Chapter 7

Discussion

7.0 Abstract

Human presence and human generated noise are causing behavioural shifts across a multitude of taxonomic groups in the animal kingdom. This thesis provides evidence that these behavioural shifts are occurring even on a small-scale gradient of exposure. This chapter outlines the contributions made in this thesis in cataloguing anthropogenic noise exposure and measuring its impacts on primate vocal structure. I outline important steps towards using automated methodologies to study these impacts to remove observer bias from studies. This chapter also discusses important next steps and research gaps that still need to be addressed, including the implementation of machine learning algorithms to help expedite the lengthy analyses processes. I suggest that the far-reaching study of the impacts of anthropogenic noise on animal behaviour will help lead to practical mitigations efforts which can support the combat of the impacts of ecotourism and urbanisation.

7.1 Introduction

This thesis details the impact of anthropogenic noise derived from human habitation and ecotourism on pygmy marmoset vocalisations and behaviour. The work presented in this thesis provides evidence of vocalisation shifts between groups exposed to varying levels of anthropogenic noise. It also highlights the different methodologies currently used in cataloguing anthropogenic noise disturbance, non-invasive audio recordings and eliminating observer bias from playback experiments. It contains the first multi-season diurnal riverine raptor survey conducted in the Área de Conservación Regional Comunal Tamshiyacu Tahuayo (ACRCTT) reserve, finding nine new documented raptor species for the reserve. I provide evidence through a pilot study with pygmy marmosets that the use of ABR technology is a viable and cutting-edge methodology for looking at the impacts of human disturbance. Below I outline recommendations for the use of these methodologies and their future use in studies examining the impacts from human expansion and tourism in the hopes to better understand the wider implications and potential mitigation practices that can be used in ecotourism settings.

7.2 Contributions

In this thesis I detail the importance of measuring responses on a gradient of anthropogenic noise exposure and provide a potential means to improve methods of cataloguing disturbance and its effects. This thesis provides the first comparison of a manual analysis versus the bioacoustics index, NDSI score, for measuring and cataloguing anthropogenic noise disturbance levels (Chapter 3). This chapter highlights the limitations and advantages of both measurement techniques but also the importance of measuring the levels of anthropogenic noise that animals are truly exposed to. This is uncommon and most literature focuses on reactions to the sounds or a binary comparison of loud versus quiet treatments (Shannon *et al*., 2016). The gradient of noise exposure created in this chapter was then used to inform an analysis of how the pygmy marmoset vocalisations were shifting along this gradient (Chapter 4). The results from Chapter 3 indicate that the NDSI score cannot be used as a replacement for manual analysis if one is looking for a comprehensive analysis of the amount of anthropogenic noise present in an audio file. This thesis also provides further support for the continued use of the NDSI score as it relates to species richness and abundance and focusing its use to serve more as a reflection of potential shifts in animal activity patterns (Ritts *et al*., 2016). Monitoring the pressures that are driving changes in biodiversity is important and I argue that gathering more comprehensive data on the amount and variety of anthropogenic noise at a site allows one to conduct more in-depth analysis on a gradient of this exposure which is currently lacking in the available literature.

An important contribution made by this thesis has been the additional evidence to the impacts of anthropogenic noise disturbance on wild primate vocalisation. It is the first to look at these effects on a gradient of exposure (Chapter 4). There is a global surge in anthropogenic noise pollution arising from the rapid expansion of human populations, resource abstraction and transportation systems which has contributed to the recent spike in the study of the impacts of noise on wildlife (Shannon *et al*., 2016). Shannon *et al*. (2016) identify gradients as a key knowledge gap in our current understanding of the impacts of anthropogenic noise on wildlife, which I was able to provide some data to fill. The use of an exposure gradient helps provide a more nuanced look at where vocalisations shifts lie along this gradient and provides a more detailed look at what specific anthropogenic sounds could be driving this change. It is particularly important to fill the knowledge gap of how these changes in vocalisation structure are occurring on a gradient of exposure, as it reveals if animals are able to adapt to these varying levels of exposure. Understanding the impact of the gradient allows researchers to explore the correlation between the duration and levels of noise exposure and habituation in a wide variety of species and habitats (Shannon *et al*., 2016). The only other study to catalogue the anthropogenic noises present in a habitat and the impacts of this noise in wild primates is Gómez-Espinosa *et al*. (2022), who looked at the influence of anthropogenic noise on male mantled howler monkey (*Aloutta palliate*) behaviour. The males were found to display more vigilance behaviours and call more frequently to audios with high sound pressure levels, although these reactions depended on group identity. The authors postulate that the frequency of exposure to these different anthropogenic sounds is the likely explanation for the group level behavioural differences found. There has only been one other study to incorporate the use of a gradient of noise levels to measure wild primates' responses to humans (Lineros *et al*., 2020). This study looked at the behavioural and hormonal responses in the Bolivian grey titi monkey (*Plecturocebus donacophilus*) to human presence on a gradient of increasing distances from a busy highway. They found that the titis' produced more alarm calls when presented with a mannequin the further away from the highway the group is located, suggesting that the groups closer to the highway are becoming more habituated to human presence.

This thesis adds to the very limited literature that primates change their vocalisations in the presence of higher levels of noise, I found that pygmy marmosets had spectral and temporal shifts in the call characteristics of three call types on a gradient of exposure to anthropogenic noise disturbance (Chapter 4). There is previous evidence of this with black tufted marmosets (*Callithrix penicillata*) calling less frequently in higher noise levels (Santos *et al*., 2017), black-fronted titi monkeys (*Callicebus nigrifrons*) calling for shorter periods (Duarte *et al*., 2018) and black tufted marmosets for longer (Santos *et al*., 2017), and black tufted marmosets changing the acoustic characteristics of their vocalisations (Santos *et al*., 2017). Anthropogenic noise also affects primate movement patterns with some actively moving to avoid noise like pygmy marmosets (Sheehan and Papworth, 2019), some increasing their time spent moving (mantled howler monkeys; Cañadas-Santiago *et al*., 2020) or decreasing it (Bolivian grey titi monkey; Lineros *et al*., 2020). Filling this knowledge gap is pertinent as even though primates have long been a fixture in scientific research (Junker *et al*., 2017) and a main draw for ecotourists (Russon and Wallis, 2014) the research into the effects of anthropogenic noise on wild primates is still lacking.

This thesis provides the first ever multi-seasonal riverine raptor survey for the ACRCTT (Chapter 5). With the tropics being a bastion for diurnal raptor species it is paramount to catalogue the species present in these areas. Especially in South America which is home to 28% of all diurnal raptor species (Jensen *et al.*, 2005), however, the raptors found in the Neotropics are understudied (Piana and Marsden, 2012). Across both the rainy and dry season, I encountered 26 species of diurnal raptors and found seasonal distribution patterns for 7 of these species. When my results were compared to the only previous bird study conducted in the area (13 years prior to this survey), I found 9 new previously unrecorded species for this reserve. Highlighting the importance of repeated long-term monitoring in highly biodiverse areas like the ACRCTT, as information on tropical wildlife is valuable as the global loss of tropical forests continues to increase rapidly (Morse-Jones *et al*., 2014; Symes *et al*., 2018). Long-term monitoring in these areas also allows for a better understanding of avian communities' distribution and abundance and other species groups as well, in order to better conserve these biodiversity hotspots.

Chapter 6 provides more evidence for how pygmy marmosets behaviour changes in the presence of humans and anthropogenic noise. With human speech audio stimuli having the second highest percentage of fleeing events, aligning with previous literature finding pygmy marmosets moving out of sight when played loud recording of human speech (Sheehan and Papworth, 2019). Focal individuals were found to be more vigilant during predator call and anthropogenic noise playbacks. Further supporting the findings in Sheehan and Papworth (2019) where the focal individual was more likely to spend time being alert and less time feeding and resting when played audio of human speech. These studies seem to indicate that pygmy marmosets see humans as a risk, falling under the risk disturbance hypothesis. With the risk disturbance hypothesis stating that prey species view humans and anthropogenic noise as risks, causing the prey species to react to humans with anti-predator behaviours (Walter, 1969). This is seen with the pygmy marmosets spending more time displaying vigilance behaviours or fleeing when played the audio of human speech, while also being less likely to engage in eating or social behaviours, further aligning with the risk disturbance hypothesis. Indicating that the marmosets are potentially not habituating to human presence even after high amounts of exposure (as groups involved in the playback experiment were located in the local community), potentially indicating that the human shield effect is not applicable in this study system. The marmosets in the study were still able to gage the predation risk by calling more on average and fleeing more in the predator call conditions that were spliced into anthropogenic noise audio. My preliminary results suggest that the marmosets are not being distracted by the motor boat audio and are still having anti-predator responses to the bird of prey calls, providing evidence that the distracted prey hypothesis might not be applicable in this study system. Evidence for the distracted prey hypothesis in this system was also not found by Hawkins and Papworth (2022), however they also did not find any behavioural change in the pygmy marmosets in response to human speech playbacks. Indicating that further research on the pygmy marmosets in this study system are needed and using groups of varying levels of human exposure is needed in order to see what is driving this difference in behaviour between these studies that were all conducted at the same site.

This thesis adds to the current literature that pygmy marmosets are affected by tourism however it also provides evidence that the marmosets are adapting to this increase in anthropogenic noise. The evidence in this thesis is the first to illustrate the impacts of the anthropogenic noise brought by ecotourists on the pygmy marmoset's vocal communication structure, with previous studies looking at the impacts on their behaviour. de laTorre *et al*. (2000) found that groups of pygmy marmosets that were in areas of high tourism were significantly less likely to engage in social play and displayed less aggression than groups in areas with lower tourist exposure. The groups in de laTorre *et al*. (2000) study that were in areas of high tourism were also found to use the lower stratum of the forest significantly less than the groups found in areas with lower levels of tourism. Which shows that human visitation is having a direct impact to feeding behaviours as pygmy marmosets are known to prefer the lower strata of the tree (0-15m off the ground) (Soini, 1988). The biggest impact on behaviour they found was a result of the capture of individuals, the marmosets reduced their vocalisations and were overall harder to observe using the upper strata of the trees. de la Torre *et al*. (2000) postulate that the marmosets at their study site are not habituating to tourists as groups at both sites have been experiencing tourism for around the same amount of time. However, the groups at the study site used in this thesis do seem to show altering behaviours, at least when it comes to vocal structure. Suggesting that the marmosets here are adapting to an increase in human presence, in the form of anthropogenic noise. Sheehan and Papworth (2019), who studied the pygmy marmosets at the same study site as this PhD, found that the marmosets were significantly less visible and moved out of sight of the observer after being played a loud playback of human speech. Furthering evidence that marmosets are disturbed by human visitation, however, they did not observe the aforementioned behaviour in control trials where the monkeys were purely exposed to human presence and not sound.

Using the evidence from previous studies and the results of this thesis I present some recommendations for viewing practices for the pygmy marmosets. There are currently very few official regulations in place for primate tourism, with the only official guidelines being that published by the IUCN which is a best-practice guideline for great ape tourism (Macfie and Williamson, 2010). For the pygmy marmosets as shown in Sheehan and Papworth (2019)'s study it is pertinent that tourists keep talking to a minimum and if needed to only whisper while viewing the marmosets. Regulating the number of tourists which view the marmosets at one time could help combat some of the behavioural changes found by de la Torre *et al*. (2000). Based off the results in Chapter 4 limiting the use of motor boats while viewing the marmosets, especially in the flooded season, could help the potential degradation of their communications. This could be done by increasing the use of canoes to view the marmosets and to slow down when driving the motor boats by known pygmy marmoset groups close to the river's edge.

The pilot study presented in Chapter 6 outlines the use of the ABR system to overcome the observer biases that come with traditional playback experiments. This trial is the first to attempt to use this system to test a behavioural hypothesis on a wild primate species. I outline different methodical practices which worked and which ones hindered the study, and how refining these techniques can yield more successful playback trials and the collection of a more robust dataset. The ABR is a powerful tool which will allow researchers to test behavioural hypotheses (those often dealing with the impacts of human disturbance) without the bias created by human observers (Suraci *et al*., 2017). Using this system will allow researchers to gain a clearer understanding as to how ecotourists are affecting an animal's perception of their environment. If we can understand how these primates are interacting with ecotourists it will allow for more targeted management changes.

This thesis furthers the use of non-invasive and passive monitoring techniques with the use of Audiomoths (Chapter 3 and 4) and the Automated Behavioural Response (ABR) system (Chapter 6). This was done in order to further support the shift from more traditional monitoring methodologies which need a human observer to be present. Researchers can be the cause for observer effects which arise when the study organism shifts their behaviours due to the presence of the researcher (McDougall, 2012). Researchers try to mitigate these effects through methods like habitation, however, the habitation process has also been found to change behaviours over the course of the study (Jack *et al*., 2008). The effects of these changes in behaviour mean that some of the findings produced in these conditions are not applicable to other individuals of the same species who are more remote areas and have less contact with humans (Metcalfe *et al*., 2022). Large-headed capuchins (*Sapajus macrocephalus*) spend less time feeding when observers are closer and when there were more researchers present indicating that human pressure gradients do influence animal behaviour (Metcalfe *et al*., 2022). With more evidence presenting proof that biases are occurring in human observational studies (McDougall, 2012) it is pertinent to explore these passive monitoring techniques which do not need researchers to be present.

7.3 Future avenues for research

Camera traps, acoustic sensors and other automated remote monitoring technology are at the forefront of conservation efforts as they are more affordable, less invasive and even allow for more versatile methods of monitoring than more traditional methods (Pimm *et al*., 2015). These methods remove the confounding factor of human observers (Suraci *et al*., 2017) and expand sample sizes (Hill *et al*., 2018). However, the manual processing of this data is time consuming, as shown in Chapter 3, 4 and 6, which serves as an obstacle to the widespread use of these methods (Pimm *et al*., 2015; Bain *et al*., 2021). A method to bypass this limitation would be to integrate artificial intelligence, machine learning and deep learning analytical methods which have all seen a recent rise in popularity in scientific studies (Pichler and Hartig, 2022). Recent advances have been made in machine learning with the generation of multiple algorithms and models which are able to partially, or fully automate data processing from both sound and video files (Bain *et al*., 2021; Stowell, 2022). Bain *et al*. (2021) is the only previous study to have successfully combined a deep convolutional neural network approach and animal behaviour analysis with videos and audio collected using camera traps on wild primates. Their study shows the early success of such methodologies and provides a promising future for integrating ABR methodologies with machine learning algorithms. This would help expedite the analysis process and allow for a more widespread application of these systems. A future project could be derived from the pilot conducted in Chapter 6 and using pygmy marmosets to show a 'proof-of-concept' for using generic, rapid and 'lightweight' audio and visual convolutional neural network architecture to process the types of data generated by ABRs, without the use of intensive computing clusters.

The use of machine learning algorithms can also be applied to studies looking to monitor and assess levels of anthropogenic noise disturbance like that conducted in Chapter 3, which would also help automate the analysis of the large dataset created. Besson *et al*. (2022) has created a framework combining acoustic sensors and artificial intelligence approaches to create a fully automated pipeline which detects, classifies, tracks and counts multiple species while also recording behavioural and morphological traits. They postulate that the expansion of these methods will allow for the collection of data which can be used to compare ecological communities on a global scale. Which would allow researchers to monitor their temporal subtleties and examine what stressors are having the largest impacts on wildlife and which animal populations are most at risk to these impacts. These automated detection methods have shown early success in estimating cryptic species abundance, with manatees (*Trichechus manatus latirostris*) in Florida (Rycyk *et al*., 2022). They have also been used to collect evidence of poaching in a nature reserve in Belize (Prince *et al*., 2019), showing that machine learning algorithms has application in bioacoustics beyond monitoring biodiversity (Stowell, 2022) and can be used to identify and monitor the pressures that are driving changes in biodiversity. Integrating machine learning algorithms in the analysis of large-scale acoustic data especially those with a focus on anthropogenic noise disturbance will allow for a global understanding of the ramifications anthropogenic noise pollution on wildlife which is needed to inform mitigation efforts.

A limitation of this thesis was the inability to collect behavioural data across varying seasons of tourist occupancy. This is a key knowledge gap that needs to be addressed as the long-lasting effects of the temporal aspect of tourism is largely understudied, especially in regards to antipredator behaviours. The environment is ever changing and animals are having to shift and alter their behaviour in reaction to this change (Buchholz *et al*., 2019). These longer lasting effects come from both the urbanisation and domestication process, however, ecotourism can still have long lasting effects even though the tourist's presence is temporary (Geffroy *et al*., 2015). This has implications not only to the animal's anti-predator behaviours (Blumstein *et al*., 2004) but the temporal increase in anthropogenic noise, the peak tourist season, could also be having impacts on pygmy marmoset communication. Literature tells us that environmental pressures can cause animals to have to adapt and alter their vocalisations (Ey and Fisher, 2009). Evidence for this has been found in primates with the characteristics of a call from black tufted-ear marmoset becoming altered when in a 'nosier' urban area compared to a rural national park (Santos *et al*., 2017) and the results from Chapter 4. Pygmy marmosets have already been shown to have social induced plasticity (de la Torre and Snowdon, 2009), this suggests that with the plastic nature of their calls they could be able to shift their calls in the short term when actively being exposed to anthropogenic noise or in longer periods of time (months) when the exposure to anthropogenic noise is higher. Addressing this question would fill the current knowledge gap of the short-term vocalisation changes wild primates may be making in order to adapt to nosier environments.

7.4 Conclusions

This thesis adds to the literature that details the impacts and effects of anthropogenic noise disturbance on animal vocalisations and behaviour. Although this thesis focuses on a specific Neotropical species, the results found can be expanded to other primates which are a focus of ecotourism across the globe. The work presented here demonstrates the importance of cataloguing and studying the abiotic pressures wildlife is exposed to, in this case anthropogenic noise, and the best methodologies to analyse them. It also highlights the importance of looking at these behavioural and vocal changes on a gradient of exposure, in order to further our understanding of the impacts the global influx of anthropogenic stressors is having on wildlife. Through the recommendations discussed in this thesis hopefully the collection of data through the use passive monitoring techniques can become more widespread allowing for a rapid and cost-effective methodology to be used to study these impacts. The widespread study of the impacts of anthropogenic noise on anti-predator behaviour and communication can hopefully allow for practical mitigations efforts to combat the impacts of not only ecotourism but urbanisation as well.

7.5 References

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