Final Evaluation Report

Your Details	
Full Name	Anja Hutschenreiter
Project Title	The Train has Not Left the Station Yet: Multihabitat Conservation in Bacalar, a Landscape Threatened by an Intercity Railway Project
Application ID	35002-1
Date of this Report	09/04/2023

1. Indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.

Objective	Not achieved	Partially achieved	Fully achieved	Comments
To assess the biodiversity in the forest around Bacalar				Using passive acoustic monitoring, we identified 93 animal species from four different taxa (birds, amphibians, reptiles, mammals) of which 25 were identified as species of key conservation concern. We further calculated four acoustic biodiversity indices from recordings made between October 2021-March 2022. However, we have not yet identified tree species occurring in the study area and are still running acoustic-index calculations for April - November 2022.
To evaluate the current effect of anthropogenic factors on forest biodiversity				We identified four sources of anthropogenic pressure in the study site (agriculture, urbanisation, noise and logging) and evaluated the impact of agricultural and urban land cover on the richness of forest-dwelling bird species with key conservation concern.
To determine whether the Bacalar lake and the surrounding forest are impacted by the same threats				We found agricultural and urban land use to affect the water quality of the Bacalar lake, as reflected in decreased levels of dissolved oxygen with increasing area used for urban and agricultural land in areas where water temperature is low. We also identified urban land use as the main threat for animal biodiversity in the surrounding forest, as reflected in decreased abundance and richness of species of key conservation concern at sites where more land was converted to urban land use.
To predict how further touristic development will impact the Bacalar environment.				We have gathered all data and identified threats for the Bacalar lake and forest which provides the base for predicting how future touristic development will impact the environment. However, we have not yet created distribution maps/maps of priority conservation areas. Note that this goal was planned in our grant proposal to be completed by June 2023.

2. Describe the three most important outcomes of your project.

a) We collected 12 months of soundscape recordings and data on anthropogenic pressure at 26 monitoring sites in the forest around Bacalar and analysed the data as a baseline assessment of animal biodiversity and forest health before the launch of the Tren Maya project.

We used passive acoustic monitoring as non-invasive and effective survey method (Deichman et al, 2018) to examine the biodiversity of forest-dwelling animals as indicator of forest health. Monitoring sites were established at 26 locations between the north and south end of the Bacalar lake with varying degrees of anthropogenic pressure in the surroundings. Recordings of up to 140 minutes per day were made at each monitoring site, from 5:00 AM to 12:00 AM, for 1 year (1 minute every 6 minutes for a maximum of 14 hours per day) between October 2021 and November 2022 (due to differing recording start dates at monitoring sites).

With the help of collaborating ornithologists and herpetologists, we were able to identify a diverse range of species based on the vocalisations found in the soundscape recordings (Appendix 1). A total of 87 species of birds, three species of mammals, two species of amphibians and one reptile species were identified. Among them, we categorised 25 as species of key conservation concern (Table 1) because they are listed as Subject of Special Protection under the NOM-059 of the Secretary of Environment and Natural Resources (SEMARNAT, Mexico), are considered Near Threatened, Vulnerable, or Endangered according to the NOM-059 and/or the assessment of the International Union for Conservation of Nature (IUCN), or are identified as umbrella and indicator species based on a literature review (e.g. Caro, 2010).

In addition to assessing the occurrence of key conservation species at monitoring sites using a semi-automated detection approach (Arbimon pattern matching, Rainforest connection, www.arbimon.rfcx.org), we calculated four acoustic biodiversity indices (ACI, BI, NP and NDSI) per minute for more than 16 hours of soundscape recording per monitoring site and survey month between October 2021 and March 2022 in R, leading to a total of 1,792 hours of calculated acoustic indices so far. Acoustic indices are rapid indicators of forest biodiversity that analyse the complexity and/or richness of frequency ranges present in a soundscape, without the need to identify vocalizations at the species level (Buxton et al, 2018).

Land use changes can cause shifts in species composition and richness of a forest due to deforestation for agriculture or urban development (Gibson et al, 2011). This can lead to a decline in the abundance and diversity of forest-dependent animal species and favour the persistence of more generalist species that are able to adapt to human-altered environments (Dornelas et al, 2019). To relate forest biodiversity to current sources of anthropogenic pressure and habitat quality, we utilised a land-cover map developed in the JavaScript API Code Editor in the Google Earth Engine (GEE) by a PhD student of our research team (based on open-access satellite imagery from the Sentinel-2 Multispectral Instrument). A collection of satellite images from January to October 2021 was used to generate a mosaic, to which atmospheric correction was applied, and a random forest algorithm was employed to delimit land-cover categories. Land covers included water bodies,

urban areas, agricultural areas, and forested areas. The student collected 849 training points in the field in in an area further north of the Bacalar region to train the classification programme, achieving an accuracy of > 90% for area layers in this region. The high accuracy of the land-cover map was confirmed for the Bacalar region through ground-truthing using 157 GPS points taken in the field. Once we assured the accuracy of the land-cover map for our study area, we assessed habitat disturbance as the proportion of urban and agricultural land use in a buffer of 500 m radius around each monitoring site.

Habitat quality of the forest was examined by calculating the average NDVI in the same buffer zones around monitoring sites. NDVI (Normalized Difference Vegetation Index) measures the amount of live green vegetation in an area by calculating the difference between the reflectance of near-infrared and visible light. It is used as an indicator of forest vegetation health, with higher values indicating more photosynthetically active vegetation and therefore better habitat quality (Tuominen et al, 2009). We used one open access Landsat-9 satellite image from the rainy season (October 2021) and one from the dry season (March 2022) with less than 5% cloud cover to extract values of near-infrared (NIR) and red (RED) bands at 20 m resolution and calculated NDVI as NDVI = (NIR - Red) / (NIR + Red) for each cell before averaging values across all cells in a buffer.

Based on occurrence data we obtained for 14 bird species of key conservation concern from acoustic detections in Arbimon per monitoring site and month between November 2021 and July 2022, we were able to determine the richness of such species at each monitoring site. We used N-mixture models to predict the abundance of the 14 key bird species depending on urban and agricultural land use and average NDVI in buffers around monitoring sites, while modelling the detection probability based on recording effort per month and monitoring site. We found the richness of key conservation bird species to be negatively affected by urban land use (Figure 1), and to not be affected by NDVI. We were not able to evaluate the impact of agricultural land use on key conservation species richness due to high multicollinearity with other predictor variables and a missing fit of the model when only including agricultural land use a predictor of key species abundance. We found similar effects of urban land use when using relative abundance of selected key conservation species as response variable (instead of species richness).

We are currently still working on analyses that use the four calculated acoustic indices as response variables to evaluate the impact of anthropogenic pressure on forest biodiversity to further confirm that urban land use is the main threat to forest-dwelling animals.

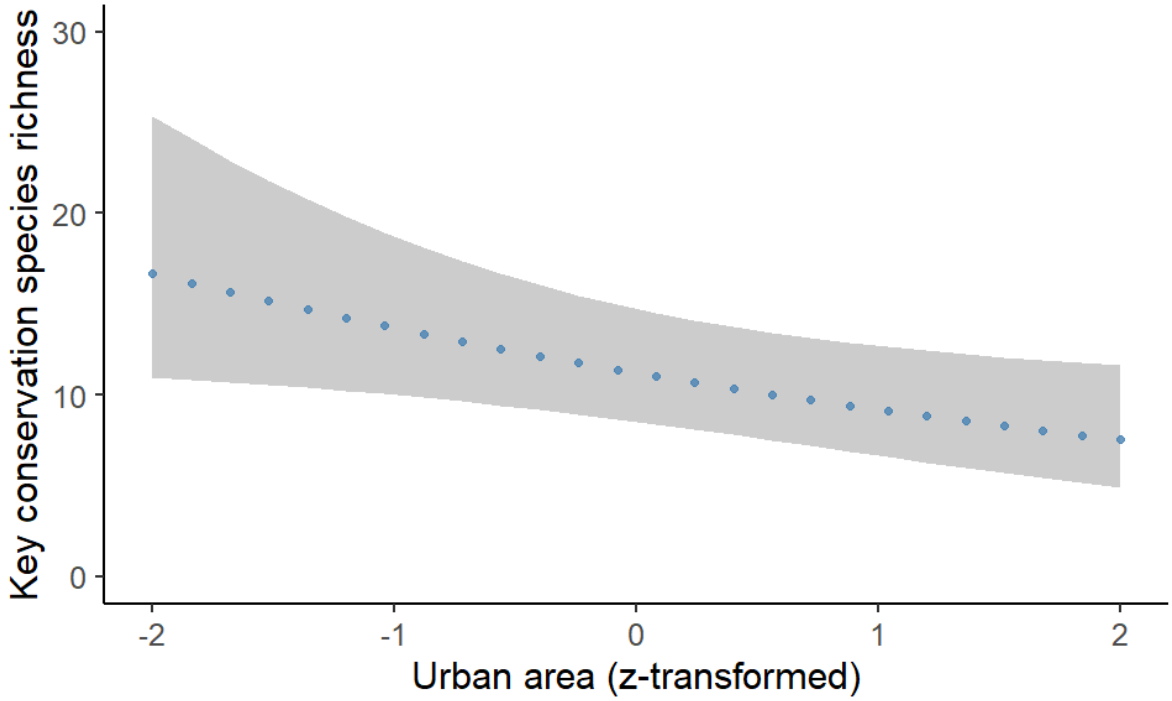

Figure 1. Predicted effect of the proportion of urban land use in 500m-buffers around monitoring sites on the richness of species of key conservation concern.

Besides evaluating the current effect of anthropogenic factors on forest biodiversity, we used our soundscape recordings to detect chainsaw noise and gunshots to infer logging and hunting activity at monitoring sites. We were successful in detecting logging activity at several monitoring sites (Figure 2), although the precision of Arbimon pattern matching for logging noise was found to be low, leading to a lot of false-positive hits which we discovered when we reviewed the output manually. Therefore, the detection process is quite slow, and it will take us more time than anticipated to identify logging activity at all sites during the 12 months of acoustic monitoring. Once this is done, we will be able to evaluate the impact of logging pressure on forest biodiversity. In turn, we found it challenging to confidently identify gunshots due to the lack of example recordings of gunshots at our study site (we used examples provided by other researchers from their study sites in Africa), coupled with untrained ears and the infrequent occurrence of gunshots. Thus, assessing the impact of hunting pressure at the study area is not feasible for us at the moment using Arbimon pattern matching.

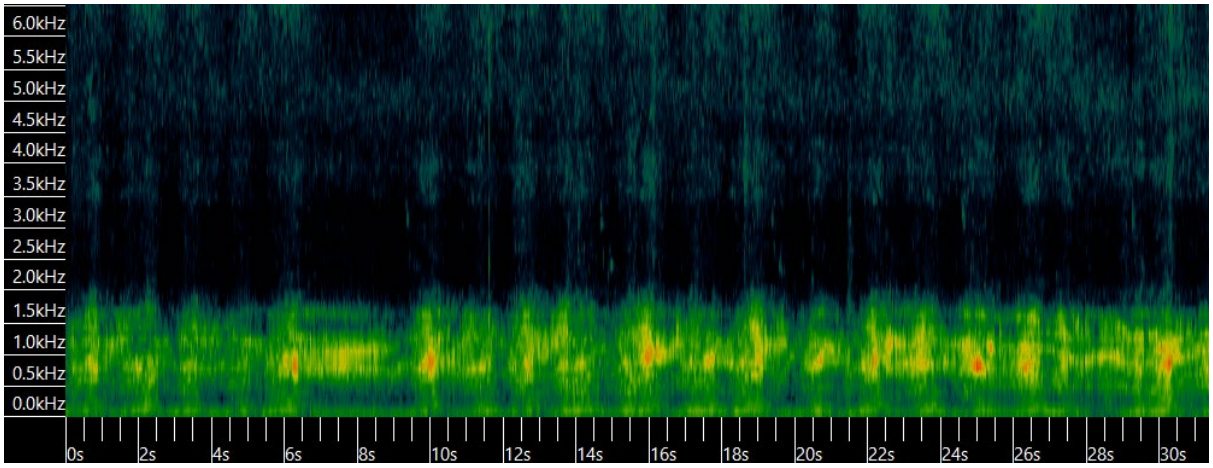

Figure 2. A typical spectrogram of chainsaw noise produced during logging near a monitoring site.

Finally, we have used our soundscape recordings to test the feasibility of detecting vocal species that previously have not been detected using passive acoustic monitoring. One successful example was the detection of the white-nosed coati (*Nasua narica*) at 18/26 monitoring sites. White-nosed coatis produce distinct chirp-like vocalisations during group communication (Figure 3) that can be easily detected and distinguished from other sounds in the environment. To further evaluate the potential of passive acoustic monitoring for this species, we plan to compare detection probability and thus method efficacy of camera trapping (see our third most important outcome for information on a side project we implemented using cellular-based camera traps) and passive acoustic monitoring using data collected simultaneously at monitoring sites during the project.

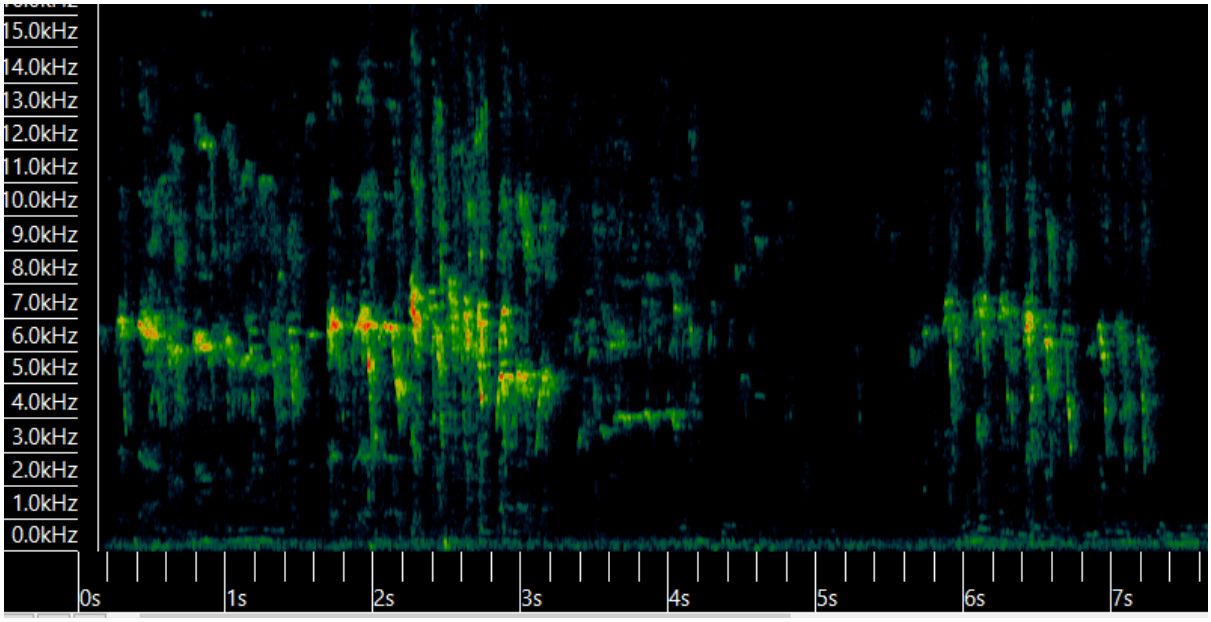

Figure 3. A typical spectrogram of vocalizations emitted by a group of white-nosed coatis.

b) We found urbanization to not only be the main threat to forest biodiversity but also to affect the water quality of the Bacalar lake, along with agricultural land use.

The impact of anthropogenic disturbance on the health of the Bacalar Lake and its surrounding forest was studied by measuring indicators of water quality at 25 sites across the lake between January and December 2022, and combining it with the results of the passive acoustic monitoring (see a). The water-quality monitoring was carried out by Agua Clara A.C. who repeatedly measured variables including water temperature, pH, dissolved oxygen (DO), and electronic conductivity (EC) values to assess the water composition and quality.

Based on temperature and pH levels measured at water-monitoring sites, we ran a Principal Component Analysis and found water characteristics to differ between four geographical zones of the lake (Figure 4 and 5). Subsequently, we categorised each PAM site into one of the four zones but realised that PAM sites were present in only three zones as we could not establish any PAM sites in the zone around the Bacalar town due to it being largely urbanised. The proportion of agricultural and urban land use in the forest west of the northern, central, and southern lake zones was measured in pre-determined buffers for each zone using a customized land-cover map (Figure 5; see 2a for details on the map).

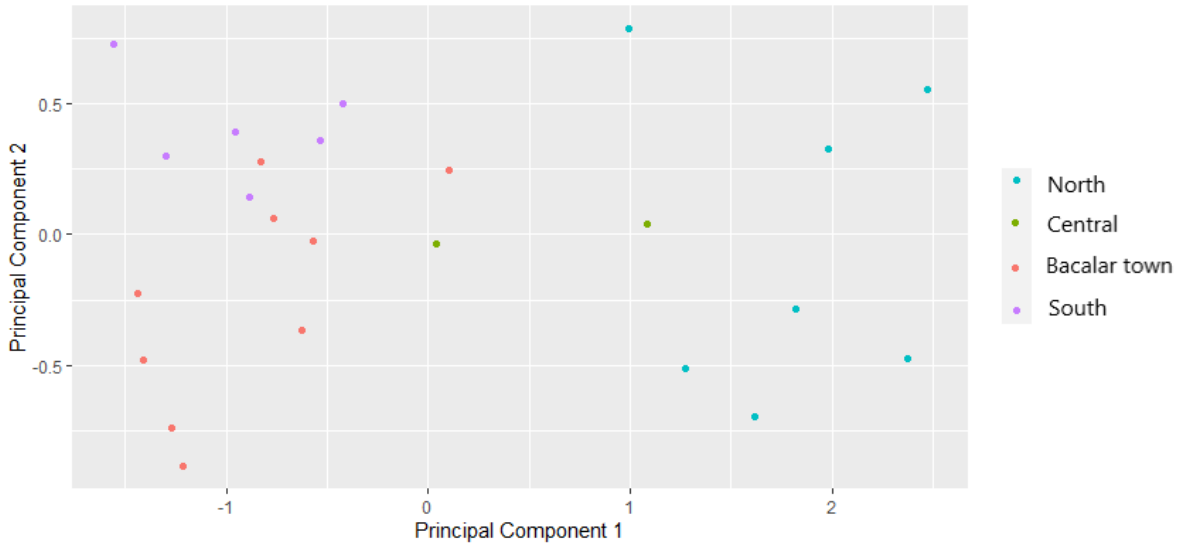

Figure 4. Results of the PCA confirming water temperature and pH levels differ between the northern, central, southern zone and the zone around Bacalar town.

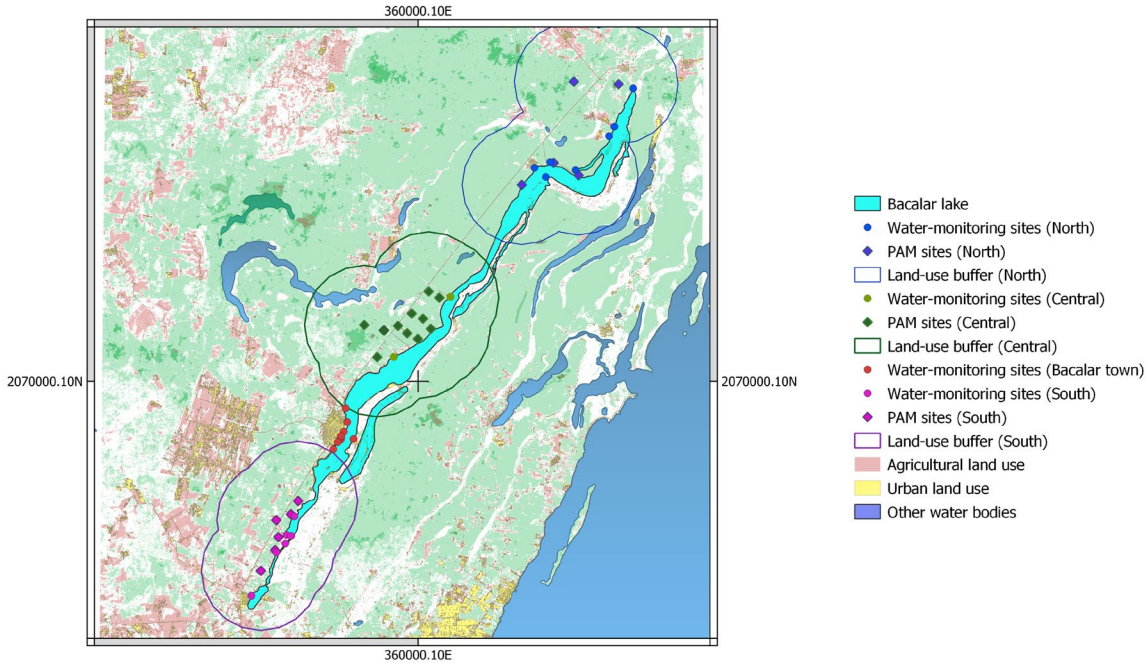

Figure 5. Study area including PAM sites, water-monitoring sites and buffers used for calculation of land-use proportion in the three zones.

Water quality can be impacted by land use in the surrounding areas, such as agricultural or urban development. These activities can lead to changes in sediment and nutrient levels that enter the water bodies (Carlson et al, 2019). Low levels of dissolved oxygen (DO) can be an indicator of poor water quality, particularly in oligotrophic lakes like the Bacalar lake where such occurrences are rare, as high level of organic matter in the water can cause low DO levels by consuming oxygen as it decomposes (Knoll et al, 2018). In addition, changes in electronic conductivity (EC) levels can indicate changes in the dissolved ion composition of the water (Gorde and Jadhav, 2013). Thus, we used DO and EC as response variables to determine the impact of land use on water quality. We predicted that an increase in land use for agriculture and urban development would lead to lower levels of DO and changes of EC levels in the lake. We further predicted that there would be higher levels of forest biodiversity (reflected by acoustic indices) in zones with higher water quality (reflected in higher DO levels).

To test our predictions, the proportion of agricultural and urban land use in the forest west of the northern, central, and southern lake zones was related to DO and EC levels in the water in each zone. Two sets of linear mixed models were run, each using 1,936 data points from water quality measurements: one for EC and one for DO as response variables. A null model consisting of only random factors (water monitoring site ID and date of the measurement) and four models using a predictor factor and water temperature as interaction term were included in each set of models. The interaction term was used since less oxygen can dissolve in warmer water, and EC increases in warmer water due to the greater movement of ions (Kaushal et al, 2008). The four predictor factors were the proportion of urban area

within the buffer, the proportion of agricultural area within the buffer, the average NDVI value in the buffer, and the average ACI (acoustic complexity index) value from PAM sites in the corresponding zones. To avoid multicollinearity, only one predictor factor was used in each model (all predictor factors showed moderate to high correlations with one another). A Likelihood-Ratio test was run to identify significant differences between the model and the null model. We found all models to be significantly different from the null model and all models showed a significant effect of the interaction between water temperature and the predictor factor (Figure 6 and 7). The colder the water,1) the stronger was the negative relationship between OD levels and urban and agricultural land use, 2) the stronger was the negative relationship between ODF levels and NDVI, and 3) the more associated were DO levels with average ACI values in the surrounding forest. This indicates that urbanisation and agriculture might negatively affect water quality, and that forest biodiversity as indicator of forest health corresponds with the health state of the lake. We found more complex interaction patterns between EC levels and the predictor factors. Increased urban and agricultural land use are associated with higher EC levels in colder water whereas the effect is reversed in warmer water. The reason for this pattern could be that warmer water promotes more biological activity in terms of metabolic processes carried out by living organisms such as bacteria, algae, and plants, which could lead to the removal of excess nutrients and pollutants, thus decreasing EC levels (Paerl and Otten, 2013).

We found the lowest OD and EC levels in the southern zone, which should receive special attention in future water monitoring efforts, and land use change in the forest surrounding the southern zone should be limited.

The finding of a relationship between DO levels and NDVI is curious as NDVI is negatively associated with DO levels, but positively associated with EC levels in colder water. Higher NDVI values indicate good health of forest vegetation, therefore the negative association with DO levels in colder water is puzzling. Possibly, higher levels of photosynthesis in the forest (which lead to higher NDVI values) are associated with greater nutrient runoff from the surrounding soil, which could contribute to eutrophication in the lake, thereby reducing dissolved oxygen levels. Further research is necessary to examine the relationship between vegetation productivity and the lake water quality.

Our findings highlight the crucial role of forest cover and its management in maintaining the health of the Bacalar region, as well as the complex and interconnected relationships between terrestrial and aquatic ecosystems. These results have important conservation implications and can serve as a valuable foundation for future research aimed at developing sustainable land-use practices and preserving the ecological integrity of this unique and biodiverse region. Therefore, these results are one of the most important outcomes of this project.

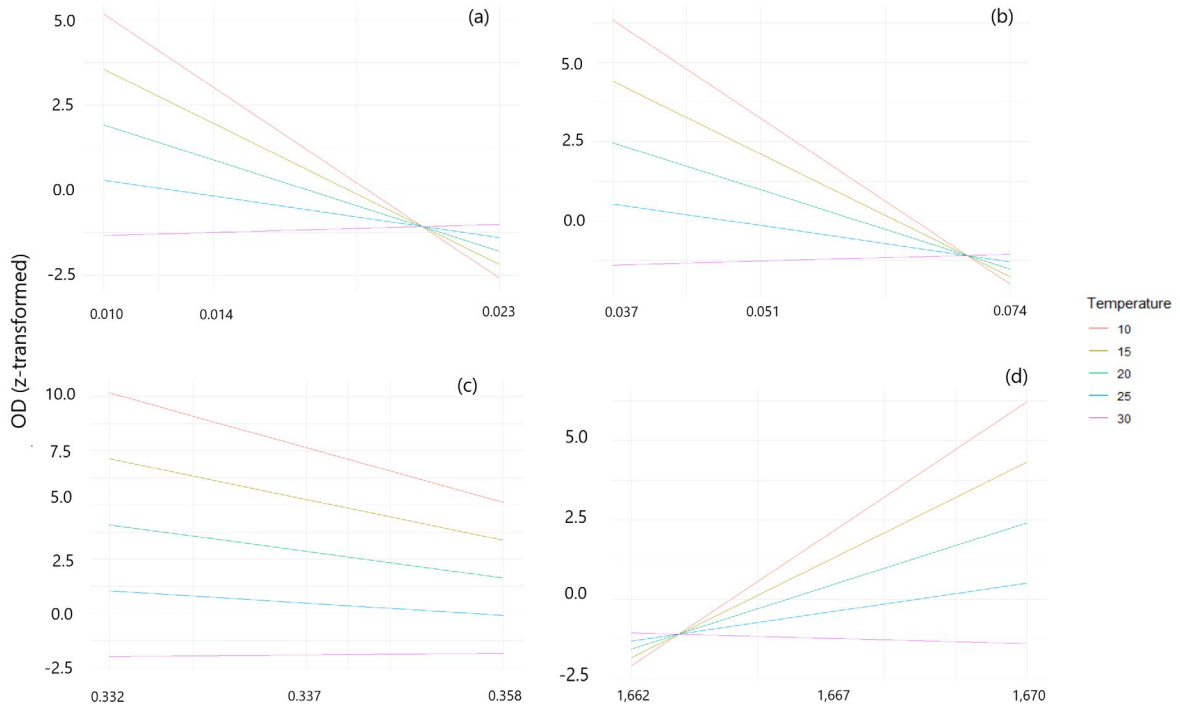

Figure 6. Effects of the interaction between water temperature and (a) urban land use, (b) agricultural land use, (c) average NDVI and (d) ACI on dissolved oxygen levels in the water of the Bacalar lake.

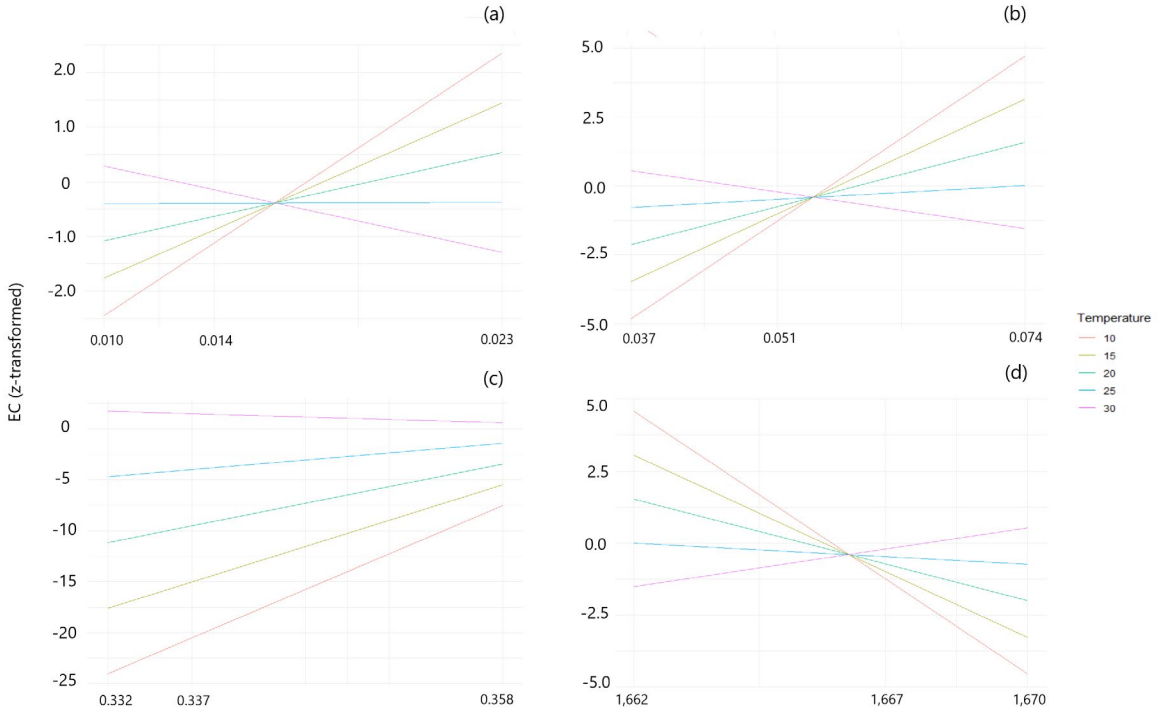

Figure 7. Effects of the interaction between water temperature and (a) urban land use, (b) agricultural land use, (c) average NDVI and (d) ACI on electric conductivity levels in the water of the Bacalar lake.

c) Through our Rufford-funded project, numerous collaborations and new projects were developed, leading to the establishment of a wide network of multidisciplinary research efforts in Mexico.

This project has yielded significant benefits to the grantee, including the receipt of two postdoctoral fellowships to work on the project. The successful identification of species based on their vocalisations from soundscape recordings was only possible thanks to close collaboration with a team of (mostly Mexican) experts in bird, frog, and bat vocalisations, and is still an ongoing process. One of our team members has started an associated research project in collaboration with a noise expert from the Universidad Autónoma de Tlaxcala, Mexico, on the impact of anthropogenic noise on vocal flexibility of birds using the acoustic data recorded during the project.

The project has also fostered closer relationships between the federal Mexican research institute "Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias" (INIFAP), Universidad Veracruzana, and Universidad Nacional Autónoma de México, when the team approached the INIFAP for permission to set up monitoring sites at their experimental field in Bacalar. As a result, these institutions have embarked on a joint camera-trapping initiative to monitor illegal hunting and logging activities at a conservation area of the INIFAP, for which the grantee was awarded funds by the National Geographic Society in collaboration with Synthetaics (see section 4). Furthermore, a science dissemination video about the Rufford-funded project is planned to be released as part of the INIFAP social media campaign in July 2023.

The project has further facilitated collaboration between Mexican and international universities, including joint efforts with researchers from the Mexican research institute ECOSUR and Liverpool John Moores University, UK, to plan the use of drones for investigating the link between water availability in the Bacalar basin and vegetation health in the Bacalar forest (see section 5). A pilot study was carried out in May 2022. Additionally, two team members supervised the master's thesis of a student at Liverpool John Moores University using data from the Rufford-funded project to study the impact of land use on spider monkey occurrence.

Ultimately, our dedication to the passive acoustic monitoring component of the study resulted in Rainforest Connection, a prominent player in the field and creator of the Arbimon platform, to approach us in December 2022 with an official collaboration proposal. As part of this partnership, Rainforest Connection will assist with additional processing of soundscape recordings and support the development of a research design for a subsequent acoustic monitoring survey aimed at assessing the environmental impact of the Tren Maya. This collaboration has the potential to increase the visibility of our Rufford-funded project and raise more international awareness about the environmental impacts of urbanisation and tourism expansion in the Yucatan Peninsula of Mexico, providing a significant publicity boost to our efforts.

3. Explain any unforeseen difficulties that arose during the project and how these were tackled.

During the project, some unforeseen difficulties arose, which required some creative problem solving. The purchase of Audiomoth recorders at the beginning of the project was limited due to the global chip shortage. To avoid a delay in the start of the fieldwork, the team borrowed seven recorders from other researchers until Audiomoth recorders were in stock again. In addition, some of the purchased Audiomoth recorders failed, as they were either not recording from the beginning or broke during the project. Consequently, the team purchased more Audiomoths (30 instead of 25 devices) and installed them at fewer monitoring sites than planned (26 instead of 30 sites).

Another challenge arose when some of the Audiomoth recorders failed while recording in the field. Especially, we observed a decline in recording capacity of Audiomoth recorders with increasing duration in the field owing to the deleterious effects of the highly humid conditions at the study area. This led to varying survey effort across months and monitoring sites. We dealt with this issue by accounting for survey effort in the statistical analyses to prevent results being affected by a detection bias. Despite the reduced recording time, the team still managed to record and store around 870,000 minutes, i.e., 14,500 hours of soundscape recording.

Finally, the team underestimated the workload required to process the acoustic data which needed to be cleaned, uploaded to Arbimon, and used for acoustic-index calculation and species detection. To tackle this challenge, the team enlisted the help of an assistant, whose subsistence could be paid by saving money on conducting vegetation surveys that were not urgently needed given that large-scale data on habitat quality were provided by a land-cover map generated by a PhD student of our research team (for a different project).

4. Describe the involvement of local communities and how they have benefitted from the project.

The involvement of local communities in the project was instrumental in ensuring its success. Landowners played a participative role from the beginning, as most acoustic monitoring sites were located on private terrain. The project team secured permission from landowners by providing information of the project and its goals. In return, the team provides landowners with progress reports, including overall project results, and species lists as well as acoustic index analyses of monitoring sites on their property. The team sent out one report in December 2022, and at least one more report is scheduled to follow.

One notable example of the project's impact was its role in altering the trajectory of the Tren Maya to protect a wetland area. When a landowner requested help in this regard, the project team wrote a support letter on behalf of ConMonoMaya A.C., highlighting the predicted occurrence of anuran species in the wetland. Thanks to this effort, the train trajectory was altered, safeguarding the wetland and its inhabitants.

Furthermore, the project team identified problems with illegal logging and hunting in the terrain of the INIFAP, a federal research institute, which contains 8,000 ha of land dedicated to conservation and contained four of the project's monitoring sites. To address these issues, the team initiated a side project to employ cellular-based camera traps for real time monitoring of such illegal activities (sponsored by the National Geographic Society in collaboration with Synthaetics). This collaborative effort began in July 2022 and is ongoing until July 2023.

Overall, the project's involvement with local communities helped to foster a sense of ownership and collaboration, resulting in tangible benefits for both the environment and the local population.

5. Are there any plans to continue this work?

The team has several plans to continue this work consisting of collaborations in ongoing and future projects. The data analysis of the project will be extended in the context of the postdoctoral fellowship of the grantee to include recordings from all months of acoustic monitoring and identify more species using stored acoustic data. The team is in contact with bat and anuran researchers to detect more species from acoustic recordings and subsequently run occupancy models for selected species. Also, we plan to run statistical analyses using acoustic indices to determine threats for forest biodiversity in addition to results based on the occurrence and richness of key conservation species. We have further started a study to evaluate the reliability of acoustic indices for the Yucatan peninsula, comparing manually assessed species richness, the number of sonotypes in a recording, and four acoustic biodiversity indices to determine if they are associated with one another.

Additionally, the team plans to compare the detections of animal species from camera traps that were set up at the study area with those obtained from passive acoustic monitoring to evaluate the most effective survey method for selected species. The team will also make use of the detected logging noise to run statistical analyses evaluating the impact of logging on forest biodiversity.

If additional funding is obtained, vegetation surveys will be conducted to determine the composition and structure of tree species around the sites and their relation to the biodiversity of the forest and the water quality of the lake. Furthermore, to extend the multihabitat conservation research tackled during our project, the team will collaborate with researchers from national research institute ECOSUR and researchers from Liverpool John Moores University to use a drone with a multispectral camera to relate the health of forest vegetation with water availability in the Bacalar water basin.

Finally, Rainforest Connection has approached the team to collaborate in a follow-up acoustic monitoring once the Tren Maya project is launched, and the data from our current project will serve as a pre-assessment for evaluating the environmental impact of the train project. The team plans to apply for a second Rufford small grant to support this work.

6. How do you plan to share the results of your work with others?

We plan to share the results of our work with the scientific community, the local community, and governmental entities.

To engage with the scientific community, the team has already presented project results at two international conferences (see section 8 for details) and is currently working on an article on the effect of urban land use on the abundance of three neotropical bird species to be submitted a peer-reviewed journal, with at least one more article planned on the validation of acoustic indices during the grantee's postdoctoral fellowship. Additionally, we plan to publish future articles on occupancy models and key species richness in the Bacalar region.

To engage with the local community, the team has been sending project progress reports to landowners, with at least one more report planned to be sent by the end of 2023. We also plan to give a community talk at a local event when the opportunity arises and continue to explore additional avenues for sharing our findings.

We already initiated the sharing of our results with actors involved in the Tren Maya project, including the governmental agency FONATUR. In December 2022, we presented our project and preliminary findings in a talk during the Council meeting of "Consejo de Cuenca Bacalar". Moreover, one of our team members provided advice on the type and placement of faunal bridges concerning the construction of the Tren Maya project in the Bacalar region to FONATUR and built links with the company in charge of constructing faunal bridges in other sections of the train.

Moving forward, our next step is to disseminate our findings on the relationship between land use change, water quality of the Bacalar lake, and forest biodiversity. We believe that our findings have crucial implications for the conservation of the region's environment with regards to the anticipated tourism development. Not only do they offer valuable insights for the urban planning for the expansion of the Bacalar town but also highlight the crucial importance of preserving the forested areas in the region (see section 7).

7. Looking ahead, what do you feel are the important next steps?

Looking ahead, there are several important next steps that need to be taken. First, it is crucial to generate a map indicating priority conservation areas and derive concrete recommendations of conservation actions for future development in the region. With the Tren Maya railways under construction, there will be increased urban and touristic development in the near future, which will lead to more land conversion, noise, pollution, and higher human population density. Our research has found that urbanisation is the leading threat to both animal forest species and water quality in the Bacalar lake. Therefore, it is necessary to disseminate our findings and corresponding conservation measures to local stakeholders.

In addition, a follow-up acoustic monitoring and water quality assessment is needed to evaluate the environmental impact of the Tren Maya project after its launch. This will allow us to compare such data with the pre-assessment data we have already collected and determine the extent of the impact of the Tren Maya project on the local ecosystem. Through continued research and monitoring, we can contribute to the development and implementation of effective conservation measures that protect both the natural environment and the local communities that depend on it. As stated above, the team plans to apply for a second Rufford small grant to carry out a follow-up passive acoustic monitoring study with the support of Rainforest Connection.

8. Did you use The Rufford Foundation logo in any materials produced in relation to this project? Did the Foundation receive any publicity during the course of your work?

Yes, we used the Rufford Foundation logo in all materials produced in relation to this project. This included two presentations about the project at international conferences: the meeting of the International Primatological Society in Quito (Ecuador) in January 2022, and the meeting of the British Ecological Society, in Edinburgh (UK, online participation) in December 2022. In addition, the logo was used in talks and presentations to local stakeholders as well as in our reports of results to landowners. We are grateful for The Rufford Foundation's support and proud to have been associated with the foundation through the use of their logo. During the course of the project, we provided The Rufford Foundation with two project update reports including photos and video material.

The Rufford Foundation
www.rufford.org @ruffordgrants

Reporte de resultados
Parte1

Diciembre 2022

Reporte para

Ecotucan

Autores

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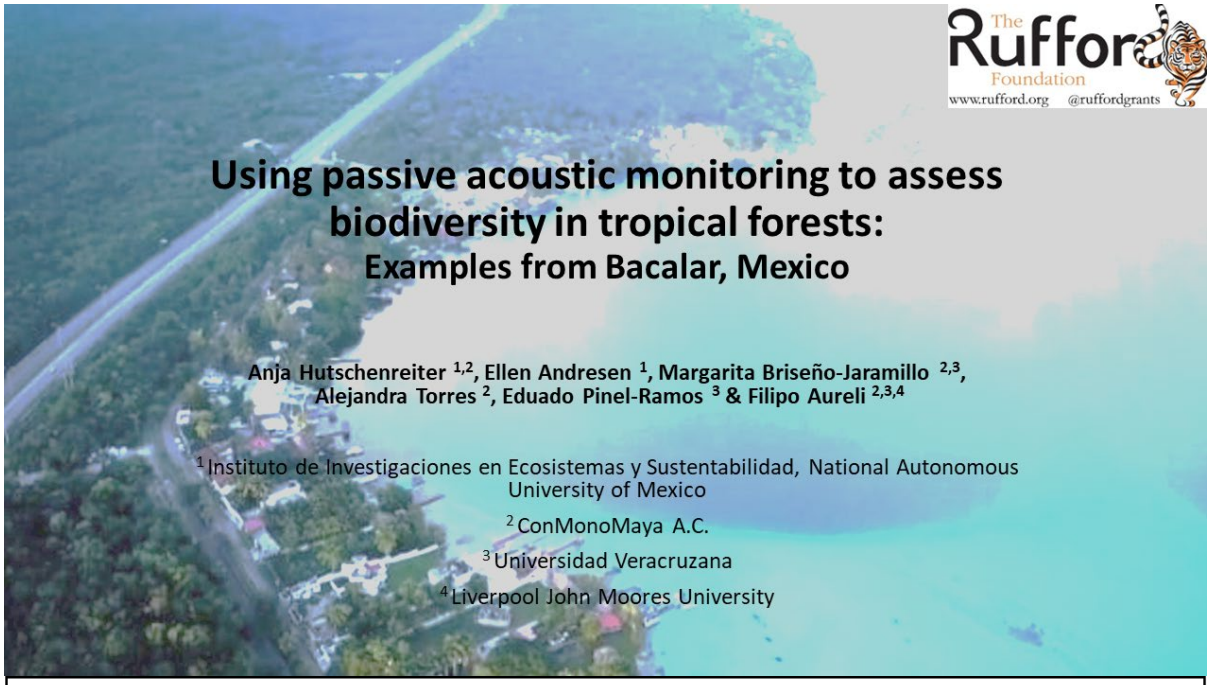

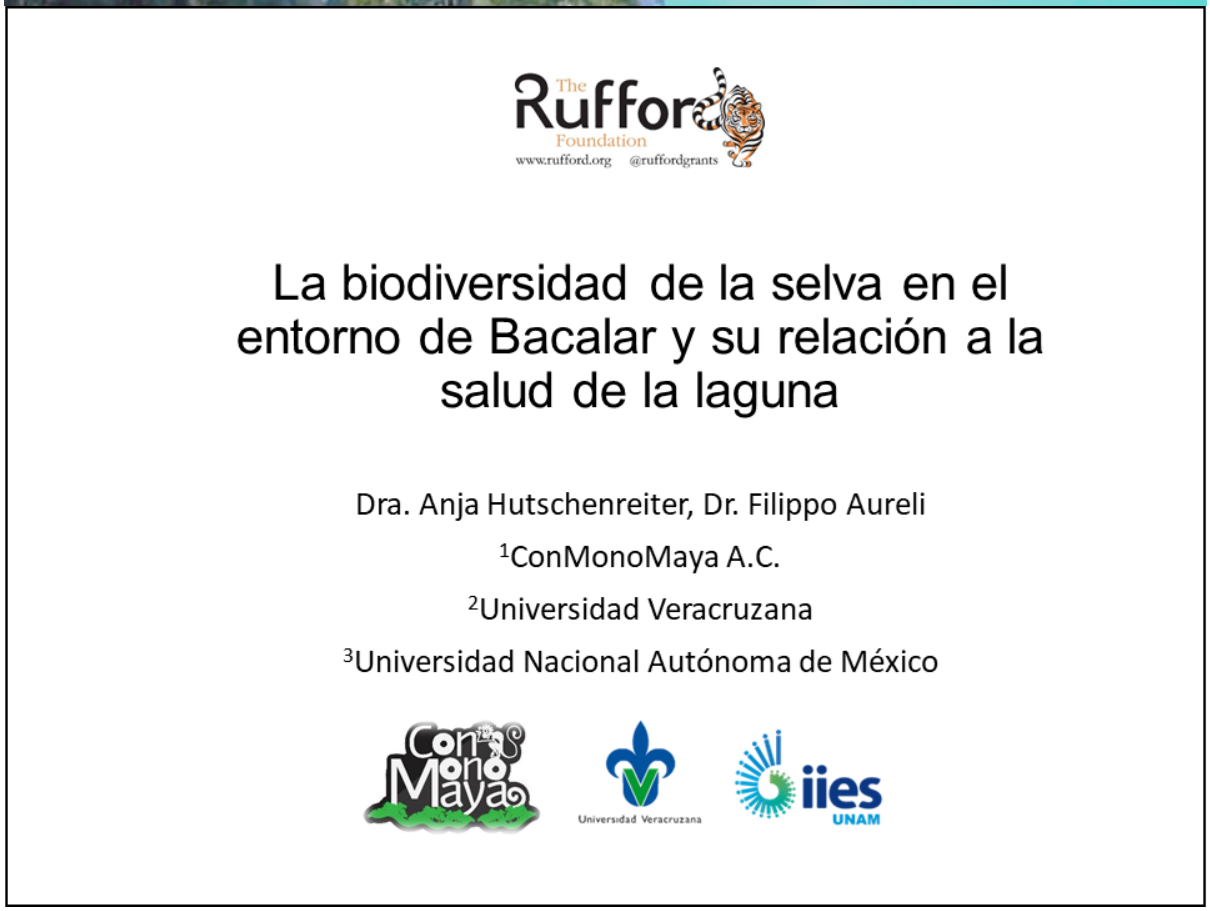

Examples of cover page for landowner reports and presentation slides as material released in the course of the project using the Rufford Foundation logo.

9. Provide a full list of all the members of your team and their role in the project.

Dr. Anja Hutschenreiter
The project was led by the grantee, who served as the head of operations and was responsible for overseeing all aspects of the project. She worked with Filippo Aureli to plan the research design and establish the study area and was also in charge of the data collection for the passive acoustic monitoring component. In addition, she and Filippo managed public relations for the project, communicating with local stakeholders and landowners to promote awareness about their research. Anja was also responsible for analysing the acoustic data using the Arbimon platform to identify species, as well as managing and assigning tasks to team members. She conducted the statistical analysis of water-quality data to assess the impact of human activities on both forest and lake health. Anja was the main presenter of the project's talks and presentations. Thanks to the Rufford-funded project, Anja was able to obtain two post-doctoral fellowships during the time of the project: one by the German Academic Exchange service (September 2021 – February 2022) and one by her current affiliation, the Institute for Ecosystem and Sustainability Research (IIES, Universidad Nacional Autónoma de México, March 2022 – February 2024), both supervised by Dr. Ellen Andresen (see below).

Dr. Filippo Aureli
Filippo Aureli, an Italian ethologist and professor at Universidad Veracruzana, played a vital role in the project. He has over two decades of field research experience in the Yucatan peninsula of Mexico and is a co-founder of the NGO ConMonoMaya, which managed the Rufford funds dedicated to the project. Filippo aided significantly in the planning and execution of all project aspects. He was actively involved in engaging the local community and stakeholders, including FONATUR, to spread information about our work and to disseminate the project results. Filippo actively and persistently advocated for the placement of faunal bridges as a mitigation strategy for the construction of the Tren Maya, based on the occurrence data of spider monkeys and other threatened animals gathered during our project. In his role as vice president of ConMonoMaya, Filippo recruited Alejandra Torres and Margarita Briseño-Jaramillo to the team who were invaluable to the success of the project.

Dr. Alejandra Torres
Alejandra Torres, a Chilean biologist and member of ConMonoMaya, joined the team in February 2022 to assist with processing the acoustic data. After one month of training, Alejandra took on many responsibilities and completed them independently. These responsibilities included uploading data, providing data to our collaborators for initial species identification, supervising the semi-automated detection process in Arbimon, and calculating acoustic indices in R. Her innovative ideas considerably improved the workflow and ensured the timely completion of the project.

Dr. Margarita Briseño-Jaramillo
Margarita Briseño-Jaramillo is a Mexican bioacoustics researcher from Universidad Veracruzana and member of ConMonoMaya who joined the team in October 2022. Not only did Margarita assist in processing the acoustic data, but her expertise in

bioacoustics was instrumental for improving our data handling methods and formulating research questions that could be answered using the data collected. In fact, Margarita initiated a collaboration with a noise researcher to study the effects of anthropogenic noise on the vocal flexibility in birds, using the data we collected during the project. This collaboration promises to yield further insights into the effects of urbanization on the forest biodiversity in the Bacalar.

Dr. Ellen Andresen
Ellen Andresen is a Mexican researcher at the Institute for Ecosystem and Sustainability Research (Universidad Autónoma de México) with extensive experience in the field of ecological functions of forest fauna in disturbed habitats. She served as the grantee's postdoc supervisor and provided guidance and support throughout the project. Along with the grantee and other team members, she is currently working on developing the manuscript for the first peer-reviewed article based on the project's findings. In addition, Ellen has provided the institutional framework for the project and will continue to supervise the grantee beyond the Rufford-funded project's duration until February 2024.

Melina Maravilla
Melina is a Mexican biologist and is the executive director at the NGO Agua Clara, dedicated to the conservation of the Bacalar lake. She was in charge of the water-quality monitoring at the Bacalar lake, and thus provided us with the water-quality data for further analysis. It was thanks to her well-established local network that we found many of the landowners willing to grant us permission to use their terrain for the passive acoustic monitoring. It was also thanks to Melina´s contacts that were able to present the project in a council meeting in front of local authorities and decision-makers of the Tren Maya project.

Karime Unda Harp had initially planned to be involved in the project. However, she had to withdraw her participation in August 2021 due to a job offer that came her way. Her foreseen roles were taken over by Filippo, Alejandra, and Margarita.

10. Any other comments?

We are incredibly grateful to The Rufford Foundation for their support, without which this project would not have been possible. Thanks to their generosity and the support of the community of Bacalar, this project has grown beyond our initial expectations.

Appendix 1. Reference list

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Appendix 2. List of registered species identified by the passive acoustic monitoring during the project including species of key conservation concern.

Taxon	Name	Latin Name	IUCN classification	SEMARNAT classification	Indicator or umbrella species
Bird	Baltimore oriole	*Icterus galbula*	Least Concern (LC)	-	
Bird	Altamira oriole	*Icterus gularis*	Least Concern (LC)	-	
Bird	Barred antshrike	*Thamnophilus doliatus*	Least Concern (LC)	-	
Bird	Black-crowned night-heron	*Nycticorax nycticorax*	Lesser Concern (LC)	-	Indicator
Bird	Black-faced antthrush	*Formicarius analis*	Lesser Concern (LC)	-	
Bird	Black-headed saltator	*Saltator atriceps*	Least Concern (LC)	-	
Bird	Black-headed trogon	*Trogon melanocephalus*	Least Concern (LC)	-	
Bird	Blue-gray gnatcatcher	*Polioptila caerulea*	Least Concern (LC)	-	
Bird	Boat-billed flycatcher	*Megarhynchus pitangua*	Least Concern (LC)	-	
Bird	Brown jay	*Psilorhinus morio*	Least Concern (LC)	-	
Bird	Canivet´s emerald	*Chlorostilbon canivetii*	Least Concern (LC)	-	
Bird	Carmiol's tanager	*Chlorothraupis carmioli*	Least Concern (LC)	-	
Bird	Black-and-white warbler	*Mniotilta varia*	Least Concern (LC)	-	
Bird	Couch's kingbird	*Tyrannus couchii*	Least Concern (LC)	-	
Bird	Dusky-capped flycatcher	*Myiarchus tuberculifer*	Least Concern (LC)	-	

Bird	Eye-ringed flatbill	*Rhynchocyclus brevirostris*	Least Concern (LC)	-	
Bird	Gartered trogon	*Trogon caligatus*	Least Concern (LC)	-	
Bird	Golden-olive woodpecker	*Colaptes rubiginosus*	Least Concern (LC)	-	
Bird	Gray hawk	*Buteo plagiatus*	Least Concern (LC)	-	
Bird	Broad-winged hawk	*Buteo platypterus*	Least Concern (LC)	Subject to special protection (Pr)	Umbrella
Bird	Great crested flycatcher	*Myiarchus crinitus*	Least Concern (LC)	-	
Bird	Great kiskadee	*Pitangus sulphuratus*	Least Concern (LC)	-	
Bird	Green jay	*Cyanocorax yncas*	Least Concern (LC)	-	
Bird	Greenish elaenia	*Myiopagis viridicata*	Least Concern (LC)	-	
Bird	Hooded warbler	*Setophaga citrina*	Least Concern (LC)	-	
Bird	Ivory-billed woodcreeper	*Xiphorhynchus flavigaster*	Least Concern (LC)	-	
Bird	Kentucky warbler	*Geothlypis formosa*	Least Concern (LC)	-	
Bird	Laughing falcon	*Herpetotheres cachinnans*	Least Concern (LC)	-	
Bird	Lesser greenlet	*Pachysylvia decurtata*	Least Concern (LC)	-	
Bird	Lesson´s motmot	*Momotus lessonii*	Least Concern (LC)	-	
Bird	Lineated woodpecker	*Dryocopus lineatus o Hylatomus lineatus*	Least Concern (LC)	-	
Bird	Long-billed gnatwren	*Ramphocaenus Melanurus*	Least Concern (LC)	-	

Bird	Long-billed hermit	*Phaethornis longirostris*	Least Concern (LC)	-	
Bird	Masked tityra	*Tityra semifasciata*	Least Concern (LC)	-	
Bird	Melodious blackbird	*Dives dives*	Least Concern (LC)	-	
Bird	Mottled owl	*Ciccaba virgata*	Least Concern (LC)	-	
Bird	Great horned owl	*Bubo virginianus*	Least Concern (LC)	Threatened (A)	Indicator
Bird	Ferruginous pygmy-owl	*Glaucidium brasilianum*	Least Concern (LC)	-	
Bird	Thicket tinamou	*Crypturellus cinnamomeus*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	Northern bentbill	*Oncostoma cinereigulare*	Least Concern (LC)	-	
Bird	Northern parula	*Setophaga americana*	Least Concern (LC)	-	
Bird	Plain chachalaca	*Ortalis vetula*	Least Concern (LC)	-	
Bird	Red-crowned ant-tanager	*Habia rubica*	Least Concern (LC)	-	
Bird	Red-throated ant tanager	*Habia fuscicauda*	Least Concern (LC)	-	
Bird	Roadside hawk	*Rupornis magnirostris*	Least Concern (LC)	-	
Bird	Rose-throated Becard	*Pachyramphus aglaiae*	Least Concern (LC)	-	
Brid	Rose-throated Tanager	*Piranga roseogularis*	Least Concern (LC)	-	
Bird	Rufous-and-white Wren	*Thryophilus rufalbus*	Least Concern (LC)	-	
Bird	Rufous-tailed hummingbird	*Amazilia tzacatl*	Least Concern (LC)	-	
Bird	Smoky-brown woodpecker	*Dryobates fumigatus*	Least Concern (LC)	-	
Bird	Golden-fronted woodpecker	*Melanerpes aurifrons*	Least Concern (LC)		
Bird	Social flycatcher	*Myiozetetes similis*	Least Concern (LC)	-	
Bird	Spot-breasted wren	*Pheugopedius maculipectus*	Least Concern (LC)	-	

Bird	Ringed kingfisher	*Megaceryle torquata*	Least Concern (LC)	-	
Bird	Summer tanager	*Piranga rubra*	Least Concern (LC)	-	
Bird	Olive sparrow	*Arremonops rufivirgatus*	Least Concern (LC)		
Bird	Tawny-crowned greenlet o gnatcatcher	*Tunchiornis ochraceiceps*	Least Concern (LC)	-	
Bird	Tropical kingbird	*Tyrannus melancholicus*	Least Concern (LC)	-	
Bird	White-throated magpie-jay	*Calocitta formosa*	Least Concern (LC)	-	
Bird	Wood thrush	*Hylocichla mustelina*	Least Concern (LC)	-	
Bird	Yellow Olive flycatcher	*Tolmomyias sulphurescens*	Least Concern (LC)	-	
Bird	Yellow-backed oriole	*Icterus chrysater*	Least Concern (LC)	-	
Bird	Yellow-billed cacique	*Amblycercus holosericeus*	Least Concern (LC)	-	
Bird	Yellow-tailed oriole	*Icterus mesomelas*	Least Concern (LC)	-	
Bird	Yellow-throated euphonia	*Euphonia hirundinacea*	Least Concern (LC)	-	
Bird	Yellow-throated vireo	*Vireo flavifrons*	Least Concern (LC)	-	
Bird	Yucatan jay	*Cyanocorax yucatanicus*	Least Concern (LC)	-	
Bird	Yucatan poorwill	*Nyctiphrynus yucatanicus*	Least Concern (LC)	-	
Bird	Limpkin	*Aramus guarauna*	Least Concern (LC)	Threatened (A)	
Bird	Vireo ojiblanco	*Vireo griseus*	Least Concern (LC)	Threatened (A)	
Bird	Yellow-lored parrot	*Amazona xantholora*	Least Concern (LC)	Threatened (A)	

Bird	Spotted woodcreeper	*Xiphorhynchus erythropygius*	Least Concern (LC)	Threatened (A)	
Bird	Keel-billed toucan	*Ramphastos sulfuratus*	Near Threatened (NT)	Threatened (A)	
Bird	Yellow-naped parrot	*Amazona auropalliata*	Critically Endangered (CR)	Endangered (P)	
Bird	Olive-throated parakeet	*Eupsittula nana*	Near Threatened (NT)	Endangered (P)	
Bird	Bright-rumped attila	*Attila spadiceus*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	Collared aracari	*Pteroglossus torquatus*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	Collared forest-falcon	*Micrastur semitorquatus*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	Gray-headed tanager	*Eucometis penicillata*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	Great blue heron	*Ardea herodias*	Least Concern (LC)	Subject to special protection (Pr)	Umbrella
Bird	Northern barred woodcreeper	*Dendrocolaptes sanctithomae*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	Northern Emerald-toucanet	*Aulacorhynchus prasinus*	Least Concern (LC)	Subject to special protection (Pr)	

Bird	Rufous-browed peppershrike	*Cyclarhis gujanensis*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	White-fronted parrot	*Amazona albifrons*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	Red-lored parrot	*Amazona autumnalis*	Least Concern (LC)	-	
Bird	White-tipped dove	*Leptotila verreauxi*	Least Concern (LC)	Subject to special protection (Pr)	
Bird	White-winged dove	*Zenaida asiatica*	Least Concern (LC)	-	
Bird	White-breasted wood-wren	*Henicorhina leucosticta*	Least Concern (LC)	-	
Mammal	Geoffroy's spider monkey	*Ateles geoffroyi*	Endangered (EN)	Endangered (P)	
Mammal	Black howler monkey	*Alouatta pigra*	Vulnerable (VU)	Endangered (P)	
Mammal	White-nosed coati	*Nasua narica*	Least concern (LC)	-	
Reptile	Common house gecko	*Hemidactylus frenatus*	Least Concern (LC)	-	
Amphibian	Yucatán casque-headed tree frog	*Triprion petasatus*	Least Concern (LC)	Subject to special protection (Pr)	Indicator
Amphibian	Gulf Coast toad	*Incilius valliceps*	Least Concern (LC)	-	