, or perhaps more expensive ones that deliver more value. Possible brands that can be evaluated are:

- Other recorders by Wildlife Acoustics (link)
- Recorders by Frontier Labs (link)
- Recorders by Labmaker (like Audiomoth) (link)
- SwiftOne by Cornell Lab of Ornithology (link)
- Anabat chorus (acoustic + ultrasonic) (link)

Quality of clustering analysis through Kaleidoscope

In the experiences gotten through the use of the software by Wildlife Acoustics, the quality of the clusters was not good at all, resulting in all kinds of different types of sounds in one group. Different configurations of the settings did not help too much. Since creating a classifier in Kaleidoscope is completely dependent on a good outcome of a clustering, it appeared this software would not be suitable for identifying birds in a rapid and automated way. The feedback from Wildlife Acoustics support was that the recording was of poor quality, meaning too much background noise, and too many different variations of sound, and that this made the clustering algorithm have those results. Since these are characteristics of the Atlantic Forest, it seems that Kaleidoscope will not be of help. Furthermore, since the clustering functionality tends to only include detections that can be clustered in the output, a lot of data is lost. Certainly species that are not as vocal as others, but of which a single call can be of value, will not show up this way. It can, therefore, be argued that Kaleidoscope's free functionality of separating detections in sound files is the most valuable one for Iracambi right now.

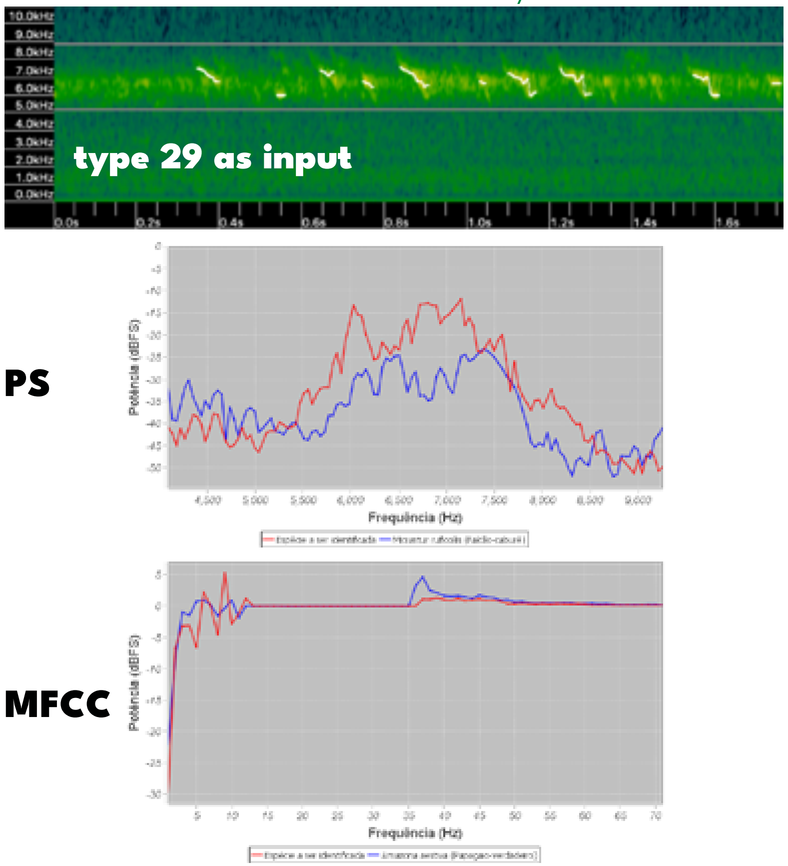
Identification of birds

Where the clustering in Kaleidoscope did not provide satisfying results, it would also be impossible to do an identification with the help of a pre-made classifier. The classifier is completely dependent on a good clustering, and classifiers cannot be made by providing labeled input training data of known species. Therefore, the option of WASIS as a software program for identification of birds was a warm welcome to the toolkit. However, also there the results were not satisfactory.

After having tried the majority of the 35 found types of songs, only a single identification was done, which also came in low on the list of suggestions. After a while, it was clear that the same 10 or so birds kept coming up with each sound type, such as the Amazona aestiva and the Pyriglena leucoptera and the Volatinia jacarina. This suggests that the database has an over-representation of those birds and insufficient data on the desired sounds. Also the different models that can be selected generate very different results as well, as can be observed from the images on the right. Here, with the same input (Type 29) two different models, Power Spectrum (PS) and Mel Frequency Cepstral Coefficients (MFCC), generate two different suggestions for birds. This is, presumably, because the program compares only part of the sound to known frequency patterns. Therefore is suggests a species as soon as a part of the song is similar, however. Also what can be observed from the graphs, is that the y-axis is in dBFS, which has to do with the amplitude (gain) relative to the full scale. Especially with background noise this will likely result in inaccurate comparisons.

Therefore, it is even questionable if the identified bird with WASIS (Rufous-Browed Peppershrike - Pitiguari - Cyclarhis gujanensis) was not an accidental identification, as this same bird was suggested for a sound file of Type 6 as well, which was on a different frequency.

Results from Brute Force Analysis in WASIS



Deep learning and neural networks (artificial intelligence)

The software used during the course of this project are algorithms, namely signal detection, clustering (Kaleidoscope) and classification (WASIS) and help to analyze data more rapidly. However, each are a preset mathematical model that executes the same steps every time and, especially in noisy environment as the rainforest, does not always work as well in separating similar sounds.

Those used algorithms for detection, clustering and classification are not, in fact, 'self-learning' algorithms, which is a growing field within artificial intelligence, also referred to as deep learning or neural networks. Self-learning algorithms use of feedback and use that as input for retraining the model. This means that when an algorithm comes up with a suggestion, one can 'answer' back if the algorithm got it right, which is incorporated in the calculations for the next time. The recent rapid developments and research on neural networks are very promising for the use in bioacoustics. An extensive overview on the current literature was made by Dan Stowell (2021) (link). From that review it becomes clear that especially Convolutional Neural Network (CNNs) are gaining ground on the algorithms evaluated by this project. Moreover, several other functionalities present themselves on the horizon, such as noise reduction, data compression and even synthesis of new sounds, used by researchers to playback sounds or to add to datasets on endangered species one which little data is available.

Until today, no software is known that incorporate these kinds of algorithms on a commercial scale. However, researchers are building on open source frameworks (link), and tutorials on standard software like R is available (link) (link), making a project at Iracambi feasible, especially since the sound bank can serve as training data.

8. Recommendations

From the findings in this project, what things can be recommended for a following phase? Several clusters of recommendations are seen.

Bioacoustics for reforestation and conservation organizations

Using bioacoustics to determine ecosystem health is certainly a potential strategy and could be pursued by organizations such as Iracambi. However, the amount of work should not be underestimated and the current state of technology is not yet at a state that the complete ecosystem is easily monitored. The developments in neural networks mentioned in the discussion are rapidly changing this, and Iracambi could play a pioneering role to help the practice of bioacoustics for broad ecosystem health further. In the mean time, monitoring of key ecosystem species lies within the technological possibilities with the tested software. It is recommended to appoint a bioacoustics coordinator within the organization, who deals with the recording equipment, sound bank management, setting up the research agenda on bioacoustics, supervising volunteers and progress monitoring. The specific application of technology is possibly better outsourced to organizations who have the capacity to operate sound analysis workflows, such as Conservation Metrics (link). The grant proposals mentioned in Chapter 9 show some other recommendations that will be elaborated there.

Managing the recordings and the sound bank

While it might be hard at this point to analyze all the data that can be generated, as can be seen from only 10% of recorded data being analyzed during this project, future development or software purchases might still become available with which this data can be analyzed. Especially in the areas where the reforestation activities are just at the start, it is important to capture the current soundscape, so that after regrowth a comparison can be made for an evaluation of changes in biodiversity and ecosystem health. Also, in the mean time, remote volunteers or interns can help to render the recordings with the help of Kaleidoscope's free version and can isolate interesting sounds. This in turn is input for the sound bank, where they can be separated according to similarity. If possible, preparing for neural networks is possible by labeling the data (see link).

During the making of this report some errors were discovered in the sounds already present in the sound bank, but due to time constraints a complete check was not feasible. It is recommended to double check if all the sounds in the type folders are indeed similar and of good quality. Furthermore, it is recommended to create an accessible online sound bank database, both for isolated detections and the raw recordings, that can help with the remote analysis of the data by the volunteers. An offline back-up should not be forgotten.

Identification of birds

Whereas the true value of the sound bank can only be obtained of the sound types are linked to an actual bird species, it is of vital importance to keep the work of identification ongoing. The strategies in chapter 6 can be used, and possibly additional strategies might be discovered. Since currently there is not a one-size fits all, this will probably require some time and effort, and several strategies at the same time will generate the best result. It could be a separate project for (remote) volunteers to identify the 33 unidentified types that are already present in the sound bank, but from continual analysis of the sound this number is likely to increase.

Ideal software requirements

When one sketches an ideal situation of how software could assist the biodiversity monitoring, a certain (not yet exhaustive) set of recommended requirements can be defined, such as:

- Create 'classes' for bird species, and possibly others, like noise
- Create 'sub classes' for variations in songs, calls
- Allow labeled training data as input for (sub)classes
- Isolate detections from recording with algorithm, removing noise
- Add metadata to detections (e.g. timestamp, location)
- Reducing background noise within detection
- Manually adjust detections (from original file, to repair mistakes)
- Select area of interest in detection (frequency band, time frame)
- Let adjustment be feedback for detection algorithm
- Provide suggestions for classifications of new detections
- Give feedback on suggestion (yes/no/unsure/other class/noise)
- Make classification algorithm learn from feedback
- Cluster similar detections that have no label in new 'special class'
- Group unclustered individual detections in 'unclusterable' class
- Manually adjust, create or remove clusters (and let it be feedback)
- Create overview of all detections, incl (suggested) labels
- Provide options for structured exporting detections to database

The recommendation is to search for software that can at least fulfill these requirements, or find a party willing to co-create such software. Some on the requirements can be found in the available software on the market, but only when all requirements can be met, a labor-minimized workflow can be operated, with which potentially full ecosystem monitoring can be reached, rather than a focus on a few species.

9. Deliverables

Several deliverables can be determined from the project

- **Grant proposal Wildlife Acoustics**
- **Grant proposal International Climate Initiative**
- **Reporting, with supporting documents and recommendations**

Grant proposal Wildlife Acoustics

From the beginning of the project it was clear that Iracambi was aiming to file a proposal with the grant program of Wildlife Acoustics, which every quarter gives out max $4000 worth of equipment per proposal. The goal of this project was, therefore, mainly to explore how the equipment and software from Wildlife Acoustics might be used, so that the proposal to the grant could be enriched.

The most important conclusion from using the Song Meter Micro and Kaleidoscope is that the proposal should be focused on mainly tracking one or a few species. In conversations with the local community, it quickly became clear that the near-threatened Bare-Throated Bellbird or Araponga (Procnias nudicollis) is an important species that is rarely heard outside of forested areas and the local state park of Serra do Brigadeiro. Hearing this bird in a reforested area, and it therefore having recolonized their, seems to be a potential indicator for ecosystem health. Furthermore, it is one of the most audible and distinguishable birds out there, making it easier to record. Placing recorders in the state park and analyzing, therefore, could help build up the sound database of araponga sounds, after which a classifier can be built that can be used to analyze the recordings made in reforested areas. This insight gave rise to a collaboration with an organization already active in improving the biodiversity in the state park, who can also benefit from the equipment from the grant.

The 'Muriqui Instituto (MIB) de Biodiversidade' is an organization specializing in tracking, monitoring and researching the endangered Woolly Spider Monkeys or Muriqui (Brachyteles hypoxanthus) the largest primate of the Americas, which resides in the state park. Currently, MIB uses camera traps to monitor the primates, but installing and maintaining these is a lot of work and the chances of not getting results is high. Sound detection of the primate could help specify the locations to where they are recolonizing up front. This way the chances of success can be improved. While the recorders are deployed for the Muriquis, the Araponga is also likely to be recorded, as their habitats overlap. Furthermore, MIB has exclusive access to closed parts of the park, meaning that they can get the recorder on places where others cannot.

Lastly, all the other sounds being picked up during the recordings, can still be isolated for manual analysis and will be added to the sound bank that was initiated during this. This way a broader species analysis might eventually rise from the data collection. Altogether, the objectives of the proposal might be summarized as:

1. What are the observable recolonization patterns of the threatened bird species of the bare-throated bellbird towards reforested areas outside of the state park and what indications for ecosystem health does this give?
2. What are the observable recolonization patterns of the endangered primate species of the woolly spider monkey?
3. What species can be detected through bioacoustics and registered in a local sound database and which of those could be further analyzed for ecosystem health of the local forest?

Grant proposal International Climate Initiative

Iracambi, in support of their envisioned Smart Forest Project, is preparing a larger proposal. In the proposal, the main outcome is the a new and better way of data-driven working by professionals in forest management, water quality, environmental protection or other ecosystem research topics. The output is a monitoring system itself, with several indicators, such as water quality, soil health, forest growth and biodiversity. The proposal contains a wide variety of measurement techniques for data generation on those indicators, of which bioacoustics is one. Tracking certain important species is part of that, as is part of the other grant proposal, but also a more advanced way of using bioacoustics might be used. The insight in that came from the academic publication by Sueur, J., Pavoine, S., Hamerlynck, O., & Duvail, S. (2008) (link), where acoustic, spacial and temporal entropy are introduced as indicators for biodiversity.

Reporting, with supporting documents and recommendations

This project has generated several deliverables, summarized in this paragraph.

- Overviews of potentially detectable bird species (xls & pdf)
- 208 hours of raw recording data in 5 different locations (wav)
- Sound bank with 845 sound files of 35 types and 2 identified (wav)
- Worksheet for comparing type of sounds and bird species (xls)
- Social media content
- Extensive report with insights and recommendations.

The main outcome is insights for Iracambi into the use of bioacoustics and how it can be of value in the work of reforestation and conservation. We leave the conclusion for the following chapter.

10. Conclusion

The main question of this report was: **What value can bioacoustics bring to monitoring forest ecosystems and how is it applied in practice?** The answer to this question is, naturally, answered in the context of Iracambi, but might be generalized to other reforestation and conservation organizations. To start, let's differentiate in what bioacoustics can do today, and what possibilities lie in the future.

Currently, the biggest value in bioacoustics, with the known software on the market, lies in tracking a single or a few species of sound producing animals. This could be a species that is an indicator for ecosystem health and for which certain recolonization patterns might be observed to determine whether they are returning to the reforested areas. Sound recorders can be used to record the species in their current environment, building up a sound database for building classifying algorithms, which can spot species in new recordings of other areas. Another potential, but not tested, possibility is the use of sound recordings in determining more general biodiversity indicators, such as acoustic, temporal and spacial entropy. This gives a more mathematical approach to biodiversity indicators.

In the future with the recent development in neural networks, however, a much more extensive analysis might become possible. In this view, a broad ecosystem monitoring becomes possible, because the scale and accuracy of data analysis is being increased with those technologies. This could generate extensive proof of ecosystem health, and can, for example, be used as evidence to donors.

The conclusion is therefore that bioacoustics generate sufficient value and continuing activities with it will serve Iracambi in the future.

Photo Credits

CHAPTER	PHOTOGRAPHER (+link)	SPECIES NAME (PT-EN)	NUMBER IN DATABASE
Cover photo	Vlad Tchompalov	Periquitão - White-eyed Parakeet	#374
Preface #1	Christian Costa	Quero quero - Southern Lapwing	#143
Preface #2	Unknown	Beija-flor-de-orelha-violeta - White-vented Violetear	#280
Table of Contents	Carlos de Almeida	Saíra-sete-cores - Green Headed Tanager	#749
Introduction	Maurício Guardiano	Tucanuçu - Toco Tucan	#321
Data Analysis #1	Gary L.Clark	Tururim - Little Tinamou	#2
Data Analysis #2	Wagner M. C. Lemes	Pitiguari - Rufous-Browed Peppershrike	#667
Recommendations	Ilona Frey	Arara-canindé - Blue-and-Yellow Macaw	#369
Deliverables #1	Ben Tavener	Araponga - Bare-throated Bellbird	#558
Deliverables #2	Laurianyf2004	Muriqui - Woolly Spider Monkey	#xx
Conclusion	Ricardo Porto	Carcará - Crested Cararaca	#357
Photo credits	Nicolas Ladino Silva	Humano - Human	#xx
Back cover	James Wainscoat	Flock of birds	#xx

APPENDIX
A.1 - Sonograms

In the 25 analyzed hours of recordings, 35 types of song and/or calls have been detected. From each type, a screenshot has been made in Kaleidoscope, and was added to this appendix.

Note that is can be that several types of sonograms belong to the same bird, as birds often have a variety of calls within their capabilities. The identified calls (Type 1 and 26) have the name of the bird in white added.

As the resolution of the images was kept similar, for better visual appearance, the scales of the axes have been changed. That means that it is not the positions on those axes that should be compared, but rather the patterns in the frequency change. In several of the screenshots, orange lines have been added, for assisting in visually determining the frequency bandwidth of a certain signal.

The files in the sound bank can individually be opened in Kaleidoscope for further, and more extensive, analysis of the sonograms. Also visual alterations can be executed, such as different colors, changes in the gain, removal of the white dots of pattern recognitions and more. This could help in reducing the often omnipresent background noise, which is represented here by general large patches of green.

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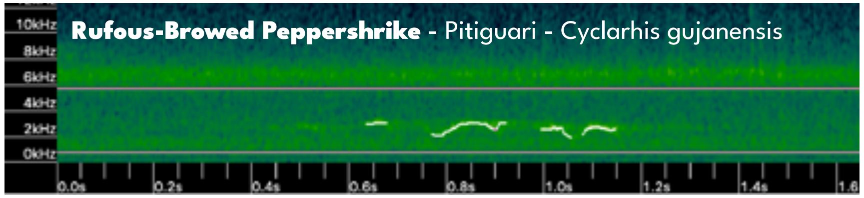

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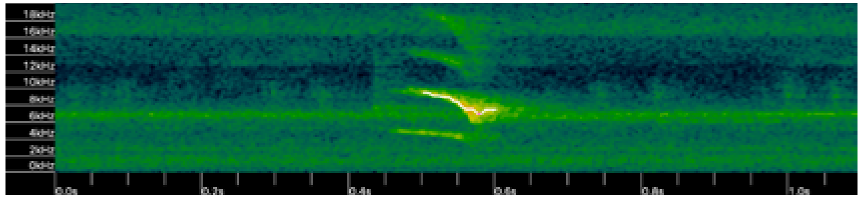

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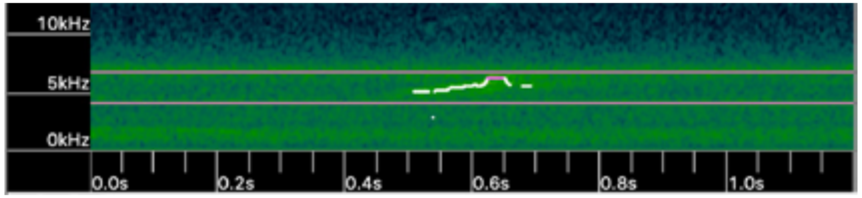

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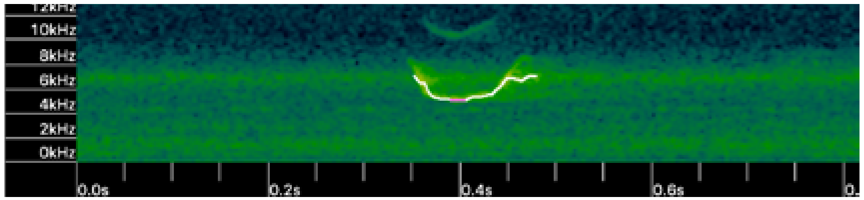

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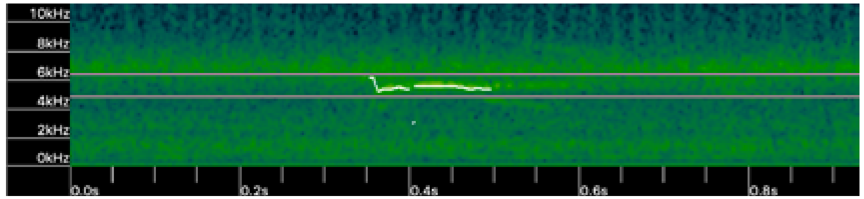

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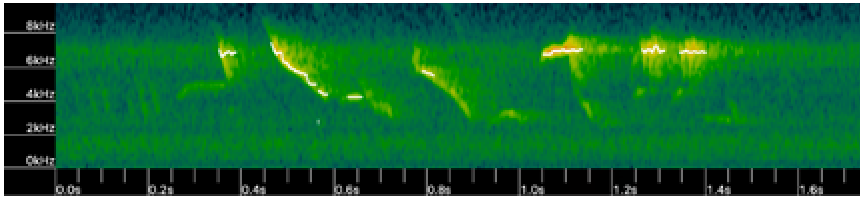

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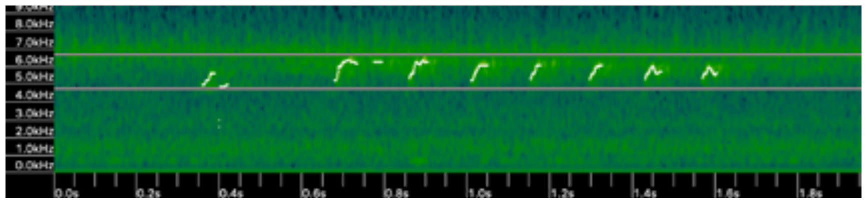

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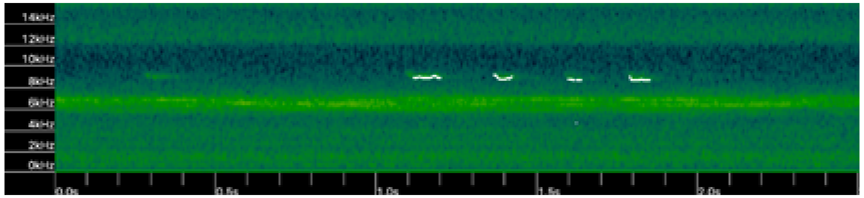

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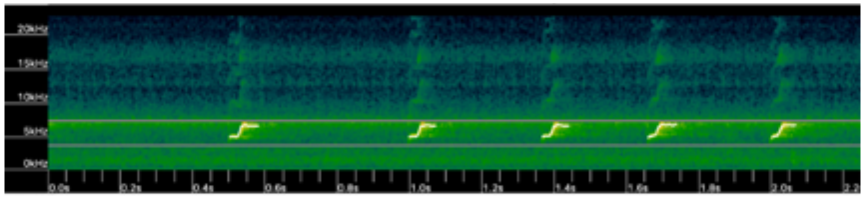

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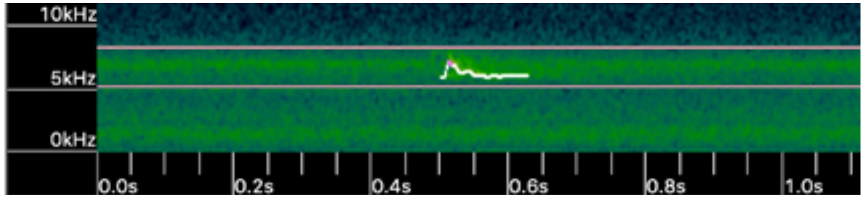

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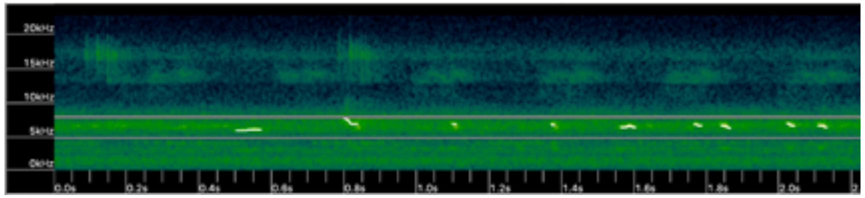

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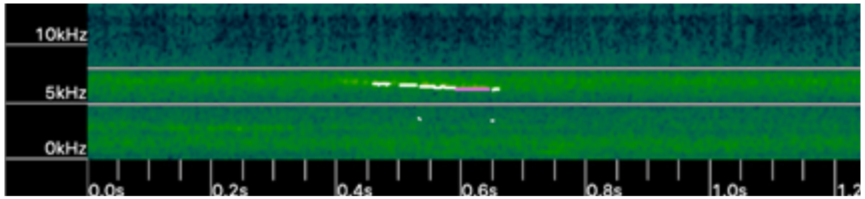

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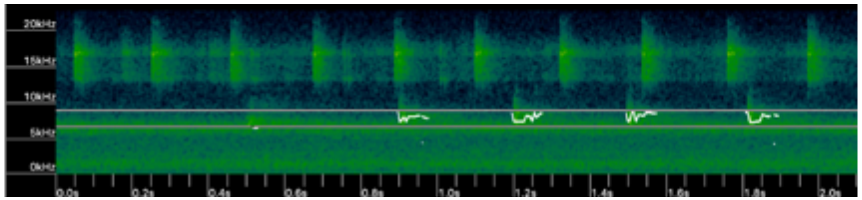

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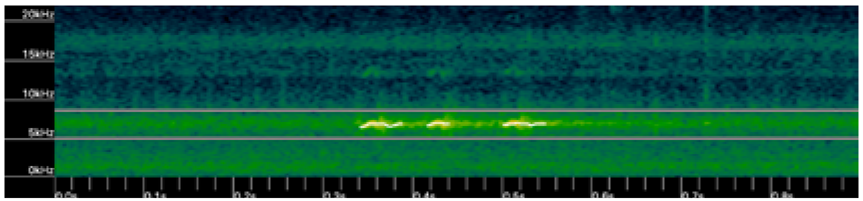

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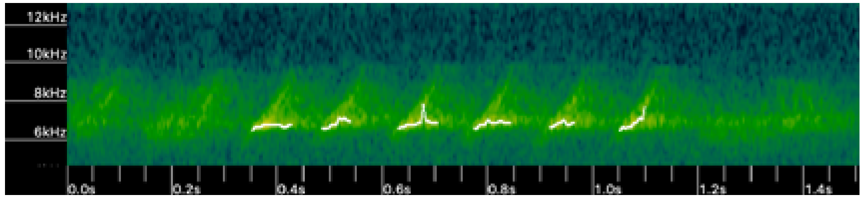

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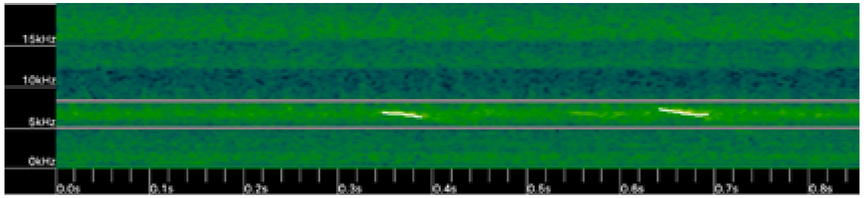

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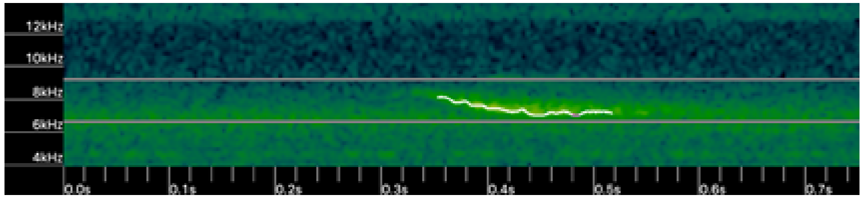

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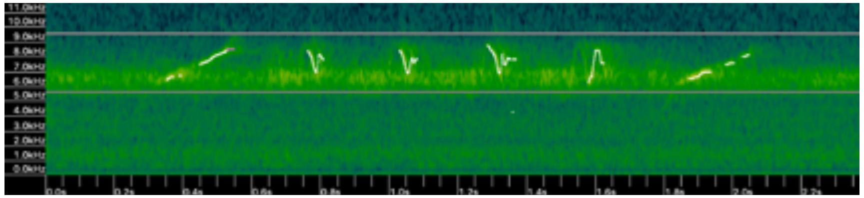

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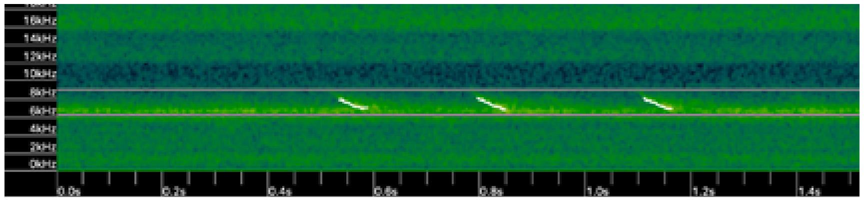

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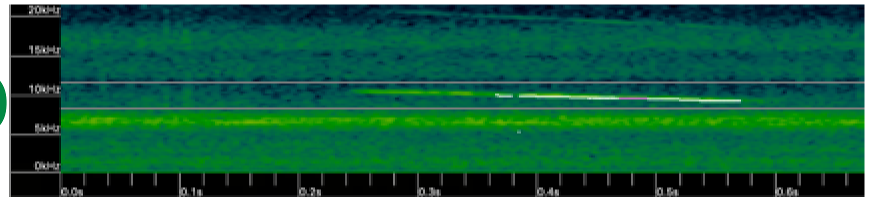

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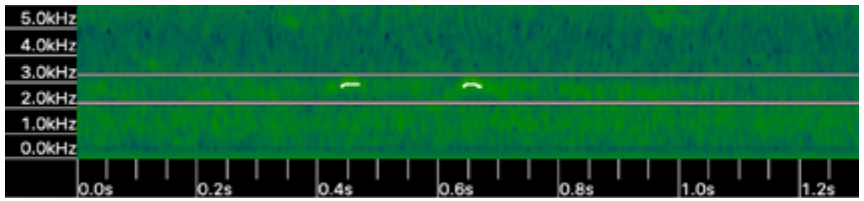

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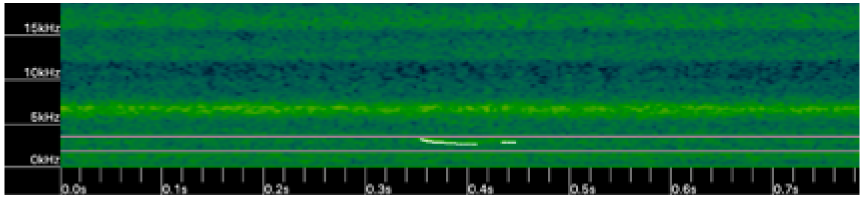

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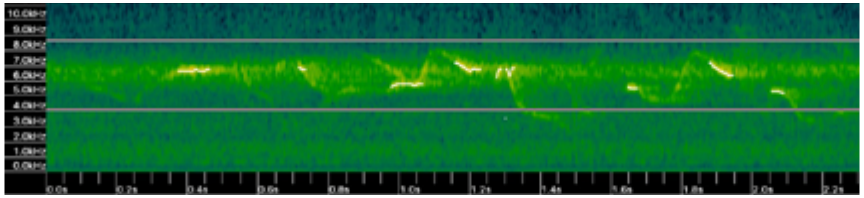

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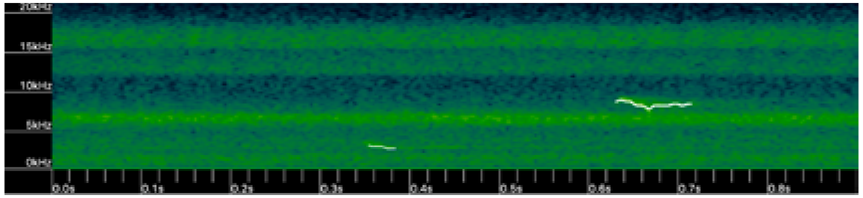

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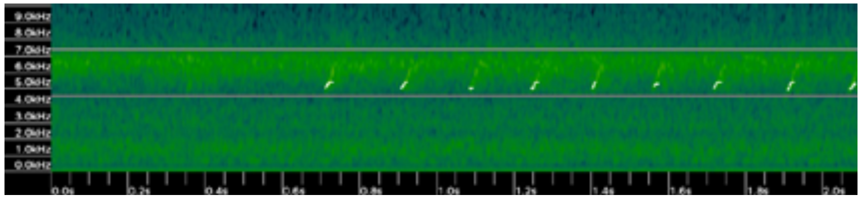

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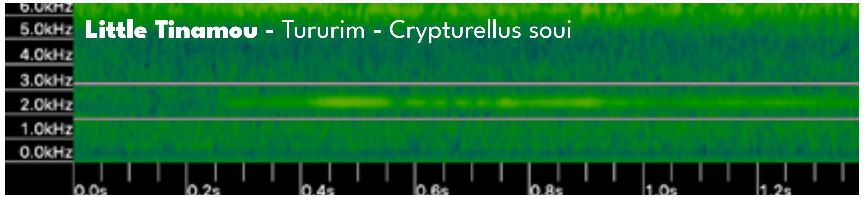

Little Tinamou - Tururim - Crypturellus soui

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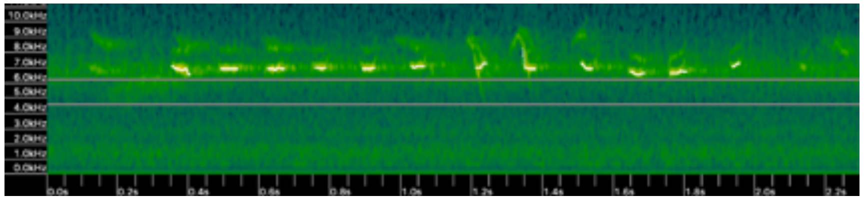

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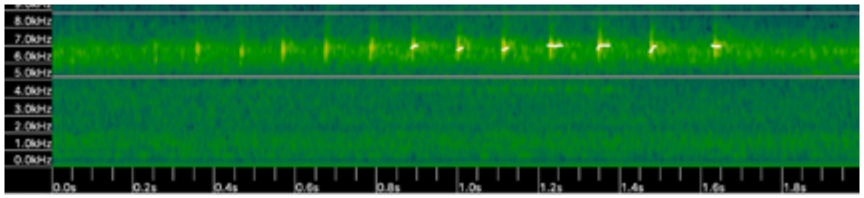

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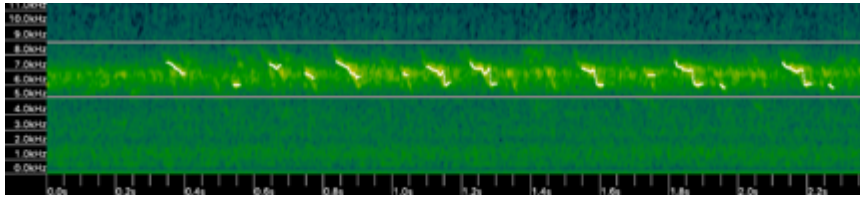

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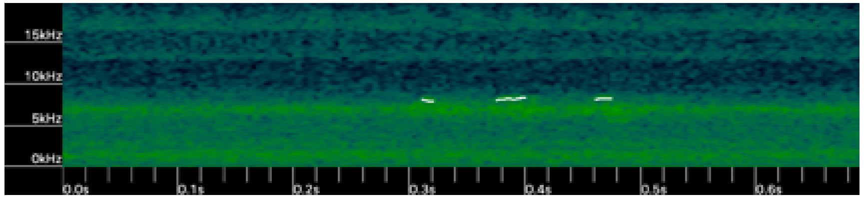

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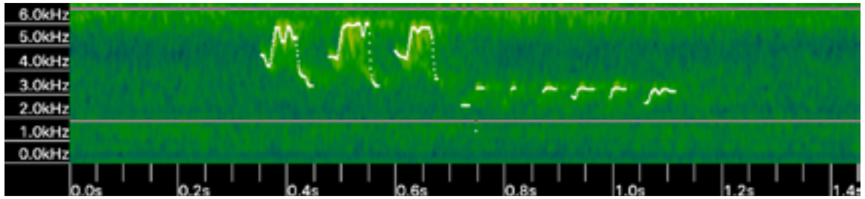

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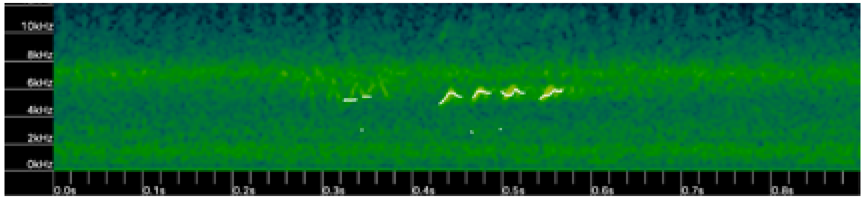

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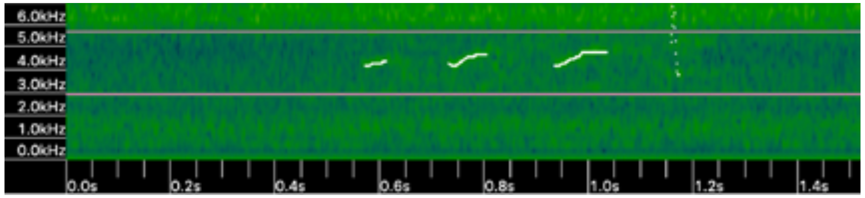

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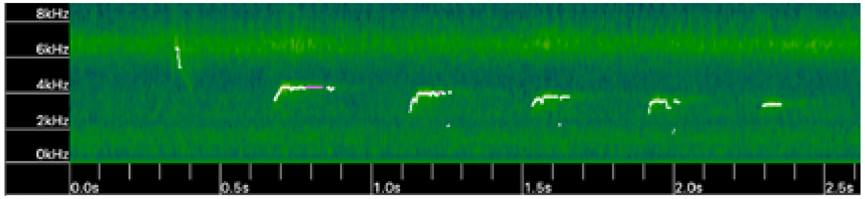
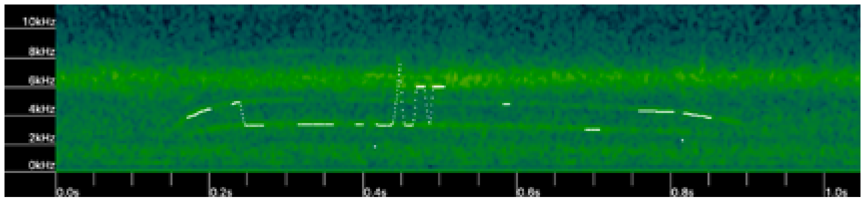


35



A.2 - List of potentially audible bird species

Establishing this list was done with the help of a research paper with a dataset of 830 bird species in the Brazilian Atlantic Rainforest (link). Afterwards, a qualitative analysis on each species was done on the likelihood of that species occurring around Iracambi, with the help of the online databases of Ebird (link) and Xeno Canto (link). The possibility of recolonization due to de- or reforestation, was included in this evaluation, as well as the types of environment that the species normally resides, such as the altitude or landscape characteristics. Upon confirmation, it was added to the list and the Portuguese name was found with the help of Avibase (link). An internal list of spotted birds at Iracambi added 20 more species. These 20 have been given back as feedback to a researcher who made the initial dataset, who replied that those species will also be included in an update. For saving space, merely the Latin name is included in the overview of this Appendix, together with the ID number.

ID	Latin Name of Species	ID	Latin Name of Species
1	Tinamus solitarius	17	Cairina moschata
2	Crypturellus soui	19	Amazonetta brasiliensis
3	Crypturellus obsoletus	23	Netta erythrophthalma
5	Crypturellus noctivagus	25	Nomonyx dominicus
6	Crypturellus variegatus	26	Penelope superciliaris
7	Crypturellus tataupa	27	Penelope obscura
8	Rhynchotus rufescens	28	Pipile jacutinga
9	Nothura boraquira	31	Crax blumenbachii
10	Nothura maculosa	32	Odontophorus capueira
11	Anhima cornuta	34	Tachybaptus dominicus
14	Dendrocygna viduata	35	Podilymbus podiceps
15	Dendrocygna autumnalis	59	Jabiru mycteria

ID	Latin Name of Species	ID	Latin Name of Species
59	Jabiru mycteria	97	Harpagus diodon
60	Mycteria americana	98	Circus buffoni
63	Nannopterum brasilianus	99	Accipiter poliogaster
64	Anhinga anhinga	100	Accipiter superciliosus
65	Tigrisoma lineatum	101	Accipiter striatus
67	Cochlearius cochlearius	102	Accipiter bicolor
70	Nycticorax nycticorax	103	Ictinia plumbea
72	Butorides striata	104	Rostrhamus sociabilis
73	Bubulcus ibis	105	Geranospiza caerulescens
74	Ardea cocoi	106	Heterospizias meridionalis
75	Ardea alba	107	Amadonastur lacernulatus
76	Syrigma sibilatrix	108	Urubitinga urubitinga
77	Pilherodius pileatus	109	Urubitinga coronata
78	Egretta thula	110	Rupornis magnirostris
82	Mesembrinibis cayennensis	111	Parabuteo unicinctus
83	Phimosus infuscatus	112	Geranoaetusalbicaudatus
84	Theristicus caudatus	113	Pseudastur polionotus
86	Cathartes aura	115	Spizaetus tyrannus
87	Cathartes burrovianus	116	Spizaetus melanoleucus
88	Coragyps atratus	117	Spizaetus ornatus
89	Sarcoramphus papa	118	Aramus guarauna
91	Leptodon cayanensis	119	Micropygia schomburgkii
92	Chondrohierax uncinatus	123	Aramides cajaneus
93	Elanoides forficatus	124	Aramides saracura
94	Gampsonyx swainsonii	125	Laterallus viridis
95	Elanus leucurus	126	Laterallus melanophaius
96	Harpagus bidentatus	127	Laterallus exilis

ID	Latin Name of Species
128	Laterallus leucopyrrhus
130	Mustelirallus albicollis
132	Pardirallus maculatus
133	Pardirallus nigricans
134	Pardirallus sanguinolentus
135	Gallinula galeata
137	Porphyrio martinicus
143	Vanellus chilensis
144	Pluvialis dominica
155	Gallinago undulata
160	Bartramia longicauda
161	Actitis macularius
162	Tringa solitaria
174	Jacana jacana
181	Chroicocephalus maculipennis
186	Sternula superciliaris
187	Phaetusa simplex
196	Columbina passerina
197	Columbina minuta
198	Columbina talpacoti
199	Columbina squammata
200	Columbina picui
201	Claravis pretiosa
203	Columba livia
204	Patagioenas speciosa
205	Patagioenas picazuro
206	Patagioenas cayennensis
207	Patagioenas plumbea
208	Zenaida auriculata
209	Leptotila verreauxi

ID	Latin Name of Species
210	Leptotila rufaxilla
211	Geotrygon violacea
212	Geotrygon montana
213	Micrococcyx cinereus
214	Piaya cayana
215	Coccyzus melacoryphus
216	Coccyzus americanus
217	Coccyzus euleri
218	Coccyzus erythropthalmus
219	Crotophaga major
220	Crotophaga ani
221	Guira guira
222	Tapera naevia
223	Dromococcyx pavoninus
224	Neomorphus geoffroyi
225	Tyto furcata
226	Megascops choliba
227	Megascops atricapilla
228	Megascops sanctaecatarinae
229	Pulsatrix perspicillata
230	Pulsatrix koeniswaldiana
231	Bubo virginianus
232	Strix hylophila
233	Strix virgata
234	Strix huhula
236	Glaucidium minutissimum
237	Glaucidium brasilianum
238	Athene cunicularia
239	Aegolius harrisii
240	Asio clamator

ID	Latin Name of Species
241	Asio stygius
242	Asio flammeus
243	Nyctibius grandis
244	Nyctibius aethereus
245	Nyctibius griseus
246	Nyctiphrynus ocellatus
247	Antrostomus rufus
249	Lurocalis semitorquatus
250	Nyctidromus albicollis
251	Hydropsalis parvula
252	Hydropsalis anomala
253	Hydropsalis longirostris
254	Hydropsalis maculicaudus
255	Hydropsalis torquata
256	Podager nacunda
257	Chordeiles minor
258	Chordeiles acutipennis
259	Cypseloides fumigatus
260	Cypseloides senex
261	Streptoprocne zonaris
262	Streptoprocne biscutata
263	Chaetura cinereiventris
264	Chaetura meridionalis
265	Chaetura brachyura
266	Tachornis squamata
267	Panyptila cayennensis
268	Ramphodon naevius
269	Glaucis dohrnii
270	Glaucis hirsutus
271	Phaethornis squalidus

ID	Latin Name of Species
272	Phaethornis idaliae
273	Phaethornis ruber
274	Phaethornis pretrei
275	Phaethornis eurynome
278	Eupetomena macroura
279	Florisuga fusca
280	Colibri serrirostris
281	Chrysolampis mosquitus
282	Stephanoxis lalandi
283	Lophornis magnificus
284	Lophornis chalybeus
286	Chlorestes notata
287	Chlorostilbon lucidus
289	Thalurania glaucopis
290	Hylocharis sapphirina
291	Hylocharis cyanus
292	Hylocharis chrysura
293	Leucochloris albicollis
294	Polytmus guainumbi
295	Heliodoxa rubricauda
296	Heliothryx auritus
298	Heliomaster squamosus
299	Heliomaster furcifer
300	Trogon viridis
301	Trogon surrucura
302	Trogon curucui
303	Trogon rufus
305	Megaceryle torquata
306	Chloroceryle amazona
307	Chloroceryle aenea

ID	Latin Name of Species	ID	Latin Name of Species	ID	Latin Name of Species	ID	Latin Name of Species
308	Chloroceryle americana	354	Campephilus robustus	391	Amazona farinosa	435	Myrmoderus loricatus
311	Galbula ruficauda	355	Cariama cristata	393	Amazona amazonica	439	Pyriglena leucoptera
312	Notharchus swainsoni	357	Caracara plancus	394	Amazona rhodocorytha	440	Rhopornis ardesiacus
314	Nystalus chacuru	358	Milvago chimachima	395	Amazona aestiva	441	Cercomacra brasiliana
315	Nystalus maculatus	359	Milvago chimango	396	Triclaria malachitacea	443	Drymophila ferruginea
316	Malacoptila striata	360	Herpetotheres cachinnans	398	Terenura maculata	444	Drymophila rubricollis
317	Nonnula rubecula	361	Micrastur ruficollis	399	Myrmotherula axillaris	445	Drymophila genei
318	Monasa nigrifrons	363	Micrastur semitorquatus	403	Myrmotherula unicolor	446	Drymophila ochropyga
320	Chelidoptera tenebrosa	364	Falco sparverius	405	Formicivora iheringi	447	Drymophila malura
321	Ramphastos toco	365	Falco rufigularis	407	Formicivora grisea	448	Drymophila squamata
322	Ramphastos vitellinus	367	Falco femoralis	408	Formicivora serrana	449	Melanopareia torquata
323	Ramphastos dicolorus	368	Falco peregrinus	410	Formicivora rufa	451	Conopophaga lineata
325	Selenidera maculirostris	369	Ara ararauna	414	Rhopias gularis	452	Conopophaga melanops
326	Pteroglossus bailloni	370	Ara chloropterus	415	Dysithamnus stictothorax	453	Grallaria varia
328	Pteroglossus aracari	371	Primolius maracana	416	Dysithamnus mentalis	456	Merulaxis ater
332	Picumnus cirratus	372	Diopsittaca nobilis	417	Dysithamnus xanthopterus	457	Eleoscytalopus indigoticus
333	Picumnus temminckii	373	Thectocercus acuticaudatus	418	Dysithamnus plumbeus	458	Scytalopus speluncae
334	Picumnus albosquamatus	374	Psittacaraleucophthalmus	420	Herpsilochmus atricapillus	461	Psilorhamphus guttatus
338	Melanerpes candidus	375	Eupsittula aurea	422	Thamnophilus doliatus	462	Formicarius colma
339	Melanerpes flavifrons	376	Pyrrhura cruentata	423	Thamnophilus ruficapillus	463	Chamaeza campanisona
341	Veniliornis maculifrons	377	Pyrrhura frontalis	424	Thamnophilus torquatus	464	Chamaeza meruloides
342	Veniliornis passerinus	378	Pyrrhura leucotis	425	Thamnophilus palliatus	465	Chamaeza ruficauda
343	Veniliornis spilogaster	380	Forpus xanthopterygius	426	Thamnophilus pelzelni	468	Sclerurus scansor
344	Piculus flavigula	381	Brotogeris tirica	427	Thamnophilus ambiguus	473	Dendrocincla turdina
345	Piculus chrysochloros	382	Brotogeris chiriri	428	Thamnophilus caerulescens	474	Sittasomus griseicapillus
347	Piculus aurulentus	383	Touit melanonotus	430	Taraba major	476	Xiphorhynchus fuscus
348	Colaptes melanochloros	384	Touit surdus	431	Hypoedaleus guttatus	477	Xiphorhynchus guttatus
349	Colaptes campestris	385	Pionopsitta pileata	432	Batara cinerea	478	Campylorhamphus falcularius
352	Celeus flavescens	388	Pionus maximiliani	433	Mackenziaena leachii	481	Lepidocolaptes angustirostris
353	Dryocopus lineatus	389	Amazona vinacea	434	Mackenziaena severa	482	Lepidocolaptes squamatus

ID	Latin Name of Species
483	Lepidocolaptes falcinellus
484	Dendrocolaptes platyrostris
486	Xiphocolaptes albicollis
487	Xenops minutus
488	Xenops rutilans
489	Furnarius figulus
490	Furnarius leucopus
491	Furnarius rufus
493	Lochmias nematura
495	Automolus leucophthalmus
496	Anabacerthia lichtensteini
497	Philydor atricapillus
498	Philydor rufum
499	Heliobletus contaminatus
500	Syndactyla rufosuperciliata
501	Cichlocolaptes leucophrus
505	Phacellodomus rufifrons
506	Phacellodomus erythrophthalmus
507	Phacellodomus ferrugineigula
508	Synallaxis ruficapilla
511	Synallaxis cinerascens
512	Synallaxis frontalis
513	Synallaxis albescens
514	Synallaxis spixi
519	Cranioleuca pallida
520	Thripophaga macroura
521	Neopelma aurifrons
522	Neopelma chrysolophum
525	Manacus manacus
528	Ilicura militaris
530	Chiroxiphia caudata
531	Antilophia galeata
533	Oxyruncus cristatus
535	Myiobius barbatus
536	Myiobius atricaudus
537	Schiffornis virescens
538	Schiffornis turdina
540	Laniisoma elegans
541	Iodopleura pipra
542	Tityra inquisitor
543	Tityra cayana
544	Pachyramphus viridis
545	Pachyramphus castaneus
546	Pachyramphus polychopterus
547	Pachyramphus marginatus
548	Pachyramphus validus
549	Carpornis cucullata
551	Phibalura flavirostris
552	Pyroderus scutatus
555	Lipaugus lanioides
558	Procnias nudicollis
560	Xipholena atropurpurea
564	Platyrinchus mystaceus
565	Platyrinchus leucoryphus
567	Mionectes oleagineus
568	Mionectes rufiventris
569	Leptopogon amaurocephalus
570	Corythopis delalandi
571	Pogonotriccus eximius
572	Phylloscartes ventralis
576	Phylloscartes paulista
577	Phylloscartes oustaleti
578	Phylloscartes difficilis
579	Phylloscartes sylviolus
580	Rhynchocyclus olivaceus
581	Tolmomyias sulphurescens
583	Todirostrum poliocephalum
584	Todirostrum cinereum
585	Poecilotriccus plumbeiceps
587	Myiornis auricularis
589	Hemitriccus diops
592	Hemitriccus orbitatus
594	Hemitriccus nidipendulus
595	Hemitriccus margaritaceiventer
598	Hemitriccus furcatus
599	Hirundinea ferruginea
601	Euscarthmus meloryphus
602	Tyranniscus burmeisteri
603	Camptostoma obsoletum
604	Elaenia flavogaster
605	Elaenia spectabilis
606	Elaenia chilensis
607	Elaenia parvirostris
608	Elaenia mesoleuca
609	Elaenia cristata
610	Elaenia chiriquensis
611	Elaenia sordida
613	Myiopagis caniceps
614	Myiopagis viridicata
615	Capsiempis flaveola
616	Phaeomyias murina
617	Phyllomyias virescens
618	Phyllomyias fasciatus
619	Phyllomyias griseocapilla
621	Polystictus superciliaris
623	Serpophaga nigricans
624	Serpophaga subcristata
625	Legatus leucophaius
626	Ramphotrigon megacephalum
627	Myiarchus tuberculifer
628	Myiarchus swainsoni
629	Myiarchus ferox
630	Myiarchus tyrannulus
631	Sirystes sibilator
632	Rhytipterna simplex
633	Casiornis rufus
635	Pitangus sulphuratus
636	Philohydor lictor
637	Machetornis rixosa
638	Myiodynastes maculatus
639	Megarynchus pitangua
640	Myiozetetes cayanensis
641	Myiozetetes similis
642	Tyrannus albogularis
643	Tyrannus melancholicus
644	Tyrannus savana
646	Empidonomus varius
647	Conopias trivirgatus
648	Colonia colonus
649	Myiophobus fasciatus

ID	Latin Name of Species
650	Pyrocephalus rubinus
652	Fluvicola nengeta
653	Gubernetes yetapa
654	Cnemotriccus fuscatus
655	Lathrotriccus euleri
657	Contopus cinereus
658	Knipolegus cyanirostris
659	Knipolegus lophotes
660	Knipolegus nigerrimus
662	Satrapa icterophrys
663	Xolmis cinereus
664	Xolmis velatus
666	Muscipipra vetula
667	Cyclarhis gujanensis
668	Hylophilus amaurocephalus
669	Hylophilus poicilotis
670	Hylophilus thoracicus
671	Vireo chivi
674	Cyanocorax cyanopogon
675	Pygochelidon cyanoleuca
676	Alopochelidon fucata
677	Stelgidopteryx ruficollis
678	Progne tapera
680	Progne chalybea
681	Tachycineta albiventer
682	Tachycineta leucorrhoa
683	Riparia riparia
684	Hirundo rustica
686	Troglodytes aedon
688	Pheugopedius genibarbis
689	Cantorchilus leucotis
690	Cantorchilus longirostris
691	Donacobius atricapilla
692	Ramphocaenus melanurus
699	Turdus flavipes
700	Turdus leucomelas
701	Turdus fumigatus
702	Turdus rufiventris
703	Turdus amaurochalinus
704	Turdus subalaris
705	Turdus albicollis
706	Mimus gilvus
707	Mimus saturninus
710	Anthus lutescens
712	Anthus hellmayri
713	Anthus nattereri
714	Zonotrichia capensis
715	Ammodramus humeralis
716	Setophaga pitiayumi
719	Geothlypis velata
720	Myiothlypis flaveola
721	Myiothlypis leucoblephara
722	Myiothlypis rivularis
723	Psarocolius decumanus
726	Icterus pyrrhopterus
727	Icterus jamacaii
728	Gnorimopsar chopi
729	Chrysomus ruficapillus
730	Pseudoleistes guirahuro
733	Molothrus rufoaxillaris
734	Molothrus oryzivorus
735	Molothrus bonariensis
736	Sturnella superciliaris
738	Orthogonys chloricterus
739	Orchesticus abeillei
740	Pipraeidea melanonota
742	Stephanophorus diadematus
743	Cissopis leverianus
744	Schistochlamys melanopis
745	Schistochlamys ruficapillus
747	Paroaria dominicana
748	Tangara mexicana
749	Tangara seledon
751	Tangara cyanocephala
752	Tangara cyanoventris
753	Tangara desmaresti
754	Tangara sayaca
755	Tangara cyanoptera
756	Tangara palmarum
757	Tangara ornata
760	Tangara cayana
761	Nemosia pileata
762	Nemosia rourei
763	Conirostrum speciosum
765	Sicalis citrina
766	Sicalis flaveola
767	Sicalis luteola
768	Haplospiza unicolor
769	Chlorophanes spiza
770	Hemithraupis flavicollis
771	Hemithraupis guira
772	Hemithraupis ruficapilla
773	Volatinia jacarina
774	Eucometis penicillata
775	Trichothraupis melanops
776	Coryphospingus pileatus
777	Coryphospingus cucullatus
778	Lanio cristatus
779	Tachyphonus coronatus
780	Ramphocelus bresilius
781	Ramphocelus carbo
782	Tersina viridis
783	Cyanerpes cyaneus
785	Dacnis cayana
786	Coereba flaveola
787	Tiaris fuliginosus
788	Sporophila lineola
789	Sporophila frontalis
790	Sporophila falcirostris
791	Sporophila collaris
792	Sporophila nigricollis
793	Sporophila ardesiaca
794	Sporophila caerulescens
796	Sporophila leucoptera
797	Sporophila bouvreuil
799	Sporophila angolensis / Oryzoborus angolensis
800	Sporophila maximiliani
801	Embernagra platensis
803	Emberizoides herbicola

ID	Latin Name of Species
805	Saltatricula atricollis
806	Saltator maximus
807	Saltator similis
808	Saltator maxillosus
809	Saltator fuliginosus
812	Poospiza thoracica
813	Microspingus lateralis
815	Microspingus cinereus
816	Thlypopsis sordida
817	Donacospiza albifrons
818	Piranga flava
819	Habia rubica
820	Caryothraustes canadensis
821	Cyanoloxia glaucocaerulea
822	Cyanoloxia brissonii
824	Spinus magellanicus
825	Euphonia chlorotica
826	Euphonia violacea
827	Euphonia chalybea
828	Euphonia cyanocephala
829	Euphonia xanthogaster
830	Euphonia pectoralis
831	Chlorophonia cyanea
832	Estrilda astrild
833	Passer domesticus
834	Crypturellus parvirostris
835	Buteo albonotatus
836	Buteo nitidus
837	Chionomesa fimbriata
838	Chionomesa lactea

ID	Latin Name of Species
839	Anthracothorax nigricollis
840	Thamnophilus punctatus
841	Anabazenops fuscus
842	Anumbius annumbi
843	Certhiaxis cinnamomeus
844	Arundinicola leucocephala
845	Attila rufus
846	Attila spadiceus
847	Cyanocorax cristatellus
848	Tachyphonus rufus
849	Arremon semitorquatus
850	Basileuterus culicivorus
851	Cacicus haemorrhous

About the author

Yvo Hunink

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During a bachelor mechanical engineering at the Technical University of Delft, Yvo first came in contact with international development, where he participated in a 3-month project in The Gambia, building a solar dryer for drying fruits and vegetables, from locally available materials. There he saw the vital role of (sustainable) energy in our reaching the international development goals, and therefore decided to continue with a master in Sustainable Energy Technology, building his thesis around Responsible Innovation Systems. Here he took rural energy technology in India as his case study, traveling to India for 3 months as well.

After trying to set up a start-up in sustainable energy access through smart energy network for rural areas, and failing (=learning) he started working as an independent consultant.

Since 2018 he works for to the City of The Hague. There he is the Smart Energy Lead in the Digital Innovation and Smart City team, but also works in computer vision projects with law enforcement, and sets out projects with digital identity in participatory budgeting and debt relief assistance.

Yvo lives with his (Brazilian) partner in the The Hague, Netherlands, where they have two cats, a garden full of life and a lot of indoor plants, of a bananeira that survived new years eve outside and an avocado planted from a supermarket seed.

A craving for nature drew his interest to work with Iracambi as part of a 2-month leave period of his work. While knowing nothing about bioacoustics, learning new things is one of his joys in life.

IRACAMBI
Mata Atlântica - Brasil