LANDSCAPE-SCALE RESEARCH AS A TOOL FOR ENGAGING COMMUNITIES IN A SHARED LEARNING PROCESS FOR CONSERVATION AND MANAGEMENT IN THE RUPUNUNI, GUYANA

By

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To my family – thank you for teaching me that I could achieve anything that I set my mind to, and never letting me believe otherwise. You may not have always understood what I was doing or why, but you always supported me anyway. To my friends near and far – I could not have done this without you. You provided me with a constant source of humor and love, and formed the most loyal support system that anyone could ask for. To the love of my life – you are the greatest gift that the University of Florida could have ever given me. Thank you for being my constant source of confidence, comfort, and inspiration, my statistics coach, and the person who supported me emotionally (and financially) through this process. To my advisor – thank you for being the only person willing to allow me to pursue this crazy idea and for all of your support along the way. To the city that raised me, thank you for making me the man I am today. Chicago, you are a living testament to the importance of diversity. You showed me what it means to care for my fellow man, to invest in people, to listen and learn from the experience of others, and to serve my community.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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By

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The Rupununi Region of Guyana serves as an ideal laboratory for testing research questions along natural and human-use gradients. It supports unique habitats that range from cerrado savanna to evergreen and deciduous tropical forest, mammalian fauna representative of the Guiana Shield, and low-density populations largely composed of indigenous people who maintain traditional subsistence lifestyles. New access to technology and global culture, national and international demand for the region's natural resources, and global climate change are driving rapid change in culture, economics, and climate, creating a need for communities to adapt their way of life. This study seeks to support this process by incorporating research tools and quantitative methods into existing traditional management using a participatory approach. Our primary objective is to increase understanding of the status of Rupununi wildlife and identify the most important drivers of their distribution and abundance; however, our process was designed with the intent to equip indigenous communities to deal with resource issues in a changing world.

Moving beyond our initial ecological question, we engaged members of indigenous communities and private landowners in a learning process, assisting in the development and testing of locally relevant research questions that address wildlife and natural resource issues. We provided training and leadership opportunities, and access to decision making in every critical aspect of the development and execution. We believe that engaging resource users as active participants in research promotes trust, high-quality data collection, and a broader understanding of ecological systems and the causal effects of resource exploitation behavior, while providing the tools that communities need to manage their own resources in a sustainable way. We hope that this project serves as an example of how participatory research can serve as an effective strategy for achieving research and conservation outcomes in areas of high biodiversity.

CHAPTER 1
INTRODUCTION

Every year, thousands of scientists head to the field seeking to answer a wide variety of questions related to biology, ecology, behavior, and conservation of species, communities, and systems. Enduring images of wildlife scientists sketching undescribed species on the shores of an unexplored archipelago or sitting alone in a remote forest quietly scribbling observations no longer reflect reality. The modern researcher works alongside people within integrated systems, seeking to understand interactions between humans and nature, and their contributions to mass extinctions and global environmental change. The daunting challenges looming on the horizon have many researchers striving to make a conservation impact with their work. This means pouring effort into not just making sure that their findings cycle back to the places where the data were collected, but facilitating processes to help make that information more accessible and ensure that it is applied to decision making or that it affects behavior in a positive way.

At its base, research invests time, training, and resources directly into communities where the opportunities for development are rare. Research is moving towards more participatory methods, creating the potential for scientific research to serve as a tool that promotes and even facilitates conservation – ultimately helping to stem the decline of global biodiversity that researchers set out to study. However, participatory methods require proper thought and careful planning with respect to how to engage communities and build capacity for research that is relevant and locally beneficial. In this chapter, we will explore trends in conservation and science, and discuss how we applied lessons learned from the past to the design and implementation of a participatory research project in the Rupununi Region of Guyana.

Community-Based Conservation

Over the last 30 years, conservation has shifted its focus and scale from maximizing protected habitat within the range of wildlife species of interest to incentivizing human communities for the sustainable management wildlife habitat within their local environment. This shift represents the recognition of human behavior as the driving force behind environmental issues like habitat loss, climate change, and others (Schultz 2011) and serves as an attempt to stem the drivers of these issues instead of responding to the outcomes.

Historically, the conservation and management of wildlife and their habitats has depended largely on rules and enforcement. Top-down conservation practices of the past sought to conserve by excluding people from utilizing wildlife and the resources that were set aside for them. However, the capacity of states to enforce laws in wilderness areas and effectively exclude people from resource use in favor of biodiversity conservation is limited, rendering these approaches largely ineffective (Agrawal & Gibson 1999). Centralized management creates a mismatch in scale for coupled human-environmental systems (Folke et al. 2002), creating a need for bottom-up approaches where solutions start at the lowest organizational level possible – communities (Berkes 2004). More inclusive, community-based approaches to conservation are a reaction to the failures of exclusionary approaches (Ghimire & Pimbert 1997), and have shown promise for bridging the gap between people who seek to use resources and those tasked with understanding, managing, and sustaining them.

Socio-economic factors have been major drivers in the decentralization and shift towards increased local participation in conservation. The spread of democratic political structures and increased acknowledgment of human, particularly indigenous peoples, rights have made centralized efforts that do not represent the needs of people undesirable (Agrawal & Gibson 1999). Community-based conservation (CBC) efforts are perceived as more accountable, fair,

and legitimate than centralized initiatives (Persha et al. 2011), and the prospect of preserving biodiversity while simultaneously reducing rural poverty has provided an economic incentive for engaging communities directly (Kiss 2004).

With the shift to promote sustainable behaviors came the acknowledgement that conservation is largely a luxury exclusive to those who are able to meet their daily needs (Adams et al. 2004). With much of the earth's biodiversity and remaining wild places in the developing world, initiatives that seek to address poverty reduction and environmental protection in an integrated manner seem the most relevant and necessary approach (Adams 1990). As a result, community-based conservation initiatives have largely opted for revenue generating activities, such as trophy hunting (Child 1996) and eco-tourism (Manyara & Jones 2007), that can increase the standard of living by providing economic incentives for co-existing with wildlife, rather than allowing communities to actively manage of their own resources within the traditional socioeconomic paradigm (Gibson & Marks 1995). The challenge that remains with community-based conservation based on economic incentives is that while exclusion from resources may have been decentralized, the wall between people and wildlife remains. In this case, interactions with resources are limited to those that meet their demand of foreign funders. This type of commercial natural resource management can be perilous because it establishes an understanding that resources are only useful for their monetary value, leaving them vulnerable to exploitation in the event that economic incentives from sustainable activities decrease or disappear.

Overall, the results of community-based conservation initiatives have been mixed – leading to a variety of debates in the literature over the merits of the concept (Agrawal and Gibson 1999). We believe that failures in community-based conservation are not due to the weakness or impracticality of the concept, but rather to its improper implementation (Murphree

2002; Berkes 2004). Past examples have shown a tendency for intended beneficiaries to be treated as passive recipients of project activities (Pimbert & Pretty 1995) and for projects to be too short term in nature and over reliant on expatriate expertise (Leach et al. 1999), causing projects to ultimately fall short of their goals. Lessons learned from community-based initiatives have suggested that they should pay more attention to issues of equity and empowerment (Berkes 2004), requiring that concerted time and energy be invested in areas such as training and capacity building (Mutandwa & Gadzirayi 2007).

Citizen Science

Historically, scientific investigation was a largely academic pursuit that was limited to highly trained and affluent members of society who could afford to undertake science as a career. Calls for the democratization of science have persisted for decades (Freire 1972; Kleinman 1998), but research continues to lag behind more applied fields in breaking down its ivory walls, despite the potential for participation to benefit research itself. The field of ecology has also, more recently, undergone a number of important conceptual shifts, from a reductionist to a systems view of the world, to include humans as part of natural systems, and from an expert-based approach to participatory research, conservation, and management (Levin 1999; Bradshaw & Beckoff 2001; Ludwig 2001; Berkes 2004), all of which further underline the need to engage people in science.

Citizen science was among the strategies developed to reconcile these shifts – a method which engages a dispersed network of volunteers to assist in professional research developed by or in collaboration with professional researchers (Trumbull et al. 2000) using methodologies for data collection which have been specifically designed or adapted to give amateurs a role (Silvertown 2009). This use of dispersed participants has been shown to complement and enhance conventional scientific studies in terms of efficiency, cost (Au et al. 2000, Pattengill-

Semmens & Semmens 2003), and scale (Cooper et al. 2007; Lee et al. 2006). Some studies have even shown that fieldwork is done better and more efficiently by members of local (especially rural) communities when compared to graduate students or postdocs because of the benefit of experience working and living in the local environment (Simons 2011).

Proliferation of citizen science programs was supported by the notion that involvement would also increase science literacy and environmental awareness among participants (Conrad & Hilchey 2011). While the hope that citizen science harbors educational benefits for those involved (Cooper et al. 2007), and can foster the type of environmental learning that leads to behavior change and direct conservation action (Trumball et al. 2000; Evans et al. 2005), the results of these initiatives have been variable. In fact, broad evaluations of citizen science programs have indicated that participation does not significantly improve understanding of scientific or natural processes, and that gains are typically limited to factual and/or procedural knowledge that does not translate well to shifting behavior (Jordan et al. 2011).

Critics of citizen science often cite the rigid nature of their engagement as a limiting factor, that merely employing volunteers to collect their data does not provide sufficient motivation to learn and grow. Successful projects actively engage with participants, creating deeper involvement that resulted in increasingly robust learning outcomes (Dickinson et al. 2012). The best examples of citizen science are those that benefit both the participants and the researchers equally (Silvertown 2009) by facilitating constructive dialogue between citizens and researchers (Brewer 2002). While participation in these programs is largely passive and restricted to prescribed standards for data collection, citizen science represented the first real effort for breaking down the ‘ivory walls’ of academia and engaging the public in science.

Participatory Action Research

Participatory Action Research (PAR) is a systematic approach to co-developing research programs with people, rather than for people, with the specific intent for the results to inform social action (Fals-Borda & Rahman 1991; McIntyre 2007). In many ways, PAR was developed to challenge the knowledge control and rigid roles that are inherent to citizen science, as a mechanism that puts the rhetoric of participation into action by empowering those involved to participate at a high level (Baum et al. 2006). PAR breaks down structured roles by prohibiting any one participants from being the expert or sole possessor of information (Feire 1970), with interactions between researchers and participants specifically taking the form of multidirectional sharing of information and perspectives (Brewer 2002). In PAR, different types of knowledge are recognized as valid, allowing participants to engage as equal participants in a learning process where knowledge and experience can be shared and created in the name of discovery and creative problem solving.

The PAR process includes collaborative investigation and analysis, followed by interpretation, reflection, and action aimed at short-term local solutions, as well as long-term institutional or cultural change (Crabtree & Sapp 2005). Recognizing both the active and relational aspects of research, new knowledge is continually constructed through critical reflection on current awareness and specific actions (Parkes & Panelli 2001). In its application with community-based conservation and management, PAR has been recognized for promoting organization and collaboration, strengthening local institutions, and its ability to assist communities in building adaptive capacity (Mapfumo et al. 2013).

The Rupununi Wildlife Research Unit

The Rupununi is widely considered the most biodiverse region of Guyana – a country that maintains a wealth of natural resources and >75% forest cover (GFC 2013). The indigenous

Makushi and Wapichan people who inhabit the region have served as its stewards for millennia, and the wealth of biodiversity and natural resources that persist there today are the direct result of their traditional management systems and continued commitment to sustainable use. However, the Rupununi is currently facing dramatic social, economic, and environmental change, resulting from exposure to technology and global culture, demand from, and access to, global markets, and a changing global climate. This overarching goal of this project is to equip these communities with tools, strategies, and structures to deal with their rapidly changing world, allowing them to continue the legacy of stewardship set by previous generations.

Project Design

Reaching a level of community development in which communities are independently managing their resources in a sustainable manner has been elusive. Many indigenous communities had historically developed traditional management practices, which guided the sustainable use of resources at a time when populations were low and demand rarely extended beyond limited regional trade. Rising to meet the challenges of sustainable resource management in a globalized world requires communities to increase their capacity in understanding and monitoring the impacts of contemporary resource use.

To meet these new challenges and build the necessary capacity, we developed a PAR project that takes a scaffolding approach which attempts to capitalize on expertise that may already exist in a community, while building skills and knowledge through collaboration. Scaffolding is both a structure for activities and a process by which to carry them out. A scaffolding process enables a learner to solve a problem, carry out a task, or achieve a goal which would be beyond their unassisted efforts (Wood et al. 1976). The concept of scaffolding is working towards the development of solutions to complex problems by starting with simpler cases and gradually building up to the full level of complexity (Norman and Spohrer 1996). By

avoiding initial complexity, learners can develop knowledge and confidence while building towards an ultimate goal (Jackson et al. 1996) and has the potential to address some of the issues encountered in the past when attempting to prepare communities to manage resources in a sustainable manner. This project was designed to generate data that addressed important local and regional issues through a participatory process that builds capacity in participants and spawns unique inquiries as a result.

Our general focus was informed by a previous survey which indicated that a lack of employment and training opportunities, conflict with jaguars and pumas, and overhunting of game mammals and fish were the primary issues facing communities surrounding the Kanuku Mountains Protected Areas (Hallett et al. 2015a). A priority setting workshop facilitated by the Guyana Protected Areas Commission reinforced these findings, as community leaders identified conflict with jaguars / puma and overhunting of game fish and mammals as the primary natural resource issues that they would like to see addressed (Figure 1-1).

Guided by an understanding of local issues, we designed a camera-trap research project that would generate specific data that could help to address these concerns and inform management in the future. In doing so, it was also our goal to design a process where Rupununi residents could gain temporary, part-time employment and training in research methods and tools that may be transferable to future projects and employment. While chapter two of this dissertation was always intended to focus on the results of this camera-trap research, we left the remainder of the project open with the intention of facilitating a process where communities could develop and answer their own locally relevant questions.

We have adopted the ladder of citizen participation (Arnstein 1969, Connor 1988; Hart 2013) as a visual representation of our strategy for engagement (Figure 1-2). The ladder

provides the ideal symbol for initiatives that emphasize building capacity, as participants are provided with experiences that incrementally increase their skills and knowledge. Our engagement strategy extends beyond the incremental progression of skills among participants to include the levels of participation associated with those skills, as well as the levels of complexity that are possible to explore when a given level of skills and participation are achieved. Our goal of having participants design and implement their own research requires skills and confidence that are built through increased participation and while considering increasingly complex questions.

This process began in chapter two by ensuring that we were transparent about the purpose and goals of our work, providing fair compensation to participants, and creating opportunities for participants to actively contribute their knowledge to a project that was intentionally selected to capitalize on their expertise (the distribution of species of interest). Over time we provided opportunities for participants to contribute in different ways and engage at higher levels, while helping them build the skills to do so. Chapters three and four represent the culmination of this process, as we collaborated directly with participants from our camera-trap project to develop and implement unique questions that were of interest to them.

Project Scale

We explicitly chose to operate this project at the landscape-scale because we knew that a broad-scale effort would allow for the accumulation of data suitable for answering our initial ecological questions, while providing a structure where communities could work at the site level to identify and formulate locally-relevant questions that they wanted to address, or choose to work with other communities who were facing similar issues. The scale of this effort is important because it allowed us to work across scales in answering questions that are relevant to

conservation in the region. Creating these vertical and horizontal linkages has proven an important addressing the complexity of social and natural systems (Berkes 2004).

Consultation and Compensation

A basic tenant of any participatory effort should be to gain the informed consent of the participants and communities that are engaged. In Guyana, informed consent is addressed before research even begins, as the Ministry of Indigenous People's Affairs and the Guyana Environmental Protection Agency (EPA) require community leaders to provide signed and dated letters that express their support for proposed research. However, our view is that consultation should go beyond the initial agreements to proceed. We keep communities and community leaders well informed of our actions, progress, and preliminary results through frequent and informal in-person and written updates. This consistent consultation and information sharing maintains transparency in our work and builds confidence in communities that we work with.

Participation in conservation and research initiatives in the developing world often requires participants to forego subsistence activities that provide for themselves and their families. This is the reality for the subsistence farmers, fishermen, and hunters that serve as the collaborators and natural historians in this project. Fair compensation has proven an important strategy for releasing participants of this burden (Child 1996), and, as such, we have included fair and prompt payment for services provided a basic tenant of our work.

Immersive Experience

One of the biggest challenges facing the scientific community is de-mystifying the process of science and translating the process and results for non-scientist citizens (Brewer 2001). This is especially true in rural communities where understanding of formal scientific and larger scale ecological processes may be limited and represents an important step in community-based efforts. To develop ecological literacy, participants need to experience the wonder of

science in addition to factual information (Orr 1989). Information gained through experience is vital as it provides a requisite contextual base for assimilating information collected through other indirect means (Tuss 1996), thus building skills that would allow communities to gather and apply information towards problem solving.

In the experiential model, participants progress from action, to understanding the consequences of action in a particular context, to generalization in a broader context (Tuss 1996). We bring participants from Rupununi communities into the scientific process by creating opportunities to set and check camera-traps as part of our landscape-scale study of drivers of the abundance, distribution, and activity patterns of jaguars across the Rupununi Region. Participants gain experience through a project that informs pressing issues of the region, but was designed by the author, allowing them to focus on learning from the experience.

Indigenous Knowledge

The support of local field assistants has long been considered an asset to scientific research, particularly in remote rural areas where resources may be difficult to reach and previous experience may be limited. Although, for much of the history of science local people have been valued merely either as laborers or for providing insights that may assist in locating research subjects or specimens. Despite their contribution to keeping scientists alive in rugged field sites and contributing to successful data collection, credit has rarely been given and local knowledge rarely recognized.

Recently, indigenous knowledge (IK) has received increasing academic and policy attention and has been applied to wider efforts in biodiversity conservation, ecosystem assessments, and ecosystem management (Heyd 1995; Huntington 2000; Gadgil et al. 2003; Fabricius et al. 2006; Chalmers & Fabricius 2007; Anadón et al. 2009). IK is based on people's direct interactions with their environment and is accumulated through trial and error, learning

from feedback and interaction (Berkes et al. 2003). This type of practical and applied knowledge is accumulated over a lifetime resulting from the harvest or traditional use of species (Gilchrist et al. 2005).

Indigenous knowledge contrasts with formal, scientific knowledge, which is the conventional source of information for formalized ecosystem management (Chalmers & Fabricius 2007). Scientific knowledge is precise and measured in an objective and repeatable manner (Moller et al. 2004), passing through strict and agreed upon sets of universally accepted rules (Fabricius et al. 2006). However, IK should not be considered merely the binary opposite of scientific knowledge (Battiste 2002), but rather an alternate subjective cultural bias (similar to the western construction of the scientific process), through which we can find common ground (Aikenhead & Ogawa 2007).

The published literature is rich with debate over the merits of IK (Berkes et al. 2000, Huntington 2000), however, because it is typically derived from people who lived with, hunted, and trapped wildlife, IK is increasingly considered analogous to "expert opinion" (Walters & Holling 1990, Zabel et al. 2002). IK is, of course, not infallible and does have certain limitations. However, one of the insights from complexity (systems) thinking is that the multiplicity of scales prevents there from being one correct perspective in a complex system. Instead, phenomena at each level have their own emergent properties and, as a result, a number of actors may hold different, but equally valid perspectives (Berkes 2004). In keeping with a conceptual shift towards a systems approach to applied ecology, adding local perspectives to scientific research presents the opportunity to add depth and complexity to scientific data. Recognizing IK has been one of the primary objectives of this project and one of the first necessary steps to engaging indigenous communities.

Engaging community members as stakeholders in a process where they are contributing to a learning process is critical for the appropriate application of IK. Acknowledgment and validation have shown to be vital in the development of a critical skill – self-directed learning (Garrison 1997). Self-directed learners are those that feel confident in their abilities to make observations, ask questions and develop solutions to issues that may arrive in future natural resource management. As participants are exposed to the scientific process through our camera-trapping effort we invite and support the contribution of local and indigenous knowledge to the process.

However, the true benefit of incorporating IK into research is in the co-production of new knowledge, in which parties recognize the strengths and weaknesses of different ways of understanding and work together to create a more complete picture of reality (Berkes 2009). Chapters three and four of this dissertation are outcomes of the co-production of knowledge, but represent only a fraction of the potential that this project has created in the Rupununi region. The contribution of indigenous knowledge to our research process is specifically expressed in the visual representation of our engagement strategy in the form of circular arrows that are pulling from sources of information outside (IK, western scientific tools and methods) and within (reflection) the process.

Feedbacks and Two-Way Learning

Combining IK with science is, however, fraught with ethical, methodological and conceptual difficulties and merging them does not address the problem (Chalmers & Fabricius 2007). What western science has to offer that IK lacks is a broader appreciation of context beyond the local level (Becker & Ghimire 2003). IK offers access to information across scales of time and space that cannot be properly assessed through conventional methods (Wohling 2009), deep knowledge of a particular place resulting from longstanding inhabitation, as well as

unique worldviews that are developed through ways of understanding draw from spiritual and other realms outside of consideration by conventional research (Aikenhead et al. 2007). Consequently, IK is rarely integrated into wildlife management decision making, because it is a discipline that historically has relied on quantitative results derived through accepted scientific methods (Mauro & Hardison 2000), when IK may actually be more relevant because specifically incorporates the human experiences, while quantitative studies view human influence as a bias that should be controlled or removed.

Increasingly acknowledging that IK may yield biological information relevant to conservation efforts (Huntington 2000), but merely accessing and utilizing IK represents only a basic form of application. It is important to recognize that IK and scientific research of information have some common ground: they both rely on direct observation, experience, experimentation, and interpretation (Becker & Ghimire 2003). These commonalities represent a shared understanding that should serve as the starting point for facilitating a collaborative learning process that results in the co-production of a knowledge system for sustainable management of ecosystems (Roux et al. 2006).

Additionally, IK can serve as a tool that helps to engage local stakeholders by bringing them to the table as part of a team addressing shared conservation concerns, an approach generally more productive than scientific studies alone (Zabed et al. 2002). One of the recognized benefits of PAR is its ability to bring together the perspectives of people who depend on the landscape for their survival and those who make a career from studying it (Colfer et al. 2011). Actively engaging incorporating IK into the PAR benefits creates the opportunity for knowledge to be co-produced. The co-production of knowledge through interpretation and reflection is explicitly expressed in the visual representation of our engagement strategy in the

form of circular arrow on each step of the ladder (Figure 1-2). Participation, capacity building, and complexity of the questions that we ask can only progress following reflection on experience and the co-production of new knowledge.

Skills and Leadership Development

There is little debate over whether or not incentives for conservation are important – they are (Berkes 2004). In the case of community conservation, there has often been a mismatch between what conservationists have thought of as community benefits (i.e. sharing of financial benefits) and what multiple stakeholders in communities may have thought of as benefits (empowerment, equity, capacity; Brown 2002). While we have made a commitment to providing fair compensation to those who give up their time to work with us, we have also invested heavily in building capacity (skills, knowledge, confidence) in our participants – an investment that is already showing rewards (as evidenced by chapters three and four). Our approach to skill and capacity building is explicitly outlined between the rungs of the ladder in the visual representation of our engagement strategy (Figure 1-2), however opportunities for capacity building were provided based on the needs of unique individuals and situations. Remaining flexible in how we provide these opportunities allows individuals to progress at their own pace.

Skills and knowledge are unevenly spread within any group, and communities are no exception. Not everyone has a holistic understanding of the environment and, in rural communities; different groups and individuals use different landscapes for different purposes (Kaschula et al. 2005). This leads to the development of local experts or leaders with regard to knowledge of local wildlife. While it is important to select and work with such local experts rather than arbitrarily selected individuals early on in a project when data collection is the goal (Donovan & Puri 2004), providing training and mentoring allows motivated individuals to learn,

grow, and emerge as leaders. The development of leaders who can fulfill tasks independently was critical for our ability to manage the landscape-scale research effort presented in chapter two, but leaders also became an invaluable asset as they developed their own questions in chapters three and four, and will continue to support the application of the results presented here in the future.

Communication of Results

Returning the results of research to the communities from which the data was collected is critical in building confidence and perceived value in the research process, while creating opportunities for results to be utilized and applied (Chavis et al. 1983). We consider the sharing of results with our project partners to be both part of the consultation and information sharing process that we discussed above, but also a critical part of the learning process. Providing (even preliminary) results of the projects that participants have contributed to creates an important opportunity to reflect upon and interpret what these results mean for to themselves and their communities. The latter is actively facilitated through informal conversations about what results may mean or how they could be applied, and these are the places where new knowledge is most often co-produced.

Information sharing in the Rupununi is typically done through in person presentations conducted in each community. While this approach may be effective and allow for the highest level of engagement, mass communication is known to influence human thought and action by informing, motivating, and guiding people directly, as well as creating feedbacks thorough communities and networks that provide additional incentives and guidance for action (Bandura 2001). Social media has proven an effective and far reaching method for communicating conservation messaging with some audiences (Parsons et al. 2014), while using print and other popular media outlets may be more effective for others (Engels & Jacobson 2007). We share

highlights and preliminary results of our work alongside conservation messaging, promotion of sustainable livelihoods, and relevant environmentally themed news stories on various social media platforms (Facebook, Instagram, YouTube, Twitter; Figure 1-3) and through the popular media in the form of newspapers and magazines (Figure 1-4). These outlets have allowed us to extend our audience beyond just residents of the communities that we directly engage with in the Rupununi, gaining recognition of the value of biodiversity and conservation in the broader Guyana.

Collaboration and Consultation

Collaboration and consultation represents the actions at the top rungs of the visual representation of our engagement strategy (Figure 1-2). Engaging with participants at this level requires researchers to relinquish much of the ownership of the research question and data collection to local collaborators who have developed the skills and confidence necessary to design and execute projects that address local issues. The research presented in chapters three and four clearly represent these higher-level efforts, as these questions were developed by local collaborators. Our role in these projects has become as consultants, helping to fill in specialized skills in fundraising, project design, data analysis, and writing. To be clear, local collaborators will be recognized as co-authors of these efforts when the results of those chapters go to publication.

Conclusion

The project presented here represents a snapshot in time. We are currently benefitting from the development of relationships that have been more than seven years in the making, but our participatory research is still in its infancy. We will continue to work with our collaborators in the Rupununi to develop projects that address local issues, and look forward to shifting towards investigating way in which these results will be applied. This project will not conclude

with the submission of this dissertation, but this dissertation has served as a moment of reflection in what we foresee as a lifelong commitment to a very special place in this world.

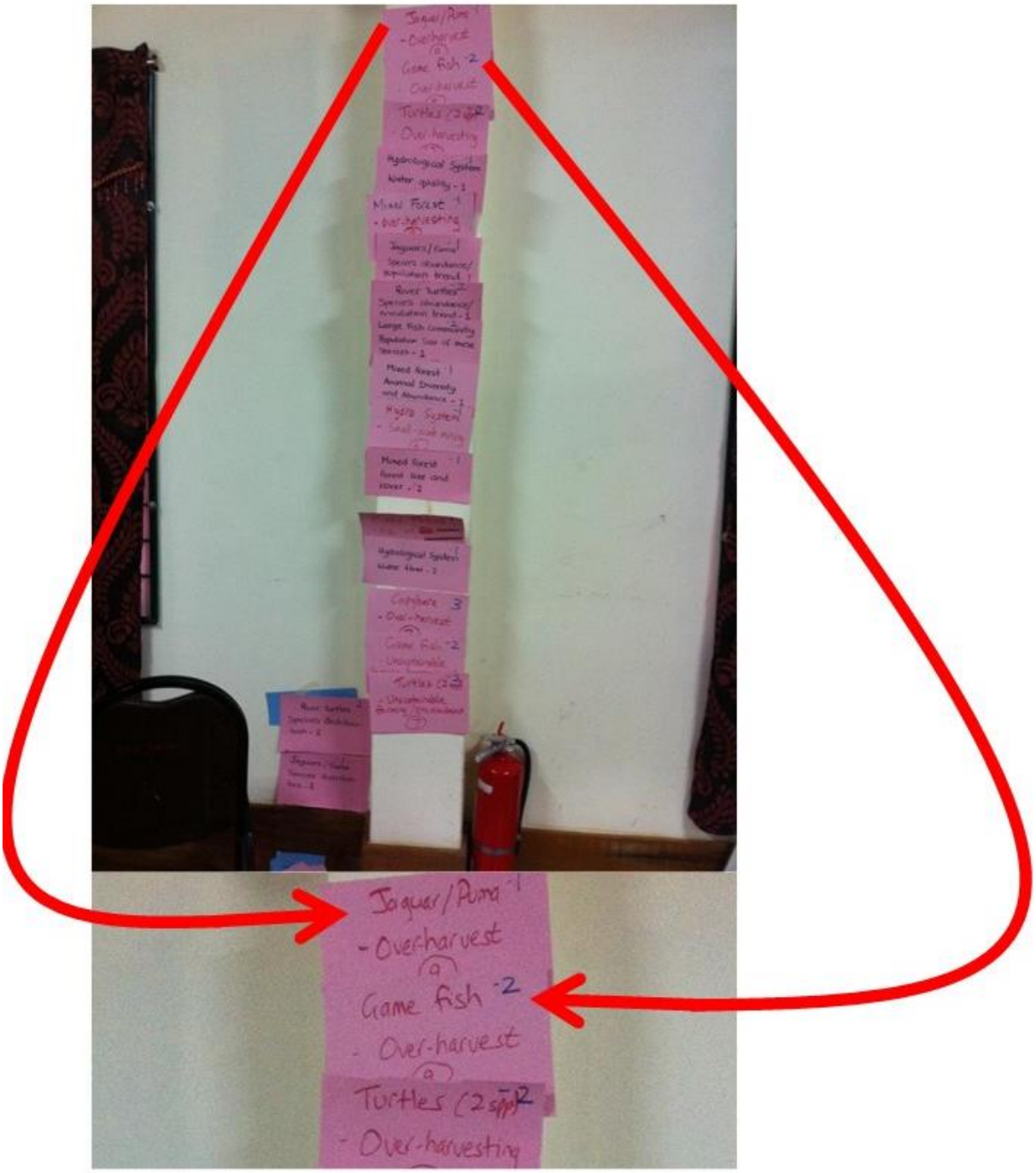

Figure 1-1. Results of priority setting workshop with Guyana Protected Areas Commission identifying ‘conflict with jaguars and puma’ and ‘overharvest of game and fish species’ as top issues to address in the Kanuku Mountains Region (photos courtesy of Matt Hallett)

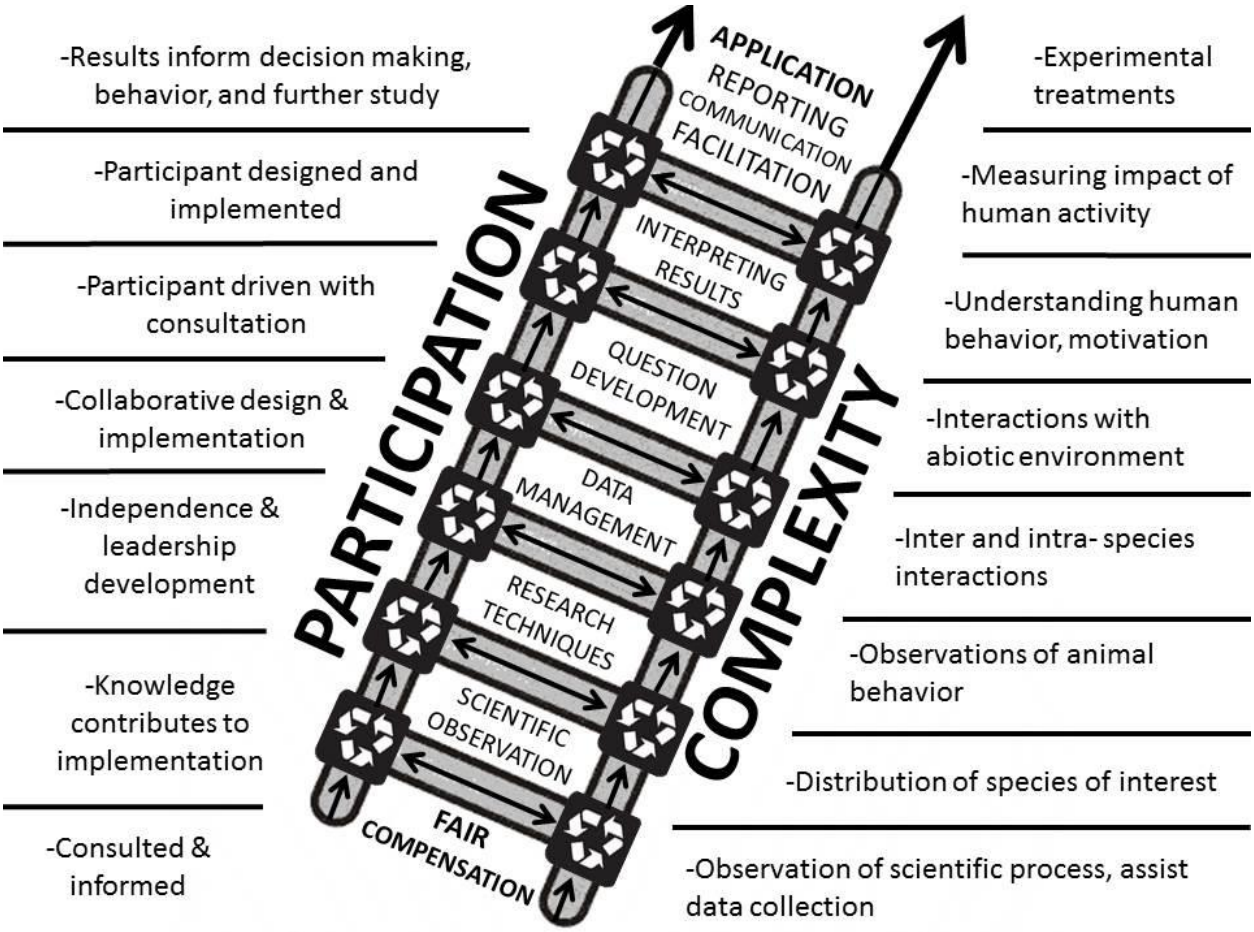

Figure 1-2. Strategy for engagement – integrating participation, capacity building, and inquiry in the facilitation of participatory research

Figure 1-3. Examples of Rupununi Wildlife Research Unit social media outreach on Facebook, Instagram, YouTube, and Twitter (photos courtesy of Matt Hallett)

Figure 1-4. Examples of Rupununi Wildlife Research Unit popular media outreach in tourism and culture magazines, as well as various newspaper outlets (photos courtesy of Matt Hallett)

CHAPTER 2
HABITAT USE, POPULATION DENSITY, AND ACTIVITY PATTERNS OF JAGUARS (*PANTHERA ONCA*) IN A HETEROGENEOUS ENVIRONMENT – THE RUPUNUNI REGION OF GUYANA

Introduction

The jaguar (*Panthera onca*) is the largest felid in the Neotropics, occupying the role of top predator in terrestrial environments, and is also identified as a keystone, indicator, flagship, and umbrella species (Terborgh et al. 1999) for a wide variety of habitats, from the southwestern United States to northern Argentina (Seymour 1989). Primary threats to jaguar populations are overhunting of prey, retaliatory killing following depredation of livestock (Caso et al. 2008), and continual loss and fragmentation of habitat that has reduced their range significantly in the last 100 years (Sanderson et al. 1999). Jaguars are classified as 'Near Threatened' by the IUCN RedList of Threatened Species; are listed under Appendix I of CITES; receive full protection in Argentina, Brazil, Colombia, French Guiana, Guyana, Honduras, Nicaragua, Panama, Paraguay, Surinam, United States, and Venezuela; and are hunted under restricted conditions in Brazil, Costa Rica, Guatemala, Mexico, and Peru (Caso et al. 2008).

Jaguars fare better than any other felid in the genus *Panthera* in terms of probability of survival, with 78% of their historic range still supporting dispersal (Zeller & Rabinowitz 2010). Blood and scat samples collected range-wide showed high gene flow and dispersal ability – evidence of landscape-scale habitat connectivity with few barriers (Eizirik et al. 2001; Wultsch et al. 2016). However, the biology, ecology and behavior of jaguars are not well understood, despite the recent proliferation of studies that have estimating population density using camera traps and capture-recapture analysis (Maffei et al. 2011). Reliable data on jaguar population size and distributions are needed, as they form the basis of conservation and management strategies (Soisalo & Cavalcanti 2006).

Scaling Jaguar Ecology and Conservation

Historically, the main tool for biodiversity conservation in the Neotropics has been to restrict access and development through the creation of Protected Areas (PAs), most of which have been focused in the largest areas of remaining intact forest (Rodrigues et al. 2004). Certainly, large, well-designed and well-managed PAs can be effective tools for conservation (La Saout et al. 2013). However, the current distribution of PAs is not representative of the habitat diversity of the Neotropics (Chape et al. 2005). Furthermore, their location, design, lack of funding, and poor management reduce their effectiveness (La Saout et al. 2013). For large carnivores, PAs are often not extensive enough to support viable populations (Parks & Harcourt 2002), and high mortality rates at their edges (Woodroffe & Ginsberg 1998) increase extinction probability over time (Brashares 2001).

Jaguars range across vast areas at relatively low population densities, earning them the label of 'landscape species' (Sanderson et al. 2002). Individual jaguars roam widely, requiring large areas of habitat populated by sufficient prey for individual survival and mates for reproduction and population survival. As a result, jaguar conservation has moved towards range-wide conservation efforts focused at the landscape scale (Sanderson et al. 2002; Coppolillo et al. 2004; Rabinowitz and Zeller 2010). Jaguar conservationists have designated Jaguar Conservation Units (JCUs) as core areas with either sufficient prey and a self-sustaining jaguar population, or fewer jaguars but adequate habitat and a diverse prey base (Sanderson 2002). Connectivity between these 'core areas' is maintained by corridors, representing the shortest distance and least cost for dispersal between core jaguar populations (Zeller & Rainbowitz 2010).

Corridors maintain movement between habitat patches, allowing for persistent exchange of genetic material between populations (Zeller & Rabinowitz 2010). Loss of genetic diversity

results in increased incidence of inbreeding and genetic drift (Young & Clark 2000; Stockwell et al. 2003), as well as reductions in mating ability, male and female fecundity, offspring survival, fitness (Frankham et al. 2002), effective population size (Frankham 1996), and adaptive capacity (Lehman & Perrin 2006), thus threatening populations and species with extinction (Frankham 2005). Corridors may take the form of continuous habitat or habitat patches, which play a critical role in maintaining landscape connectivity as 'stepping stones' between core habitats (Sweanor et al. 2000), both of which provide cover and prey that may dramatically increase fitness and survival of dispersing individuals (Sondgerath & Schroder 2001).

Connectivity between core habitat areas and the landscape scale needed for jaguar conservation makes the inclusion of unprotected, heterogeneous, or human-dominated landscapes in jaguar conservation efforts critically important. Unprotected areas with low human population density, lack of infrastructure, poor soils (low potential for conversion to agriculture), game species, and proximity to large protected areas have shown the greatest potential for conserving jaguars (Payan et al. 2013).

Jaguar Habitat Use

In many ways, jaguars are the most emblematic species representing Neotropical forests. However, tropical forests only cover ~50% of tropical South America (FAO 1997) and jaguars readily adapt to the savanna, wetland, scrub, and even desert habitats that cover the remaining area of the Neotropics (Eisenberg 1989). Researchers have largely assumed that jaguars prefer moist lowland forests in close association with water (Schaller & Crawshaw 1980), however more recent analysis indicates that more heterogeneous environments like the Pantanal, Llanos, and Gran Chaco may actually be more suitable of sustaining jaguar populations than contiguous forests such as in Amazonia (Tôrres et al. 2007).

In heterogeneous landscapes, jaguars use a wide variety of habitats, including open savannas and closed forests (Scognamillo et al. 2013), pastures, and areas disturbed by human activity (Foster et al. 2010). Preference seems to vary based on site conditions, with individuals favoring forested areas in close proximity to water and prey (Sollman 2011; Davis et al. 2011). Distribution of resources (forage, fruits, and browse) for prey can be patchy and predators are forced to hunt in parts of the matrix where prey are most abundant (Rabinowitz & Nottingham 1986). Studies from the Venezuelan Llanos indicate that prey animals are most abundant along the forest-savanna ecotone, and jaguar foraging intensity follows suit (Scognamillo et al. 2003). Heterogeneous landscapes may allow for greater co-existence and higher carnivore densities and diversity (Hanski 1994), as patchy distribution of resources allows potential competitors to avoid one another across space (Emmons 1987; Aranda & Sánchez-Cordero 1996) and time (Karanth & Sunquist 2000).

While 'core areas' and 'JCUs' continue to be focused on large areas of intact forest, the capacity of heterogeneous habitats, habitat mosaics, and habitats other than tropical forests to host sustainable jaguar populations is in need of further evaluation. Increased understanding of the abundance, distribution, and activity patterns of jaguars in these habitats will inform the prioritization of important jaguar conservation areas, as well as increase the opportunity to engage communities and private landowners in jaguar conservation.

Guyana is a country with an abundance of potential jaguar habitat, as >75% of its total land cover is tropical forest; with a largely inaccessible interior, and one of the world's lowest human population densities (GFC 2013). Though Guyana does not contain any designated JCUs, Guyana's forests are considered to have a 'high probability of supporting the long-term survival of jaguar populations' (Sanderson et al. 2002) and support a Jaguar Corridor running

through central Guyana from the Pakaraima Mountains to the Iwokrama International Centre and into eastern and central Suriname (Zeller & Rabinowitz 2010). The Rupununi Region is considered Guyana's most intact and biodiverse region, hosting large tracts of tropical forest alongside cerrado savanna, savanna forests, and seasonally flooded wetlands. The Rupununi savannas are considered part of the Gran Sabana / Rio Branco savanna system of neighboring Venezuela and Brazil, an area of immediate conservation concern because of a low probability of long-term survival of jaguar populations (Sanderson et al. 2002).

The Rupununi Region of Guyana hosts an annually flooded savanna wetland and is bordered by large tracts of lowland and upland tropical forest. Understanding the abundance and distribution of jaguar populations across this heterogeneous landscape represents a first step to identifying key areas for conservation and management, corridors maintaining connectivity with forested areas in Brazil and Venezuela, and the contribution of SW Guyana to range-wide jaguar conservation efforts. This study seeks to identify drivers of variation in the use, density, and activity of jaguars using camera-traps set across a variety of habitat types in the Rupununi.

Methods

Study area

Rupununi (Region 9), Guyana (Figure 2-1), is named for the river, savannas and wetlands that bear this name, but the region is actually an ancient rift valley, the Takutu Basin, that is bordered by the Iwokrama, Pakaraima and Kanuku mountains (Crawford et al. 1985). The floor of Takutu Basin consists of cerrado savanna, gallery and savanna forests, rivers, creeks and seasonally flooded wetlands bordered by large tracts of lowland and montane tropical deciduous and evergreen forests. The Rupununi savannas are ecologically connected to Brazil's Rio Branco savanna system (Montambault & Missa 2002), and tree: grass ratios indicate that the moist savannas of the North Rupununi are most analogous to the cerrado savannas of eastern

Brazil (Eden & McGregor 1992). The Rupununi savannas are contiguous with the Iwokrama International Centre for Rainforest Conservation and Development and Guyana forests to the north, the Pakaraima Mountains and Gran Sabana to the west, and the Kanuku Mountains to the east, which join a vast expanse of intact Guiana Shield forest shared with Brazil, Suriname and French Guiana (Mittermeier et al. 1998). Mountainous areas in Guyana have long been revered as 'places of refuge' by local indigenous communities and, thus, they have never hosted permanent residents (L. Haynes pers. comm.). As a result, these areas support a wealth of intact habitat and corresponding biodiversity.

The primary habitat types found in the Rupununi, savanna and moist forest, are principally determined by soil conditions, with savanna habitat occurring where trees cannot take root because a hard underlying clay layer limits penetration of their roots (Montambault & Missa 2002). 'Bush islands' are scattered across the landscape on hilltops where topsoil remains out of the reach of seasonal flood waters. Moist forest occurs on porous substrates along the slopes of hills and mountains, along rivers, and in adjacent low-lying areas which receive nutrient runoff (Clarke et al. 2001). The Rupununi savannas are found at elevations of 120-150 m above sea level (highest mountain peaks are at 1,067 m, with a number of minor peaks above 900 m; Montambault & Missa 2002). Protected areas in the Rupununi are composed of roughly 99% forest and <1% savanna (PAC 2015). This region of Guyana experiences a single rainy season (May to August), with the heaviest rainfall in May, and a longer dry season (September to April). Average annual rainfall is between 1,500-2,000 mm per year and average temperatures are between 25.9°C-27.5°C (PAC 2015). During the height of rainy season, the main rivers rise by as much as 15 m, flooding low-lying forests and/or inundating adjacent savannas.

Human population density in the Rupununi is very low. Communities are typically small to medium in size, with few containing >1,000 residents, for a total of ~10,000 people spread across 46 indigenous communities (Stone 2002). The notable exception is Lethem, a booming town at the Brazilian border. The region also contains a number of privately held cattle ranches and terrestrial mining operations. Rupununi communities are made up of predominantly indigenous Makushi and Wapichan people with mixed populations that include all of Guyana's nine indigenous groups, as well as Chinese-, Brazilian-, Afro-, and Indo-Guyanese (Stone 2002). Makushi people are of Carib descent, inhabit villages in the north and central Rupununi, and number ~7,750 in Guyana (NDS 1996). Wapichan people are of Arawak descent; inhabit villages in the south Rupununi, and number ~6,900 in Guyana (NDS 1996). Rupununi villages typically range in size from ~120-615 people; subsistence fishing, farming and hunting are the primary means of livelihood (Stone 2002).

Camera-trap Survey

Camera-trap photos were obtained as part of a multi-species camera-trap study of the Rupununi Region, following well-established methods for camera-trap research (Karanth & Nichols, 1998). Camera traps (Bushnell Trophy Cam #119447C, #119734C, #119736C, and #119837C; Bushnell®, KS, USA) were set 2-3 km apart, with a single camera at each site set 30-40 cm from the ground in proximity to observed signs of jaguars and their preferred prey. Cameras were active 24 h per day, with a 1-second delay between captures, recording the date and time with each 3-image sequence.

Camera-traps were set at 357 sample sites across 13 indigenous communities (Yupukari, Quatatta, Markanata, Kwatamang, Wowetta, Rupertee, Surama, Karasabai, Katoka, Shulinab, Meriwau, Quiko, and Rupunau), 5 private ranches (Dadanawa, Karanambu, Saddle Mountain, Manari, and Waikin), and two protected areas (Iwokrama International Centre for Conservation

and Development and Kanuku Mountains Protected Area) from May 2014 – May 2017 for a total of 62,010 trap nights (Figure 1-1). Camera traps were spread across habitat types in a manner representative of the composition of the Rupununi habitat mosaic (Table 2-1). In an effort to avoid bias in the sample and increase understanding of the impact of variables of interest, camera traps were set across a variety of trail types and a gradient of anthropogenic activity (Table 2-2). Images of the species of interest that occurred at the same trap site within a period of 30 minutes were excluded ensure that photo occasions were independent (Silver et al. 2004).

Statistical Analysis

Statistical analysis was structured in three tiers to understand the impact of habitat heterogeneity on the (1) distribution, (2) abundance, and (3) circadian rhythms of jaguars in the Rupununi Region. Shifts in distribution were considered to be the most severe response to habitat variables (used rarely or completely absent), followed by abundance (persisting but decreasing), and activity patterns (present in numbers, but shifting behavior). The preceding trends are expressed as habitat use, population density, and activity patterns below. Statistical analyses were performed in R (version 3.2.4; R Core Team 2013) unless otherwise indicated.

Habitat use

A relative abundance index (RAI) was calculated by dividing the number of jaguar occurrences by the number of trap nights at each site and standardizing for 100 trap nights (O'Brien 2011). Due to seasonal flooding, theft, equipment malfunction, vegetation growth, and manipulation of cameras by human and animal subjects, trap effort varied among sites. A Pearson's Correlation Coefficient (Pearson 1895) was calculated to measure the strength of the linear relationship between relative abundance and the number of trap nights. A strong linear relationship would

require standardization of trap effort at each site and, ultimately, the loss of jaguar occurrences from the dataset.

The relative abundance indices from each trap site were plotted to understand the distribution of the data. A Kruskal-Wallis test, a non-parametric one-way analysis of variance (ANOVA) that assesses the differences among three or more independently sampled groups and a non-normally distributed continuous variable (Kruskal & Wallis 1952), was performed to identify any significant differences in jaguar relative abundance across habitat and trail types. Dunn's test for multiple comparisons, a post-hoc pair-wise non-parametric test of the strength of the relationships between the means of multiple pairs of variables (Dunn 1964; Zar 2010), was performed to identify frequency with which pairs of habitat and trail variables were used.

We converted the relative abundance data to presence and absence to remove the bias associated with the observed skewed distribution of captures at a few, heavily used sites. A generalized linear model (GLM), a flexible application of linear regression that relates to response variables via a link function, error distributions that are not normally distributed (Nelder & Baker 1972), was applied to the naive occupancy data set to understand the relationship between jaguar presence and habitat types. Finally, we used Akaike's Information Criterion (AIC; Akaike 1981), an estimator of the relative quality of statistical models, to rank the models that best predicted habitat use by jaguars in the Rupununi Region of Guyana.

Population density

Spatially-explicit capture-recapture (SECR) models utilize density as their population parameter, while detection is represented by a function of declining capture probability as the activity center moves further from each detector (Williams et al. 2002), or camera trap in this case. By using the locations where each animal is detected to fit a spatial model of detection, SECR models are proven more effective at adjusting for edge effects and incomplete detection,

and accommodating individual variation in capture probability and home range size (Obbard et al. 2009). Individual jaguars were identified by the unique pattern of their rosettes (Silver 2004) and jaguar population density was estimated using a maximum likelihood based spatially-explicit capture-recapture model in program DENSITY 5.0.2.1 (Efford et al. 2004). Population density at each sample site was compared based on habitat composition (% forest cover) to provide insights on habitat as a driver of jaguar abundance.

Activity patterns

Data on the time and date of each encounter recorded during each occasion provides an important source of information with regard to the activity patterns of a species of interest. We chose to analyze the temporal overlap of jaguar activity patterns as a method for quantifying shifts in activity related to variables of interest. We used the "Overlap" package in R (version 3.2.4) to estimate the percentage of overlap in the activity patterns of jaguars at sites with variables of interest (Ridout & Linkie 2009). 'Overlap' observes capture times as random samples from a continuous distribution, and the 'coefficient of overlap' is a non-parametric measurement of the overlap between the probability distribution functions of these underlying distributions estimated by bootstrapping (Ridout & Linkie 2009). 'Overlap' characterizes time-of-day as a circular random variable whose distribution may be bimodal – an important difference from smoothing techniques like kernel density estimation. The overlap of activity patterns of jaguars were examined with respect to sex, habitat type, trail type, and presence of hunters.

Results

After removing sites where equipment malfunction and theft led to low sampling effort, we achieved 442 independent captures of jaguars from 264 trap sites (Figure 2-2; Appendix A). Jaguar records occurred in six main habitat types (in order of number of jaguar occurrences) –

lowland forest, gallery forest, bush islands, riverine forest, montane forest, and cerrado savanna. Gallery and riverine forest sites showed the highest number of occurrences/site and RAI, followed by bush islands, lowland forests, montane forest, and cerrado savanna (Table 2-3). A plot of the RAIs at each site showed a non-normal distribution of data (Figure 2-3) and a Pearson's product moment correlation test (Table 2-4) indicated no significant correlation between sampling effort and the relative abundance of jaguars.

Habitat Use

The Kruskal-Wallis test (Table 2-5) showed a significant relationship between RAI and both habitat (p = 0.002) and trail type (p = 2.45e-07). A post-hoc Dunn's test for multiple comparisons (Table 2-6) showed significant differences between the relative abundance of jaguars at trap sites in savanna and bush islands (p = 0.03), gallery forest (p = 0.00), lowland forest (p = 0.00), montane forest (p = 0.00), and riverine forest (p = 0.01). These results suggest that jaguars use savanna habitats differently than all forested habitats surveyed. Within these habitat types, the Dunn's test also showed significant differences between the relative abundance of jaguars along game trails compared to foot trails (p = 0.01), dry creek beds (p = 0.00), and roads (p = 0.00), as well as foot trails when compared to roads (p = 0.01). These results suggest that jaguars use dry creek beds, foot trails, and roads similarly (with a higher relative abundance on roads), while using game trails less frequently.

A general linear model (Table 2-7) showed that the most important variables with regard to habitat use by jaguars are (in order of least to most important): montane forest, lowland forest, gallery forest, bush islands, elevation, presence of hunters, and cerrado savanna. Riverine forest sites were excluded because of insufficient sample size. The results of our AIC model evaluation (Table 2-7) suggest that Model 3 (AIC = 343.45, df = 6), Model 4 (AIC = 342.75, df = 5), and Model 5 (AIC = 343.09, df = 4) are equally well supported and that the presence of hunters (+

correlation), elevation (+), bush island habitat (-), gallery forest habitat (-), and cerrado savanna habitat (-) are the most significant variables for predicting habitat use by jaguars in the Rupununi. R-Code for statistical analysis is available in Appendix B.

Population Density

We identified a total of 74 individual jaguars – 39 male and 35 females (Table 2-8). The relative abundance of male jaguars (0.45) was almost double that of females (0.27), although sex ratios in the sample were nearly equal (Table 2-8). Population density varied between sites (Table 2-9), with the sites hosting the highest percentages of forest cover also hosting the highest density of jaguars. The Kanuku Mountains Protected Area (KMPA) showed the highest site-level population density (5.58 individuals / 100 km^2), followed by Surama Village (4.98), Rewa Village (4.76), Read Head (4.68), Saddle Mountain Ranch (3.56), Karanambu Ranch / Yupukari Village (2.91), Shulinab Village (2.84), and Dadanawa Ranch (2.54), and Karasabai Village (1.96).

Activity Patterns

Pair-wise comparisons of overlap in jaguar activity patterns focused on variation driven by sex, habitat type, trail type, and human activity (Table 2-10). Male and female jaguar activity patterns showed a high degree of overlap (0.9; Figure 2-4). Activity pattern varied across habitat types (Figure 2-5), with the lowest overlap between gallery and riverine forests (0.72; Table 2-10; Figure 2-6), followed by lowland and riverine forests (0.79; Table 2-10; Figure 2-7), lowland forests and bush islands (0.83; Table 2-10; Figure 2-8), and lowland and montane forests (0.83; Table 2-10; Figure 2-9). Additional variation in activity patters was observed in hunted and non-hunted sites in lowland forests (0.77; Table 2-10; Figure 2-10) on vs. off-road sites in lowland forests (0.79; Table 2-10; Figure 2-11), and dry creek beds vs. other trail types in gallery forest (0.79; Table 2-10; Figure 2-12). Results demonstrate biologically significant shifts in behavior

that are likely driven by thermoregulation, activity patterns of preferred prey, and human activity. R-Code for statistical analysis is available in Appendix B.

Discussion

The Rupununi Region of Guyana hosts large areas of intact tropical forest alongside a mosaic of Neotropical savanna, wetlands, and gallery forest. Our research suggests that jaguars use each habitat type available in this matrix that also includes a variety of human activities (hunting, farming, livestock rearing), although they showed a clear preference for forested habitats. Understanding patterns of use has implications for jaguar conservation in the Rupununi, as the region is faced with a growing demand for its natural resources and rapid changes to its culture, economy, and climate.

Use of Savanna Habitat

Our models indicate that savanna habitats supported the lowest relative abundance of any habitat type, and a highly negative correlation with jaguar presence. Although the GLM model showed that other habitat types were negatively correlated with jaguar presence, the pair-wise Dunn's tests clearly showed that savanna habitat was used differently, and far less often, than any of the forested habitats. We predicted that jaguars would prefer forested habitats to those in savanna because the lack of canopy and cover, and the close proximity to humans renders savanna habitat too hot, too exposed, and too dangerous for regular jaguar activity.

While there were a low number of captures at savanna sites overall, RAIs were inflated by a high number of captures at a few sites. The majority of these 'highly used' savanna sites shared some common attributes – in close proximity to water and forest edges in areas known for human-jaguar conflict. At each of these sites, the cameras were set along existing foot trails, which jaguars were observed using repeatedly as they traveled between the forest and savanna. It is likely that these sites provide access to a single unique resource – cattle (*Bos taurus*).

Jaguars are known to regularly depredate cattle across their range (Polisar et al. 2003), and it is believed that the access to large prey outweighs the risks, prompting jaguars to move out into open areas. That said, two of the 'highly used' savanna sites existed in small savanna patches that were free of cattle, suggesting that jaguars may use savanna areas naturally with some frequency. Further research comparing the frequency of use in savannas with and without cattle would provide important insights into the importance of the presence of cattle in determining jaguar's use of savanna habitat.

Use of Bush Islands and Gallery Forest Habitat

Models indicate that jaguars use gallery forest and bush islands, both forested habitats found within the matrix, similarly. Both habitat types showed high RAIs, with gallery forest exhibiting the highest RAI of any site. However, the GLM model showed that both bush islands and gallery forest had a negative correlation with jaguar presence. These seemingly conflicting results indicate that while the overall percentage of use across these habitat types may be low, there are some hotspots that are 'highly used' and worth further consideration.

Bush islands are forest fragments surrounded on all sides by savanna habitat. Generally formed on hills or small mountains, bush islands provide cover, but also serve as dry refuges during the seasonal inundation of the Rupununi savannas. Of the forested habitats represented here, bush islands showed the lowest percentage of trap sites used by jaguars. However, this does not mean that one should conclude that bush islands are not important for jaguar conservation and management in the Rupununi. Forest fragments are known to play an important role as 'stepping stones' for dispersing individuals (Sweanor et al. 2000) navigating an unfavorable matrix of largely open habitat. While it is impossible to understand the 'intent' of an animal, examples of individuals in this study that were observed on several occasions in bush

islands before being re-captured in highly forested sites indicates that bush islands in the Rupununi savannas may serve as stepping stones that facilitate dispersal between forested areas.

Additionally, while jaguars used bush islands of all sizes and proximities to large areas of intact forests, the majority of the bush island captures came from the surveys of the region's two largest bush islands (Kusad Mountain at Saddle Mountain Ranch and three-mile bush at Karanambu Ranch). These bush islands were orders of magnitude larger than the rest of the forest fragments, allowing for multiple cameras to be set within a single bush island. Comparison to a previous camera-trap study at Karanambu Ranch suggests that these large bush islands support permanent, reproductive populations (E. Paemelaere pers. comm.) in addition to dispersing individuals.

Jaguars are known to be frequently associated with water (Schaller & Crawshaw 1980), which would reinforce their use of gallery forest habitat. We defined gallery forest as any narrow band of forest running along a river, creek, or oxbow lake, and bordered by savanna habitat on both sides. The percentage of forest cover was highly variable in gallery forest sites, with very dense, closed canopy forest bordering the larger rivers and sparse, open forests bordering creeks. The smaller rivers and creeks that flow through the Rupununi savannas are generally bordered by a narrow band of ité palm (*Mauritia flexuosa*) and may stop flowing completely in the dry season, drying down to isolated pools in low-lying areas. While our camera-traps captured jaguars using gallery forests of all types, the denser gallery forests that run alongside large rivers showed more frequent use than open forests. The latter may still have important conservation implications, as they still represent forested corridors running through undesirable habitat.

While bush islands and gallery forest may not serve as primary jaguar habitat, they still play an important role in supporting healthy jaguar populations and should be managed accordingly. These forests are increasingly targeted by logging and rotational farming in recent years because of their proximity and accessibility to villages, and have been subject to savanna intrusion following savanna fires (Kellman & Meave 1997; Biddulph & Kellman 1998). Further research into the impacts of bush island size, gallery forest connectivity, and the distance of each from large forested areas may help identify the bush islands and gallery forests that are the most likely to serve as corridors and thus should be prioritized for conservation and management.

Use of Lowland and Montane Forest

Although lowland forest sites had a higher RAI and hosted more captures and more individuals than montane sites, pairwise models did not show a significant difference in habitat use between lowland and montane forests. Both lowland and montane sites showed more even and consistent use than other forested habitats, with fewer captures at each site and longer intervals between occasions, but a larger proportion of the total number of sites used. Forested habitats are clearly important for sustaining jaguar populations, population models showed a positive correlation between percent of lowland and montane forest cover and population density.

Although it appears that elevation can be discarded as a factor to consider when predicting jaguar habitat use, montane forests had fewer captures of fewer individuals with even longer intervals than lowland sites, and the distribution of the captures that did occur in montane forests were skewed towards lower elevations, near the foot of mountains. During the rainy season, many of the lowland habitats are inundated with the flood waters of rivers, creeks, and wetlands. This shift may force jaguars into upland areas during the rainy season, where they may continue to frequent water edges which have shifted to near the foot of mountains. The data

showed that jaguars do use areas upland areas >1000 m, most activity appears centered on low elevation areas near seasonal water edges and the occasions that did occur at high elevations appeared to be isolated events (only a single capture over the study period). All of the high elevation captures from this study involved seemingly young (judged by their relative size) male individuals, indicating that high elevations habitat may be useable, but not preferred habitat. That said, prey species showed equal distribution across all elevations, with jaguars using lower elevation mountains, particularly those with flat areas at their peaks, with some regularity. Further research into the use of elevation gradients by jaguars and their prey would provide additional insights on the importance of mountainous areas for supporting jaguar populations.

At lowland sites more captures occurred at sites that were closer to forests edges than those further away. This tendency to frequent areas near forest edges has been observed elsewhere, and is believed to be related to the distribution of prey (Scognamillo et al. 2003). This preference for sites near edges may also have important conservation implications, as most Rupununi communities are also situated near forest edges, which increases the probability of jaguars coming into contact with people and domestic animals. Edges are known to be among the highest mortality areas in protected areas (Woodroffe & Ginsberg 1998), an issue which may require special management to avoid the transformation of edges into a population sink.

Impact of Microhabitat on Camera-trap Surveys

Variations in microhabitat around a camera-trap site can lead to inaccurate detection rates depending on the individual preferences of the species of interest (Weckel et al. 2006). Jaguars are considered ‘trail walkers’, choosing to travel or hunt along existing roads and trails when they are available (Harmsen et al. 2010). Setting-camera traps along lightly trafficked (Blake et al. 2017) roads and trails is a proven method for increasing capture rates in jaguar studies (Rabinowitz & Nottingham 1986; Maffei et al. 2004; Weckel et al. 2006; Harmsen et al. 2010;

Blake & Mosquera 2014), although a focusing trapping effort exclusively on roads is problematic because female jaguars have shown to actively avoid using roads (Conde et al. 2010). While selecting sites that boost capture rate has long been identified as an advantageous strategy for camera trap studies of large carnivores (O'Connell et al. 2010), this variable should be seriously considered in studies seeking to understand preferences in habitat use, as it creates the potential for erroneous results suggesting that areas with networks of established roads or trails support higher jaguar populations than road less areas simply because of the increased rate of capture rate along roads (Harmsen et al. 2010).

Jaguars used human-made roads and trails more frequently than off-trail areas when available and dry creek beds may serve a similar role when human-made infrastructure is not present. While the presence of roads and trails may not attract jaguars to an area on their own, it is clear that the presence of roads bias the distribution of (male) jaguars in the survey area. All cameras set along roads in this study were in a single habitat type – lowland forest. Although these sites did show a higher RAI than off road sites (more captures at shorter intervals), patterns of use (measured by presence / absence) remained consistent.

Presence of Hunters

Unexpectedly, jaguar habitat use was positively correlated with the presence of hunters at camera-trap sites in GLM model. Jaguars sensitivity to human activity seems to vary across their range, avoiding in time and space in some studies (Woodroffe 2000), while frequenting human-dominated landscapes in others (Foster et al. 2010, this study). The apparent tolerance of hunting activity observed in this study may have social, cultural, or ecological interpretations. The Rupununi hosts one of the world's lowest population densities. Hunters are largely pursuing prey to meet subsistence needs, doing so mainly with traditional bow and arrow. These socio-cultural factors mean that overall hunting intensity and disturbance associated with that activity

are low. Most camera-traps registered very low relative abundances of hunters, with only a few sites experiencing frequent hunting activity. Hunting intensity is seemingly low enough not to alter natural jaguar hunting patterns.

Additionally, hunters frequent places where they are most likely to encounter prey. Jaguars also are known to structure their movement and activity patterns to increase the probability of encountering their primary prey species (Harmsen et al. 2011). With low intensity hunting in the region, we believe that the positive correlation with the presence of hunters may actually be an indication that jaguars prefer to use areas also frequented by game species.

Population Density

Site-level jaguar population density in the Rupununi Region ranged from 1.96 – 5.58 individuals / 100 km^2. These density estimates fall within the known range of jaguar population densities from previous studies that employed camera traps and SECR methodology. The lowest population densities came from sites with the highest percentage of savanna habitat within the study area (Karasabai, Dadanawa). The 1.96 and 2.54 individuals / 100 km^2 were similar, although slightly higher, than the 0.31 – 1.82 individuals / 100 km^2 estimated for comparable habitat in Bolivian Gran Chaco (Noss et al. 2012). The highest population densities came from sites with the highest percentage of forest cover (Rewa Head, Rewa, Surama, KMPA). The 4.68, 4.76, 4.98, and 5.58 individuals / 100 km^2 were similar, although also slightly higher, than the 4.4 ±0.7 individuals / 100 km2 estimated for Los Amigos Conservation Concession in the southwestern Amazon (Tobler et al. 2013).

The sites whose population densities feel between these highest and lowest densities (Shulinab, Karanambu / Yupukari, Saddle Mountain) were sites within the matrix that contained mix of forest types (primarily gallery forest and bush islands) and savanna. Population density at these sites (2.84, 2.91 and 3.56 individuals / 100 km^2 respectively) fell between the highest and

lowest densities observed, seemingly also correlated with the percent forest cover. Saddle Mountain and Karanambu / Yupukari were on the higher end of these middling densities, reiterating the importance of large bush islands, which may support both permanent residents and dispersing individuals.

Interestingly, although the Kanuku Mountains Protected Area showed the highest jaguar population density in the region, land tenure does not appear to be a driving factor of population density, as two indigenous community-owned sites had similar and only slightly lower population densities. Within the matrix, ranch sites appear to support higher densities than those managed by indigenous communities; however, these sites also contained greater percent forest cover than community lands. Retaliatory killing of jaguars following depredation of livestock at ranch and community sites may play a role in reducing population density at some sites, as each of the sites with highest density either lacked or had very few livestock. Additionally, within each habitat type sites that supplemented their income with ecotourism (Surama, Rewa, Karanambu / Yupukari, Saddle Mountain, Dadanawa) rather than depending on cattle rearing and extractive activities, also showed higher densities than their counterparts with similar habitat composition. The impact of human-jaguar conflict and land use patterns on the population density of jaguars are variables that warrant further research.

Overall, population density seems to be positively correlated with forest cover and the Rupununi showed relatively high population densities when compared with studies of similar habitat elsewhere in the jaguar's range. Extrapolating even a median population density observed in the matrix across the study area suggests that the Rupununi may support upwards of 600 jaguars. Although this extrapolation is presented with the recognition that this is not an actual population estimate that captures all the possible variation across the region, however even

as a rough estimate, the high number of individuals possible seems to justify consideration of the Rupununi Region for a Jaguar Conservation Unit, with the potential for Jaguar Corridors to be identified with further study.

Activity Patterns

Jaguar activity patterns varied among habitat and trail types, which may provide insights into how jaguars deal with environmental conditions, pursuit of prey, and the presence of humans in the landscape. Male and female jaguars showed a high degree of overlap in activity, which differed from findings in the western Amazon (Blake et al. 2012). We believe that the heterogeneity of the Rupununi landscape may serve as the primary driver of activity and, as a result, negates any sex-related variation that has been observed in more homogenous landscapes.

Habitat as a driver of activity

Among habitat types, those with similar composition and forest cover showed the highest overlap in activity patterns, while the lowest overlaps were observed between habitats with the biggest differences in forest cover. Savanna habitat was excluded from these comparisons, as savanna showed different usage patterns from any of the forested habitat types and the majority of the captures occurred at a low number of sites and included only a few individuals, thus increasing the probability of individual bias. However, the comparison of gallery and riverine forests, which at first consideration would seem to be similar in that they are both forested habitats that border rivers and creeks, showed the lowest degree of overlap of any two habitat types (0.72). Jaguars are known to frequent areas nears water, but jaguars in gallery forest habitat were most active before dawn and after dusk, while those in riverine forests showed activity throughout the day with peaks in activity during the morning hours and before dusk. The composition and forest of gallery forests was highly variable, but included a number of sites along small, seasonal creeks that with open canopies. Shifts in activity patterns toward more

nocturnal activity at these sites may be driven by the susceptibility of this species to heat stress (McBride & McBride 2007) resulting in the need to avoid the hot sun in areas of high exposure.

Prey as a driver of activity

Prey is known as a major factor driving the distribution of jaguars, but studies have shown that they may also shift their activity patterns to match their preferred prey (Harmsen et al. 2011). While the species composition may differ, functionally, lowland and riverine forests are very similar habitat types in terms of forest structure and cover. The primary difference between these habitat types is the presence of rivers or creeks that seasonally inundate the riverine forest understory. Despite the similarities, a low degree of overlap (0.79) was observed between lowland and riverine forests, which may be attributed to jaguars matching their behavior to their preferred prey in each habitat. Jaguars are known generalists, and dietary studies in lowland forest indicate that a variety of large and medium sized mammals make up the majority of their diet, with white-lipped (*Tayassu pecari*) and collared (*Pecari tajacu*) peccaries and armadillos (*Dasypus novemcintus*) often representing their most common prey (Garla et al. 2001; González & Miller 2002; Weckel & Giuliano 2006; Foster et al. 2010). Data from this study showed consistent activity patterns across all times of the day in lowland forest, providing further evidence for a generalist strategy that includes predation on a number of large- and medium-sized mammals.

However, within riverine forests, jaguars showed shifts in their behavior with dramatic peaks in activity during the morning hours and around dusk. Previous dietary studies conducted in flooded forests have shown that riverine specialists, such as spectacled caiman (*Caiman crocodilus*) and capybara (*Hydrochoerus hydrochaeris*), make up the largest proportion of their prey (Schaller & Vasconcelos 1978; Da Silveira et al. 2010). The shift in activity pattern towards more diurnal activity indicates that jaguars may be matching the activity patterns of

caiman (who bask during the daylight hours) and capybara (who graze along river edges around dusk and dawn).

Proximity to humans as a driver of activity

Lastly, while jaguars showed a high level of overlap in their activity patterns across game trails, foot trails and dry creek beds, there was a low degree of overlap (0.79) in their activity on roads compared to all other trail types. Jaguar activity on game trails, foot trails, and dry creek beds was consistent across all times of the day, with some dips in activity just before dusk and dawn. However, on roads, jaguar activity decreased steadily throughout from peaks in the hours before dusk and after dawn, with the lowest activity during the middle of the day. The majority of roads in the sample were in lowland forest habitat, which indicates that the presence of humans, and potentially the noise associated with vehicles, may drive these shifts in behavior towards more nocturnal activity. While this study focused exclusively on the effects of habitat on jaguar activity, this is the first indication of the potential impact of human activity, a variable which should be studied further.

Conclusion

While jaguars utilize all habitat types in navigating the mosaic that is the Rupununi Region of Guyana, they showed a clear preference for forested habitats over savanna. The importance of cover for hunting and thermoregulation, low abundance of natural prey, and the threat of conflict with humans may limit use of open savanna habitat. The region's intact lowland and montane forests supported the highest use and highest jaguar densities, indicating that these areas are the core habitats with the greatest probability of supporting long-term survival. The high jaguar population density across region suggests that Rupununi forests warrant consideration as a Jaguar Conservation Unit, while further research is needed to identify critical corridors with the broader habitat matrix of the Rupununi savannas.

Table 2-1. Distribution of camera-trap across habitat types

Site name	Trap sites	Trap nights	# of photos	Cerrado savanna	Bush island	Gallery forest	Lowland forest	Montane forest	Riverine forest
Rupunau	17	1,161	91,460	7	4	2	4	0	0
Dadanawa	21	3,095	34,389	3	16	10	2	0	0
KMPA	30	7,789	108,944	0	0	0	11	11	8
Mapari	15	3,477	62,746	0	0	0	6	7	1
Shulinab	22	3,902	72,934	7	1	8	3	5	0
Rewa Head	22	2,937	58,484	0	0	0	11	2	9
Rewa	20	4,352	44,334	4	0	1	7	4	10
Surama	24	5,233	91,701	1	0	0	18	2	3
BHI	22	1,934	41,226	1	3	5	9	4	0
Saddle Mtn.	20	4,478	88,496	6	8	6	0	0	0
Karasabai	20	3,876	61,205	8	2	5	4	1	0
Iwokrama	47	11,499	119,282	0	0	1	42	2	2
Yupukari	34	4,157	41,855	2	8	7	0	0	0
Karanambu	23	4,162	119,554	8	5	3	0	0	0
Manari	20	-	-	5	4	13	0	0	0
TOTAL	357	62,052	1,036,610	52	51	61	117	38	33

Table 2-2. Distribution of camera trap sites across trail type and anthropogenic activities

Site name	Trap sites	Game trail	Creek bed	Foot trail	Vehicle road	Hunted sites	Livestock present?	Logged sites	Near farm?
Rupunau	17	9	2	6	0	12	8	0	8
Dadanawa	21	14	6	0	0	18	9	1	0
KMPA	30	30	0	0	0	0	0	0	0
Mapari	15	14	0	0	1	0	5	2	2
Shulinab	22	7	7	8	0	8	18	1	7
Rewa Head	22	16	4	1	0	0	0	0	0
Rewa	20	9	0	10	1	0	12	2	5
Surama	24	5	2	4	13	3	12	14	7
BHI	22	10	0	10	2	4	14	8	8
Saddle Mtn.	20	12	5	3	0	12	10	0	1
Karasabai	20	15	2	3	0	15	13	2	6
Iwokrama	47	23	1	9	14	0	7	27	0
Yupukari	34	29	1	4	0	9	17	10	9
Karanambu	23	14	1	5	3	8	12	4	3
Manari	20	-	-	-	-	-	-	-	-
TOTAL	357	207	31	63	34	89	137	71	56

Table 2-3. Number of jaguar captures, sites with captures, capture per site, and relative abundance per habitat type

Habitat type	Sites w/ captures	Jaguar captures	Captures/site	RAI / 100 nights
Savanna	6	19	3.17	0.35
Bush Island	17	82	4.82	0.92
Gallery forest	22	100	4.54	1.25
Riverine forest	13	57	4.38	1.20
Lowland forest	36	141	3.91	0.57
Montane forest	20	43	2.15	0.42

Table 2-4. Results of Pearson's product-moment correlation test between sampling effort and relative abundance

Variables	t-value	df	p-value	LCI	UCI	corr
Sampling Effort – Rel. Abundance	0.84	261	0.4	-0.07	0.17	0.05

Table 2-5. Results of Kruskal-Wallis test among habitat and trail types sampled by camera-traps

Variable	Chi-squared	df	P-value
Habitat Type	19.04	5	0.002*
Trail Type	33.56	3	2.45e-07*

Table 2-6. Results of Dunn Test for multiple comparisons between habitat and trail types sampled by camera traps

Comparison	Z-value	Unadjusted p-value	Adjusted p-value
Bush Island - Gallery	-1.32	0.19	1
Bush Island - Lowland	-1.68	0.09	0.92
Gallery - Lowland	-0.27	0.78	1
Bush Island - Montane	-1.02	0.31	1
Gallery - Montane	0.18	0.86	1
Lowland - Montane	0.44	0.66	1
Bush Island - Riverine	-0.90	0.37	1
Gallery - Riverine	0.21	0.83	1
Lowland - Riverine	0.45	0.65	1
Montane - Riverine	0.04	0.96	0.96
Bush Island - Savanna	2.11	0.03*	0.38
Gallery - Savanna	3.44	0.00*	0.01
Lowland - Savanna	3.94	0.00*	0.001
Montane - Savanna	2.96	0.00*	0.04
Riverine - Savanna	2.72	0.01*	0.08
Dry Creek Bed - Foot Trail	1.46	0.14	0.29
Dry Creek Bed - Game Trail	3.81	0.00*	0.00
Foot Trail - Game Trail	2.52	0.01*	0.04
Dry Creek Bed - Road	-1.21	0.23	0.23
Foot Trail - Road	-2.55	0.01*	0.04
Game Trail - Road	-4.55	0.00*	0.00

Table 2-7. Results of GLM and AIC of association between jaguar relative abundance and habitat type

	Model 1	Model 2	Model 3*	Model 4*	Model 5*	Null
Intercept	-0.54	-0.53	-0.50	-0.62	-0.74	-0.30
Elevation	0.003	0.003	0.003	0.003	0.003	NA
Hunted	0.58	0.58	0.58	0.48	0.50	NA
Bush Is.	-0.6	-0.61	-0.64	-0.53	NA	NA
Gallery	-0.38	-0.39	-0.41	NA	NA	NA
Lowland	0.05	0.044	NA	NA	NA	NA
Montane	0	NA	NA	NA	NA	NA
Riverine	NA	NA	NA	NA	NA	NA
Savanna	-1.94	-1.95	-1.97	-1.83	-1.73	NA
df	8	7	6	5	4	1
logLik	-165.72	-165.72	-165.73	-166.37	-167.55	181.36
AIC	347.44	345.44	343.45	342.73	343.09	364.71
delta	4.71	2.71	0.73	0	0.36	21.99
Weight	0.03	0.09	0.23	0.34	0.28	0.00

Table 2-8. Number of occurrences and relative abundance of jaguars by sex overall and by sample site

	Male	Female	TOTAL
Occurrences	276	169	445
Relative Abundance	0.45	0.27	0.72
Total Individuals	39	35	74
Karasabai	2	1	3
Dadanawa	2	2	4
Shulinab	4	4	8
Karanambu/Yupukari	4	4	8
Saddle Mountain	3	2	5
Rewa Head	5	4	9
Rewa	4	3	7
KMPA	4	4	8
Surama	5	4	9
BHI	3	2	5
Rupunau	3	1	4
Mapari	2	3	5

Table 2-9. Results of site-level population estimation using spatially-explicit capture-recapture (SECR) methodology

Site	LL	SE	LCI	UCI	Density	g0	sigma	Ind. / 100 km^2
Karasabai	-47.93	0.01	0.006	0.06	0.0196	0.07	2913.52	1.96
Dadanawa	-59.41	0.01	0.01	0.07	0.0254	0.04	3831.26	2.54
Shulinab	-77.18	0.01	0.01	0.07	0.0284	0.06	3637.11	2.84
K'Bu / Yups	-154.37	0.01	0.01	0.06	0.0291	0.07	3516.32	2.91
Saddle Mtn.	-81.49	0.02	0.01	0.09	0.0356	0.16	1804.61	3.56
Rewa Head	-84.53	0.02	0.02	0.09	0.0468	0.06	4012.94	4.68
Rewa	-74.73	0.02	0.02	0.1	0.0476	0.02	4954.56	4.76
Surama	-175.83	0.02	0.03	0.13	0.0498	0.05	3510.29	4.98
KMPA	-103.64	0.02	0.02	0.09	0.0558	0.06	2330.61	5.58

Table 2-10. Results of evaluation of overlap (%) in a variety of variables affecting jaguar activity patterns

Comparison	Overlap	Lower CI	Upper CI
Male v. female	0.90	0.87	0.98
Lowland v. montane	0.83	0.77	0.96
Lowland v. riverine	0.79	0.74	0.96
Lowland v. bush island	0.83	0.76	0.94
Gallery v. riverine	0.72	0.59	0.84
Hunted v. non-hunted	0.77	0.68	0.90
On v. off road	0.79	0.69	0.92
Creek bed v. other	0.79	0.70	0.95

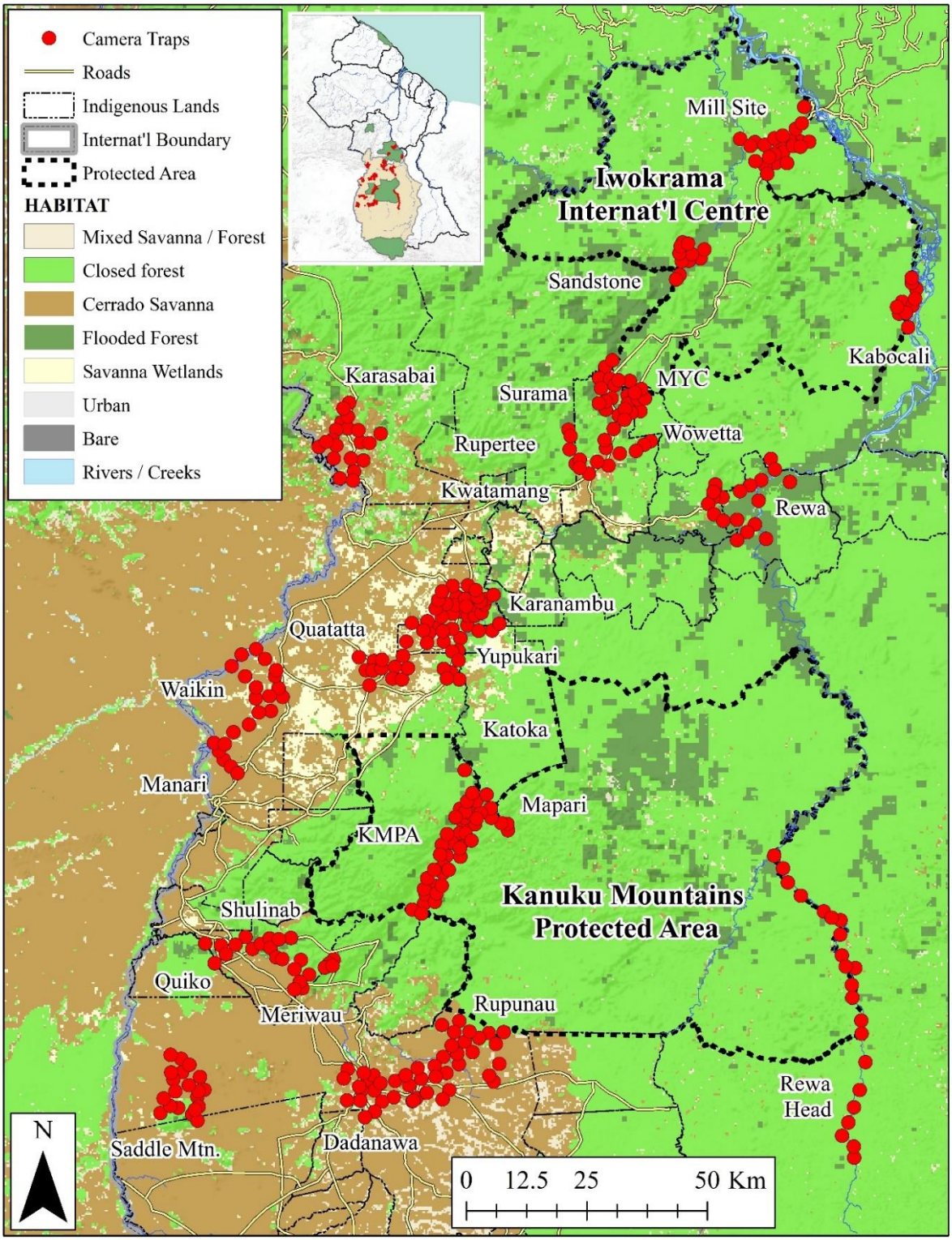

Figure 2-1. Map of distribution of camera-trap sites across habitats in the Rupununi Region, Guyana (ESRI 2016)

Figure 2-2. Examples of camera-trap photos of jaguars in the Rupununi Region of Guyana across various habitat and trail types (photos courtesy of Matt Hallett)

Figure 2-2. Continued (photos courtesy of Matt Hallett)

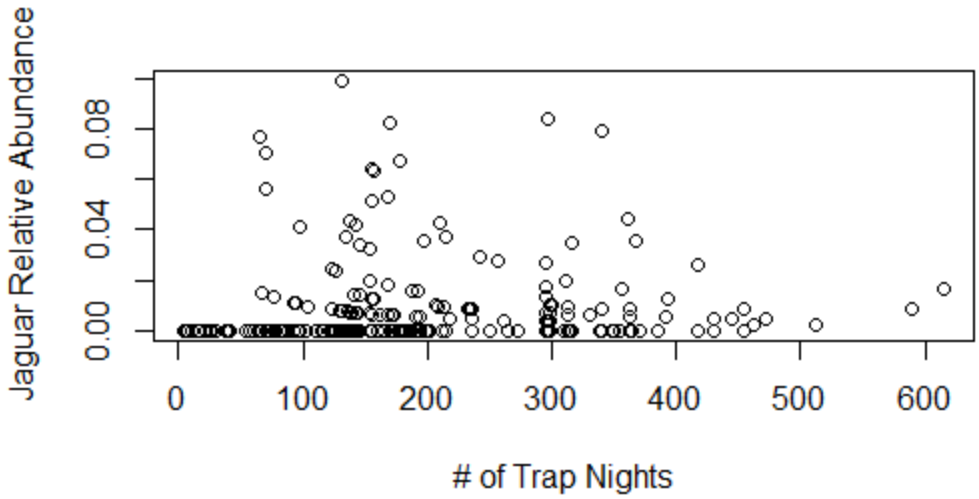

Figure 2-3. Plot of sampling effort and jaguar relative abundance

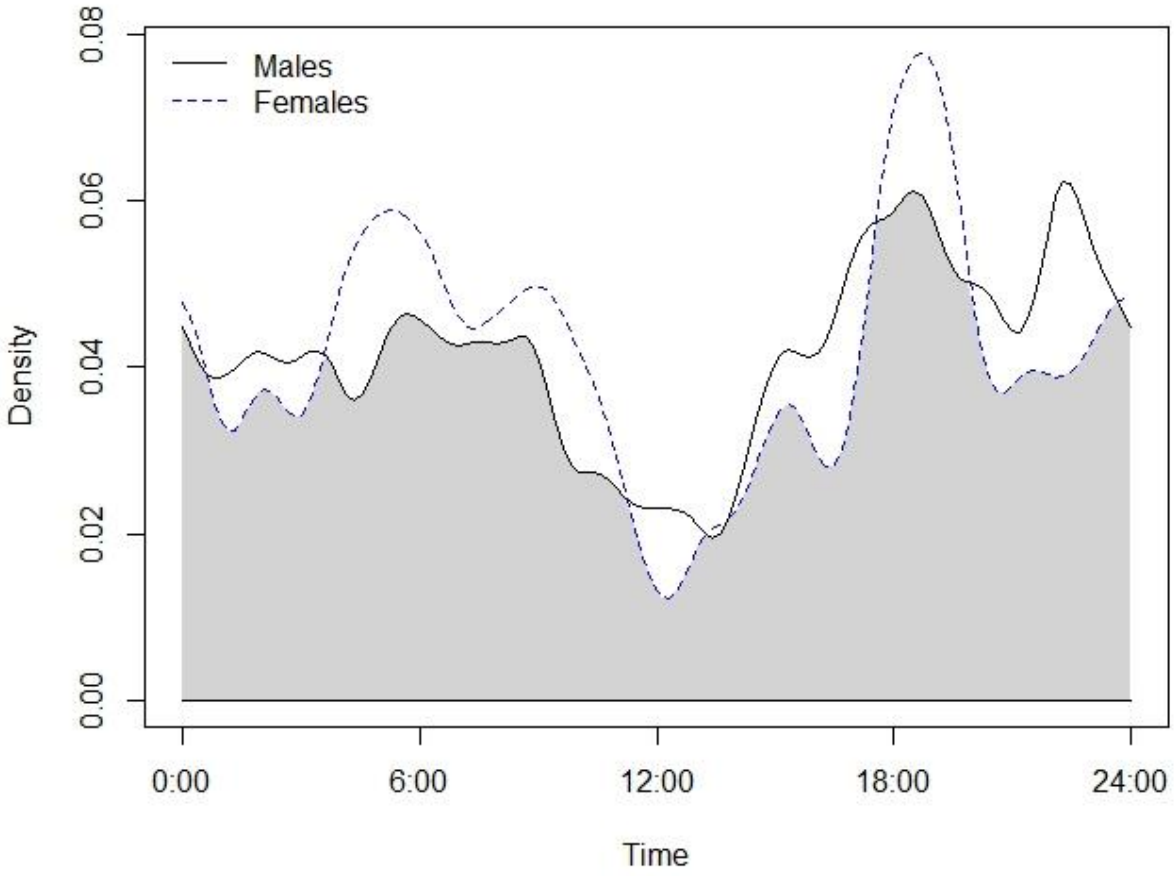

Figure 2-4. Evaluation of overlap of male and female jaguar activity patterns

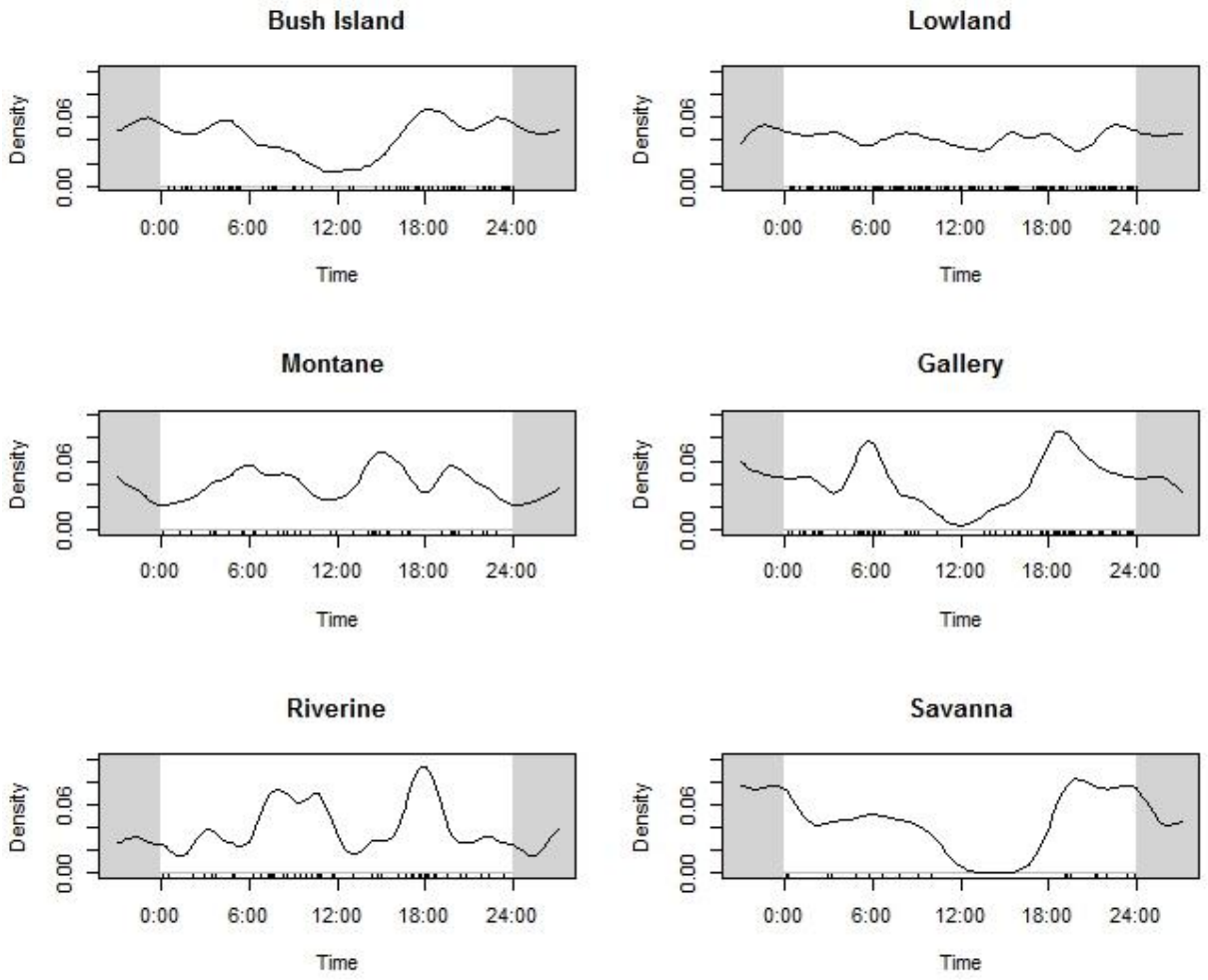

Figure 2-5. Comparison of jaguar activity patterns between Rupununi habitat types

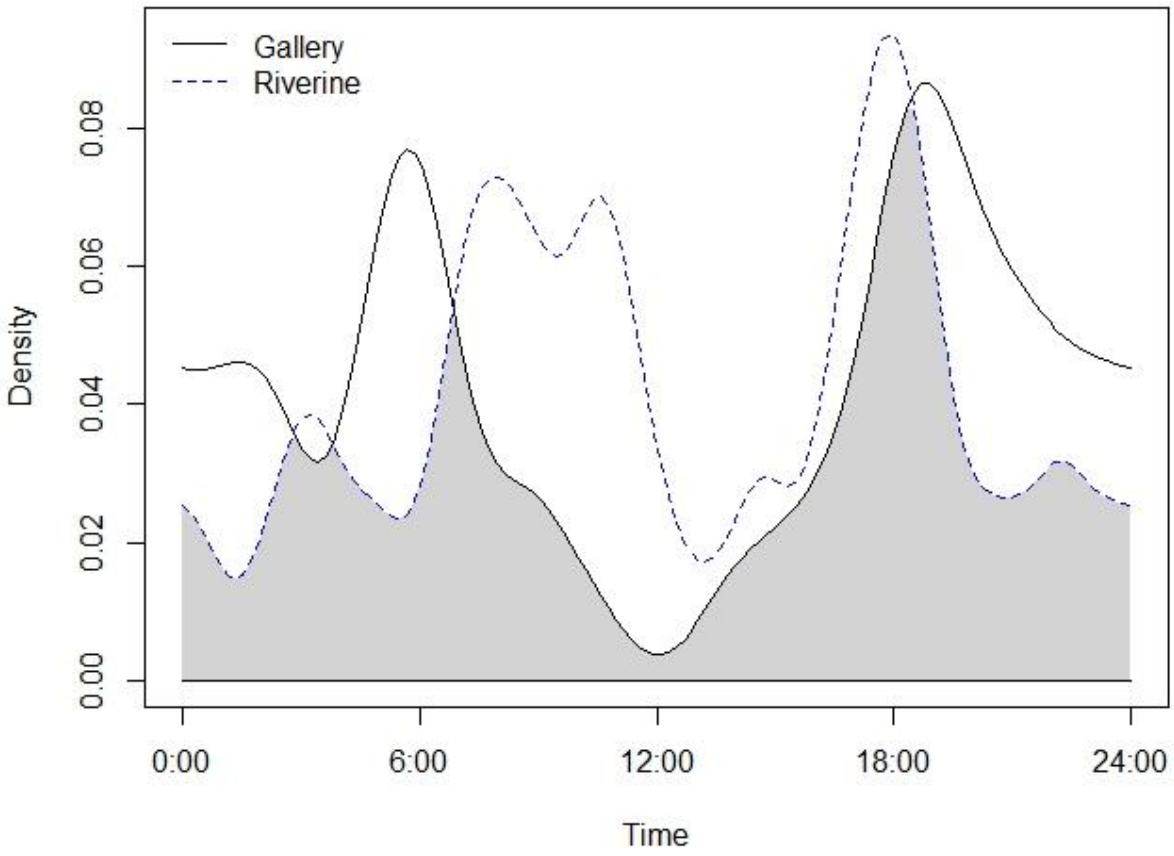

Figure 2-6. Evaluation of overlap of jaguar activity patterns in gallery and riverine forest

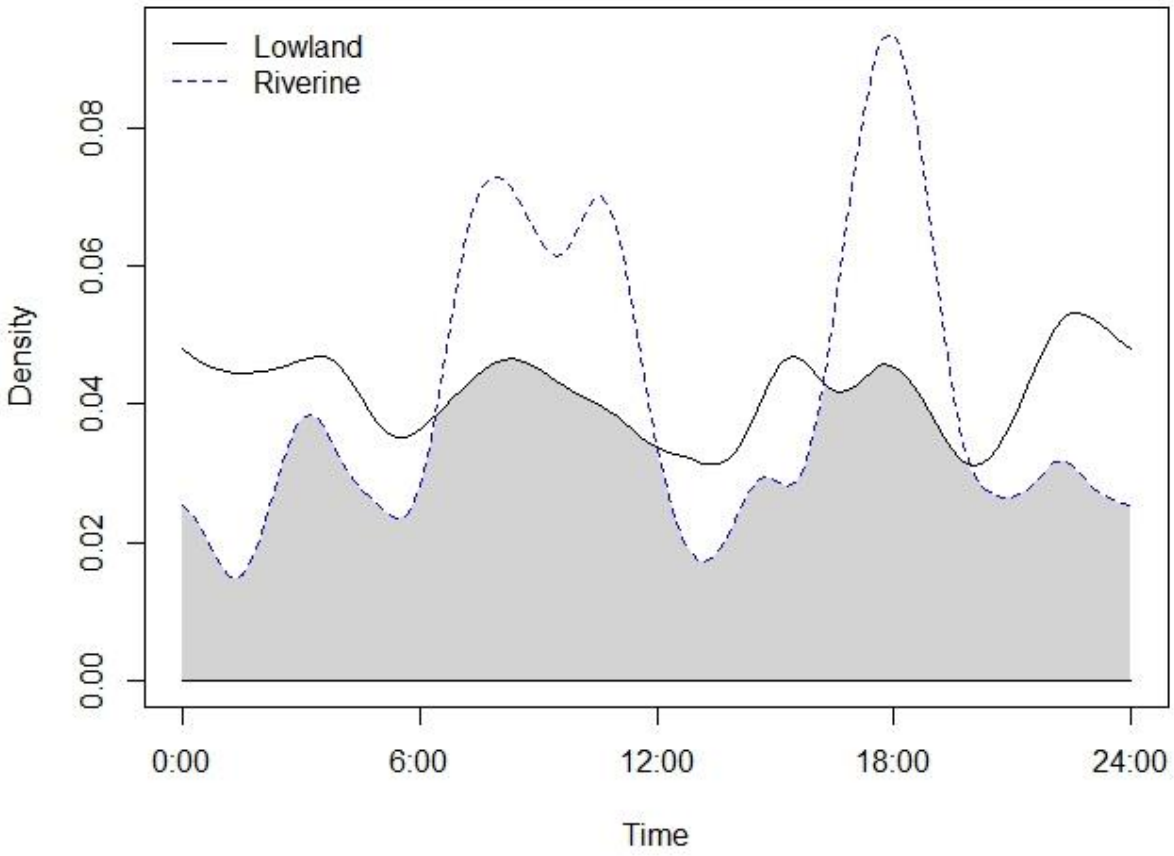

Figure 2-7. Evaluation of overlap of jaguar activity patterns in lowland and riverine forests

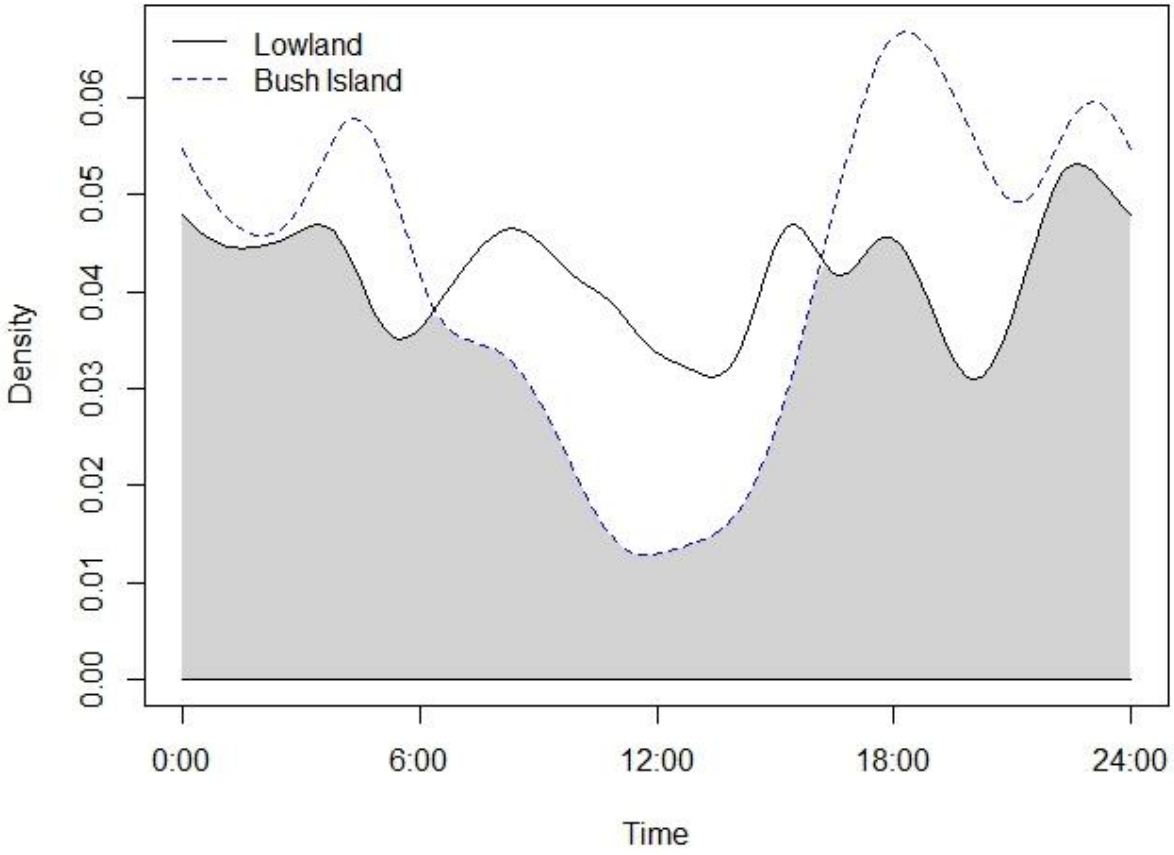

Figure 2-8. Evaluation of overlap of jaguar activity patterns in lowland forests and bush islands

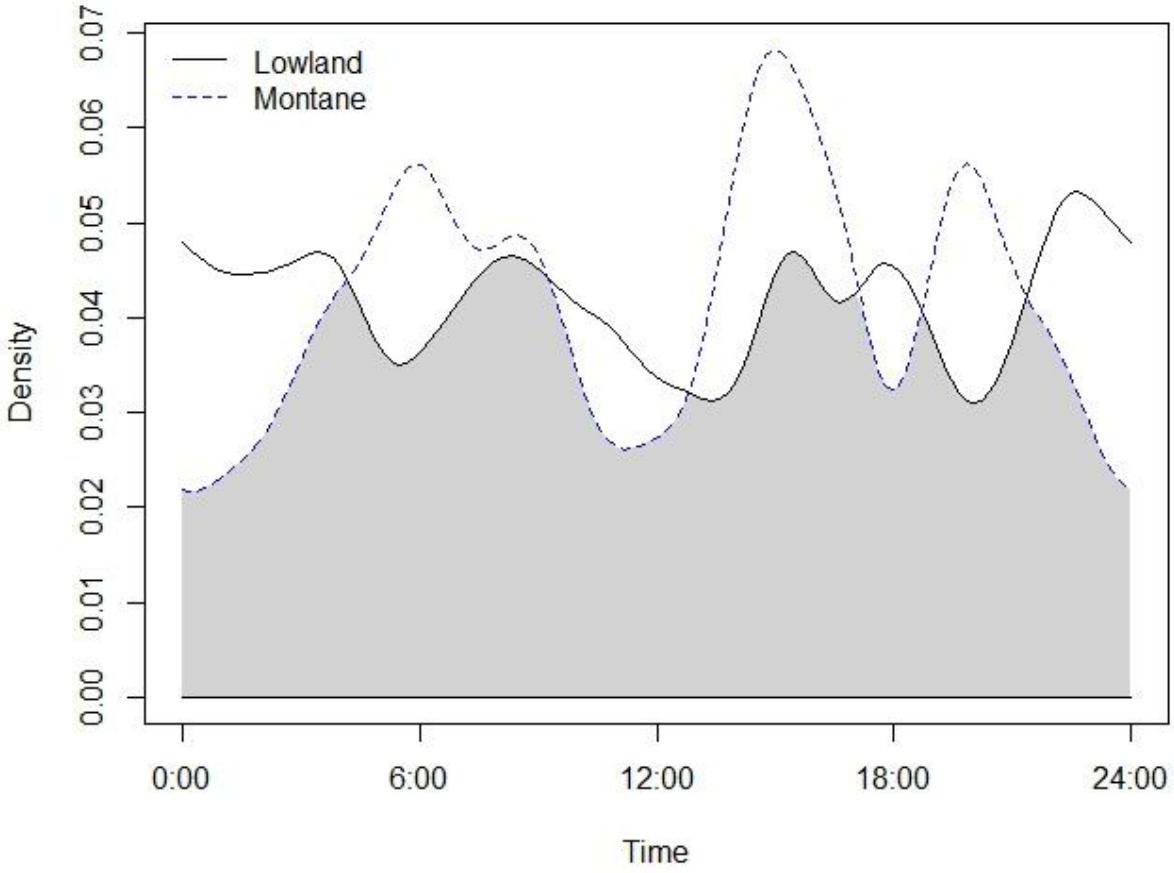

Figure 2-9. Evaluation of overlap of jaguar activity patterns in lowland and montane forests

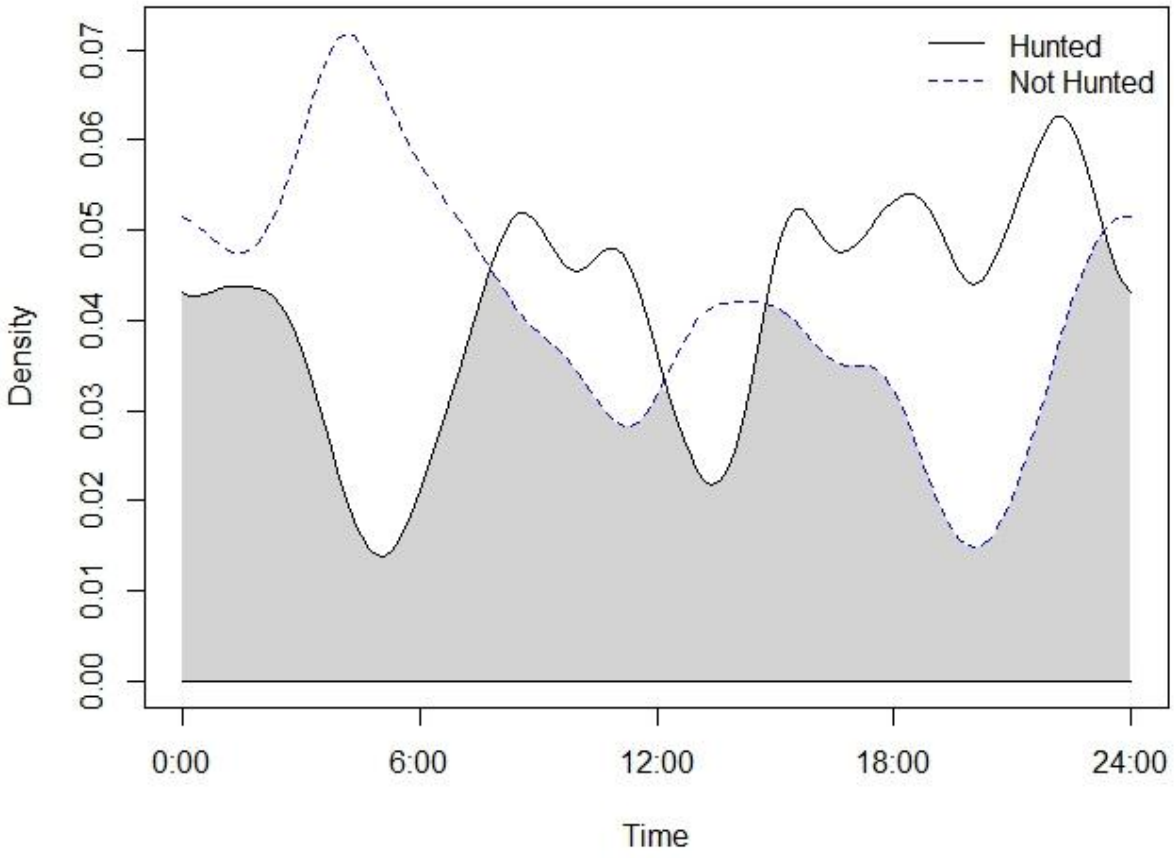

Figure 2-10. Evaluation of overlap of jaguar activity patterns in in hunted and non-hunted areas in lowland forests

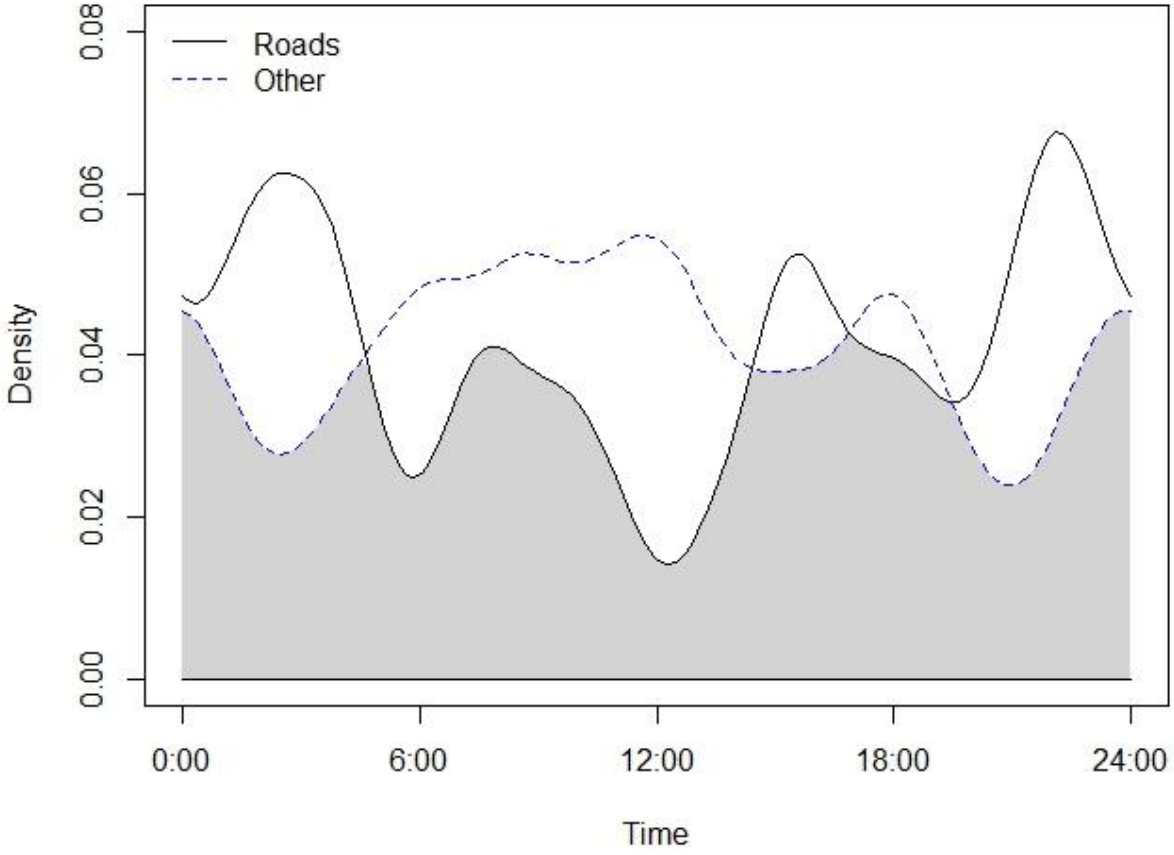

Figure 2-11. Evaluation of overlap of jaguar activity patterns on and off roads within lowland forests

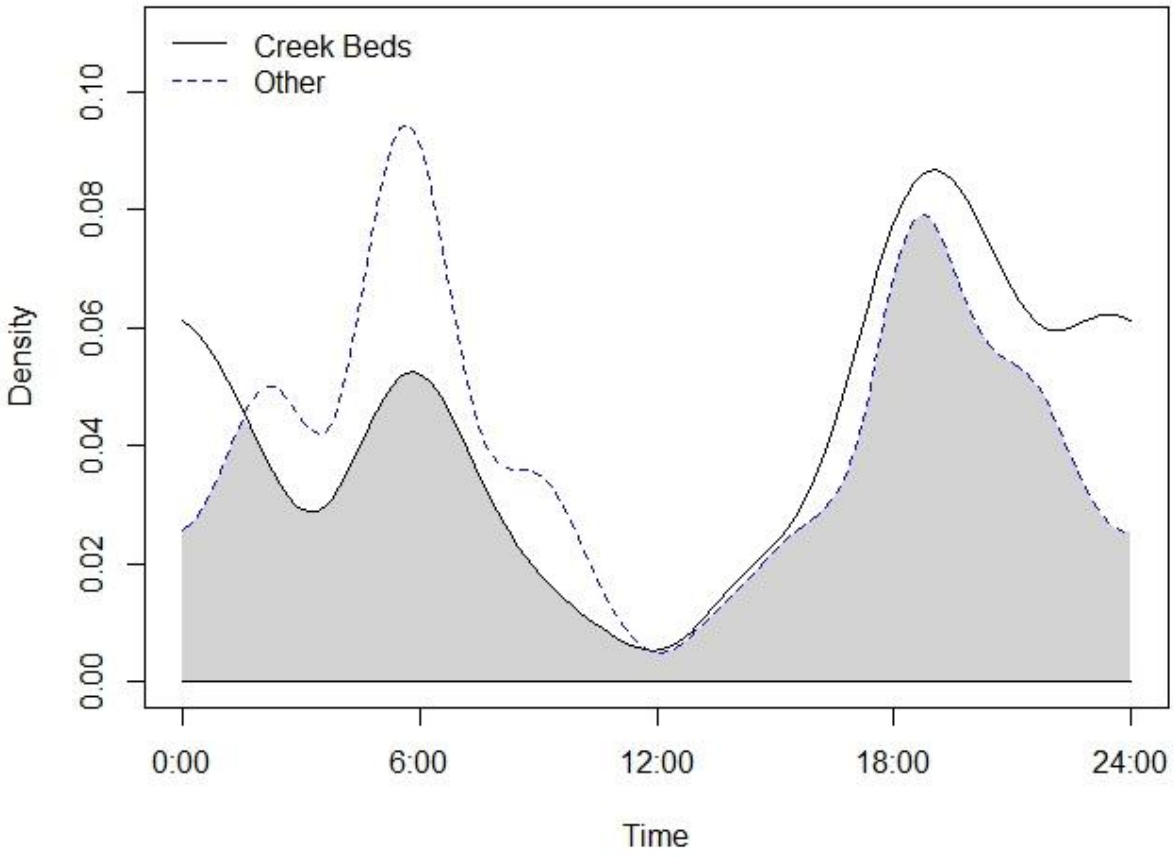

Figure 2-12. Evaluation of overlap of jaguar activity patterns in dry creeks and other trail types within gallery forests

CHAPTER 3
OPPORTUNISTIC ENCOUNTERS BY RESOURCE USERS AS A TOOL FILLING KNOWLEDGE GAPS IN THE MANAGEMENT OF A RARE SPECIES: BUSH DOGS (*SPEOTHOS VENATICUS*) IN THE RUPUNUNI, GUYANA

Introduction

Historically, wildlife management planning and decision making has been built on population estimation and monitoring – a model that relies heavily on time and resource-intensive quantitative data collection through rigorous, structured scientific studies (Mauro and Hardison 2000). Well-planned and executed research that takes place across broad spatial and temporal scales, includes precise measurements of population size, and comparisons to control sites for variables of interest is undoubtedly an effective method for accurately identifying the degree and drivers of population change (Moller et al. 2004). However, constraints to time and resources, as well as the ability of scientists to properly characterize complex human interactions with the environment limits our capacity to conduct such studies in the field – a fact that becomes particularly apparent with regard to naturally rare, wide-ranging species that inhabit remote or hard-to-access locations.

The Bush Dog – A Rare and Elusive Neotropical Canid

The bush dog (*Speothos venaticus*) is a naturally rare and extremely elusive canid that ranges widely across South America. This species is highly social, hunting in groups of 2-10 individuals (Aquino & Puertas 1997; Barnett et al. 2001; Beisiegel & Zuercher 2005). Little is known about the movements and habits of bush dogs, but they reportedly are mostly diurnal and semi-nomadic over extensive home ranges (>100 km^2). They also use a variety of habitats including intact forest, well vegetated cerrado savanna, and disturbed agricultural and ranchland sites associated with forest fragments (de Souza Lima et al. 2012).

The wide ranging nature of bush dogs is associated with their predatory behavior (de Souza Lima et al. 2012). They are strongly carnivorous, favoring small mammals up to their own weight, including *Cuniculus paca*, *Dasyprocta* spp., *Myoprocta* spp., *Dasypus* spp., and various species of mice, rats, opossums, terrestrial reptiles, and ground birds (Eisenberg 1989; Emmons 1997; Hunter 2011). Bush dogs have also been documented pursuing larger prey, such as *Hydrochaeris hydrochaeris*, *Pecari tajacu*, and *Mazama* spp. (Hunter 2011), and consuming terrestrial invertebrates and fruits in small amounts or incidentally (Zuercher et al. 2005).

Bush dog populations are estimated to have declined 20-25% from 1996-2008 (DeMatteo et al. 2011), but actual abundance and distribution are unknown. Major threats include habitat loss related to extractive activities, reduction of prey base by unsustainable hunting, and lethal diseases contracted from domestic canids (DeMatteo 2008). The degree to which each threat impacts bush dog populations is unknown because of the difficulty of studying this species in the wild. They are listed as 'Near Threatened' by the IUCN Red List of Threatened Species and under Appendix I of CITES (DeMatteo et al. 2011).

Current knowledge of bush dogs comes from museum specimens (Engstrom & Lim, 2002; DeMatteo & Loiselle 2008; De Oliveira 2009), interviews with practitioners (DeMatteo 2008; DeMatteo & Loiselle 2008), indirect evidence in the form of tracks and scat (DeMatteo et al. 2004; Zuercher et al. 2005; Lima et al. 2009; DeMatteo et al. 2009; Pickles et al. 2011), opportunistic encounters (Peres 1991; Barnett et al. 2001; DeMatteo & Loiselle 2008; Beisiegel 2009; De Oliveira 2009; Gil & Lobo 2012; Carretero-Pinzón 2013), camera-trap captures (Beisiegel 2009; Michalski 2010; Fusco-Costa & Ingberman 2012), and studies of captive individuals (Kleiman 1972; Porton et al. 1987; Montalli & Kelly 1989; MacDonald 1996; DeMatteo et al. 2006). Few field studies have been robust enough to detail bush dog diet, home

range, and behavior (Beisiegel & Ades 2002; Beisiegel & Zuercher 2005; de Souza Lima et al. 2012; DeMatteo et al. 2014). As a result, the abundance, distribution, and ecological requirements of this species are poorly understood, hampering conservation and management efforts (Eisenberg 1989; Emmons 1997; Hunter 2011).

Research Tools for Surveying Rare Species

Field studies on bush dogs have thus far been limited by the ability of researchers to effectively locate packs in the wild. Both active and passive capture techniques have been suggested as potential solutions for filling knowledge gaps on this species, and although each has contributed some data, returns have been insufficient to guide management.

Physical capture and deployment of radio or GPS collars provides the most comprehensive data on distribution, activity, and home range of species of interest. These tools are inherently expensive and bush dogs have proven exceedingly difficult to locate and physically capture, thus limiting application. Two studies that successfully captured and tracked bush dog packs produced estimates of home ranges that varied from 140 (Lima et al. 2012) to 709 km^2 (De Matteo et al. 2014). While authors hypothesized that differing amounts of natural habitat between study sites may account for the variation in home range size (de Matteo et al. 2014), more replicates are needed to increase the applicability of these results. The potential for a dramatic increase in the number of similar studies remains constrained by costs and the rare and elusive nature of this species.

Domesticated detection dogs have been suggested as an effective technique for locating physical evidence (scat, hair) of bush dogs, with the genetic information in each sample providing important data on the structure and health of populations that goes beyond simply documenting their occurrence in a given area (DeMatteo et al. 2009). The olfactory ability of detection dogs goes far beyond what human observers can sense in their environment and it has

been suggested that surveys with detection dogs are more cost and time effective than other methods (DeMatteo et al. 2009), but this method also requires access to specially trained canines, which limits its application (Oliveira et al. 2016).

Camera traps are considered an effective tool for surveying medium and large terrestrial rainforest mammals (Tobler et al. 2008), and a consistent and reliable means for estimating the relative abundance of cryptic species (Carbone et al. 2001), and of bush dogs in particular (de Oliveira 2011), when sample size is sufficient (O'Connell et al. 2011). However, a number of robust camera-trap studies conducted in areas with high quality habitat failed to detect bush dogs (when the expectation was that they would be present), including 14 of the previous 15 camera-trap projects conducted in Guyana (Table 3-1). Some suggest that the lack of captures in these studies may have resulted from insufficient sample size or ineffective trap placement, because many studies in the Neotropics are focused on jaguars (Tobler et al. 2008). However, even studies that focused their study design specifically on bush dogs and/or those with high sampling effort have resulted in few captures (Table 3-2; de Oliveira et al. 2016). Camera-trap studies measuring occupancy or relative abundance assume a consistent detection probability across time and space and a positive linear relationship between capture rates and true abundance (O'Connell et al. 2011). But bush dogs captures have been too few to apply these analyses.

Bush dogs are naturally rare and semi-nomadic across large home ranges. They also tend to avoid roads and foot and game trails frequented by other species, making camera trapping alone too inconsistent for gaining a reasonable understanding of the abundance and distribution of this species (Fusco-Costa & Ingberman, 2012). We present the findings of a multi-species landscape-scale camera-trap survey of the Rupununi Region of Guyana here and discuss the limitations of resulting data for informing management.

Local Ecological Knowledge and Research

Gaps in knowledge are recognized as a central factor limiting the effectiveness of bush dog conservation and management, and traditional qualitative research tools (i.e. transects, camera traps, collars) have shown limited success in closing these gaps. To address this issue, local ecological knowledge, the dynamic and ever-changing information and experiences embedded in the practices, institutions, relationships, and rituals of people and communities that are developed in a given place over time (Warburton & Martin 1999), should be integrated with limited data produced by western methods. Reaching across disciplines to broaden data sources and methods, may provide the innovation needed to produce critical information that has, to date, been elusive but that is necessary for effective management of this species.

The term 'local ecological knowledge' (LEK) is used here as it most accurately characterizes those who contributed to our study – a group that includes indigenous and non-indigenous people whose knowledge may encompass generational or contemporary experience in our study area. LEK is derived from a lifetime of experience of those who depend on the local environment for their survival (hunting, fishing, and farming) and subsistence (wildlife trapping, commercial harvest). LEK differs from indigenous knowledge (IK), which is a body of knowledge that is aggregated over time by a given cultural group in their long-term adaptation to a given biophysical environment (Purcell 1998). Distinctions between IK and LEK may be important for incorporating IK into research, as observations and reflections made by indigenous people who maintain traditional belief systems may be based in a spiritual worldview that recognizes connections between organisms and the natural environment that are not recognized in the scientific literature (Pierotti & Wildcat 2000).

Incorporating LEK into the scientific process has shown considerable potential for improving research and natural resource management (Baird et al. 2005), particularly when

focused on species and their distribution (Moller et al. 2004; Kaschula et al. 2005). LEK may be particularly important to conservation and management when the species of interest is rare, elusive, and/or have populations that occur in remote locations where extensive scientific studies may be impractical (Barsh 1997; Ferguson et al. 1998). Although LEK may be imprecise and qualitative, the spatial and temporal scales at which LEK is collected may be more consistent with the biology, ecology, and behavior of semi-nomadic species than traditional scientific studies. The capability of rigorously vetted surveys of species observations by local natural historians to produce accurate and reliable data should result in LEK being considered analogous to the "expert opinion" of formal wildlife managers that is oft applied to population modeling (Zabel et al. 2002; DeMatteo and Loiselle 2008). However, despite its potential to contribute to research and management, LEK is often viewed with heavy skepticism or outright dismissed by academics and practitioners due to the lack of structure in data collection and lack of formal training among data collectors (Gilchrist et al. 2005).

By collaborating with local natural historians, western scientists have boosted research productivity and efficiency, cut investigative costs, and can produce large enough sample sizes for hypothesis testing, all while supporting conservation and building capacity in local communities (Moller et al. 2004; Simons 2011). Inviting the participation of natural historians into the investigative processes may provide the additional benefit of addressing disconnects between research and implementation (Toomey 2016). Although this requires skillful facilitation, clear objectives from the outset, and a process that is underpinned by a philosophy that emphasizes empowerment, equity, trust and learning (Reed 2008), inviting resource users into the planning and investigative process only increases the chance that research findings will be applied locally in daily decision making, and build momentum towards shaping policy.

Bush Dogs in the Rupununi Region of Guyana

Bush dogs are an understudied canid of conservation concern. Their remote habitats, elusive and wide-ranging nature and naturally low population densities have made it difficult to understand and effectively manage this species. Guyana hosts an abundance of suitable bush dog habitat, but is one of only two countries (Suriname is the other) for which the status of this species has not been assessed (DeMatteo et al. 2011). Bush dogs were recently listed as 'Vulnerable' under Guyana's Wildlife Management and Conservation Regulations (EPA, 2009), but this status was adopted from an out-of-date IUCN RedList status and needs to be updated.

Bush dogs are known in Guyana from opportunistic encounters at Kaieteur National Park, the Iwokrama International Centre for Rainforest Conservation and Development, Timberhead (Barnett et al. 2001), Mabura Hill (ter Steege et al. 1996), and the Berbice and Corentyne Districts (Quelch 1901). Indirect evidence was reported in the Rewa Head (Pickles et al. 2011), while local experts confirmed the presence of this species during rapid assessments of the Kanuku Mountains Protected Area (Parker et al. 1993; Montambault & Missa 2002) and Konashen Community-owned Conservation Area (Alonso et al. 2008). Two wild-caught specimens from the Rupununi Region are held as museum specimens (Barnett et al. 2001; Engstrom & Lim 2002), and bush dogs were documented by camera-traps in the Kanuku Mountains Protected Area (Hallett et al. 2017).

In the Rupununi Region of Southwestern Guyana, bush dogs are known as *Ai* (Makushi), *Wechawar* (Wapishana), *Savanna Dog*, or *Short-tail dog* (Creole; NRDDB 2000). They are highly respected by indigenous people for their hunting skills and there is a long history of interactions with the people of the region. They are not targeted for hunting or trapping (NRDDB 2000), nor are they considered a high-conflict species (Hallett et al. 2015b), despite a reputation for depredating chickens elsewhere (Hunter 2011). With large tracts of intact forest

and savanna habitat, abundant prey, lack of direct hunting/trapping pressure, and little conflict with human communities, the Rupununi Region of Guyana should host healthy populations of this species. Lack of documentation of bush dogs indicates that either, (a) population densities are low; (b) research time and effort has been insufficient; or (c) new methods are needed to increase species detection and sample size.

While previous studies of bush dogs have incorporated surveys of conservation and law enforcement professionals (DeMatteo & Loiselle 2008; Fusco-Costa & Ingberman 2012), reports of opportunistic encounters from natural historians represent a wealth of data that has yet to be employed in the study of this species. This study documented 95 opportunistic encounters with bush dogs from across the Rupununi Region. These new records dramatically increase our understanding of bush dogs in Guyana, and represent an effective method that could be applied elsewhere for studying this, and other rare, elusive, and wide-ranging data-deficient species.

Methods

Study area

The Rupununi (Region 9), Guyana (Figure 3-1), is an ancient rift valley (Crawford et al. 1985), that supports a habitat mosaic of cerrado savanna, gallery and savanna forests, rivers, creeks, and seasonally flooded wetlands, bordered by large, undeveloped tracts of lowland and montane tropical deciduous and evergreen forests. While the forests of northern Guyana host a relatively high density of logging and mining concessions and the adjacent Rio Branco savanna to the west in Brazil has been largely degraded by large-scale agriculture and urban development, Rupununi forests remain unbroken, in pristine condition, and extend virtually uninhabited to the east and south towards Suriname and Brazil. Human settlements in the Rupununi consist of small-medium-sized villages (100-700 people) which contain ~20,000 people spread over 40+ villages (Bureau of Statistics, 2012). Communities are composed of

predominantly indigenous Makushi and Wapishana people, the majority of whom maintain traditional subsistence lifestyles.

Camera-trapping

Camera trap photos were obtained as part of a multi-species camera-trap study of the Rupununi Region, following well-established methods for camera trap research (Karanth & Nichols 1998). Camera traps (Bushnell Trophy Cam #119447C, #119734C, #119736C, and #119837C; Bushnell®, KS, USA) were set 2-3 km apart and 30-40 cm from the ground in proximity to observed signs of jaguars (*Panthera onca*) and their preferred prey. Cameras were active 24 h per day, with a 1-second delay between captures, recording the date and time with each 3-image sequence. We sampled 372 trap sites from May 2014 – May 2017 for a total of 62,010 trap nights. Study design was informed by habitat, proximity to resources, and trail type (Table 2-1; 2-2). Relative abundance index (RAI) was calculated by dividing the number of independent captures by the total number of traps night (then standardized for 100 trap nights).

Interviews of Natural Historians in the Rupununi

Rupununi residents who contributed observations of bush dogs were identified as 'natural historians' – a cross-disciplinary and multi-scaled term describing those who observe species and describe their interactions with each other and the environment (Tewksbury et al. 2014). Our use of this term is meant to convey respect for local ecological knowledge and to those who have earned and knowingly contributed it to this project. The term 'natural historian' also accurately represents our application-focused objectives, as natural history has played a critical role in the conservation and responsible management of species and places of interest, while serving as an important means for connecting science and society (Tewksbury et al. 2014).

Survey sites and natural historians (NHs) were identified through a snowball sampling approach (Biernacki & Waldorf 1981). We visited villages where bush dog sightings were

locally known and identified individuals who were respected for their subsistence hunting, fishing, or farming expertise. Those who confirmed first-hand encounters were asked to provide informed consent to share their knowledge, and to share any other known locations of bush dog encounters and the names of potential contributors. Interviews were conducted in each village until known leads were exhausted.

Natural historians were screened based on their abilities to differentiate bush dogs from other canids found in the region (Appendix C). Each was asked to identify the animal in question by name and to describe its physical characteristics. Encounters were only considered valid if the animal(s) in question were described as having some variation of the following attributes: small canid with pale brown, tawny yellow or dark brown coat, characteristic stocky build and combination of broad (bear-like) head, small eyes, short muzzle, short rounded ears, short bushy tail, short legs, and/or relatively long body (Eisenberg 1989; Emmons 1997; Hunter 2011). The short tail is considered the key attribute for differentiating this species from other regional canids – *Canis familiaris* and *Cerdocyon thous*. Information was only included from NHs who were able to successfully differentiate bush dogs from biological sketches and photographs of similar species (Appendix D).

Once accounts were verified, opportunistic encounters were documented through semi-structured interviews (SSI; Dickman 2008). NHs were asked to provide information on when (date, season, time of day) and where (geographic or relative location) the encounter occurred and what they observed (how many animals, notable behaviors; Appendix E). They were encouraged to share anecdotal information and could stop the interview or refrain from answering questions at any time. Locations were taken from the nearest point to the location described using Garmin eTrex 20 handheld GPS units. Sightings were independently verified by

other parties present where possible. Complete descriptions of opportunistic encounters were compiled (Hallett et al. 2015b) and coded using key words in the data, with those containing insights on behavior, reproduction, habitat use, and threats prioritized (Appendix G).

Results

Camera-trapping

In total, 15 bush dogs (individual animals could not be identified) were captured on camera traps at six locations across the Rupununi (Figure 3-2). Bush dogs were photographed at cameras set near Surama, Karasabai, Shulinab, and Rewa Villages, as well as the Iwokrama International Centre for Rainforest Conservation and Development (IIC) and the Kanuku Mountains Protected Area (KMPA). Across the entire study area bush dogs showed a relative abundance of 0.01, with RAIs of 0.02, 0.03, 0.03, 0.02, 0.01, and 0.01 from Surama, Karasabai, Shulinab, Rewa, IIC, and KMPA respectively.

Interviews of Natural Historians

One hundred and three interviews with NHs claiming to have opportunistically encountered bush dogs were conducted, of which 95 were considered valid. Previously undocumented bush dog encounters were recorded from Paramakatoi, Surama, Rupertee, Toka, Aranaputa, Yakarinta, Apoteri, Rewa, Kaibaiku, Karasabai, Yupukari, Quatatta, Kwaimatta, Nappi, Katoka, Moco Moco, Quarrie, Parikwarnau, Shulinab, Meriwau, Potarinau, Sand Creek, Rupunau, Katoonarib, Maruranau and Awarunau Villages, Dubulay, Manari and Dadanawa Ranches, Demerara Timbers Limited and Bai Shan Lin logging concessions, state land along the Berbice, Rewa and Kwitaro Rivers and Kusad Mountain, the Iwokrama International Centre for Rainforest Conservation and Development, and the Kanuku Mountains Protected Area (Figure 3-1; 3-3). The general consensus among NHs was that bush dogs exist in the Rupununi, potentially

even in relatively high numbers for this species, but that they are rarely seen – even by those who have spent extensive amounts of time in forest and savanna.

According to NHs, bush dogs are diurnal, although a number of records also included descriptions of hearing their barks after dusk and before dawn as well. Mean observed pack size was 3.45 (mode = 4, range = 1-12 individuals). Several encounters described only a single animal or observations of only part of a pack. Behaviors observed included (from most to least often reported) running in single file, vocalizing (barking), pursuing prey, crossing roads, searching / smelling along the ground, resting (laying down), interacting with other members of the pack, and interacting with offspring. Interactions between members of packs included 'playful' barking and growling with tails wagging. Mean litter size in encounters where pups were observed together was 3.3, but single pups were also observed. Bush dogs were observed hunting *Cuniculus paca* most frequently, followed by *Dasyprocta leporina*, *Mazama americana*, *Mazama nemorivaga*, *Pecari tajacu*, *Tupinambis teguixin*, and *Sus scofra*. Six successful kills were observed.

Encounters occurred in a variety of habitat types, with the majority occurring in lowland forest followed by upland forest, savanna, bush islands, and gallery forest. With regard to land use, encounters occurred within (from most of least often reported) indigenous titled lands, protected areas, private ranches, state-owned land, and logging and mining concessions. In terms of key resources, encounters occurred most often along rivers, creeks and ponds, followed by along forest edges, within traditional hunting grounds, near traditional farming sites, along the foot of mountains, and within tourism areas. Observed threats to bush dog populations included wild-caught individuals kept locally as pets, legal possession by commercial pet traders, disappearances following human disturbance, disease transfers from domestic animals, road

strikes, and individuals killed for sport by hunters. The number and frequency of observations of each behavior, prey species, habitat types, land use, key resources in proximity, and threats can be found in Table 3-3.

Discussion

Bush dogs are notoriously difficult to study in the wild. Active and passive captures of this species have been sparse and first-hand observations by university-trained scientists in the field have resulted in few published accounts. While documentation of bush dogs from camera traps is important, the documentation of opportunistic encounters by local informants may serve as a critical tool for filling the knowledge gaps currently plaguing the management of this species.

Predatory Behavior

Hunting behavior was described similarly in all accounts, with bush dogs following closely behind their potential prey in a single file, all individuals having their ears down, tails either straight up or wagging side to side, and barking intently. In the Rupununi, bush dogs are named (*Ai* – pronounced 'I-yee') for their high-pitched, yapping vocalizations and most NH's reported hearing them long before the animals came into view. Hunting packs were always described with the largest individual in front and smaller animals towards the back.

Bush dogs are revered in the Rupununi for their hunting prowess. They are believed to have extraordinarily high success rates, typically attributed to stamina and sheer determination. Hunts were described as bush dogs pursuing their target at a moderate pace for extended periods until their prey was eventually overtaken or collapsed due to extreme exhaustion. A powerful sense of smell allows bush dogs to follow their prey even when it is out of sight (Nilsson et al. 2014) and its high-pitched barks keep prey constantly in motion (B. Phillips pers. comm.). Pack

hunting strategies based on stamina instead of speed are not unusual in the genus canid (Bailey et al. 2013).

Descriptions of predatory events indicated a preference for *C. paca*, but a willingness to pursue a wide variety of prey. This supports existing literature on bush dog diets (Eisenberg 1989; Emmons 1997; Hunter 2011), but differs from a preference for *D. novemcinctus* documented in the Brazilian Pantanal (de Souza Lima et al. 2009; 2013). Interviews revealed unusual descriptions of predatory behavior such as bush dogs entering the underground den of *C. paca* and several accounts of overtaking prey in the water. Bush dogs are known to be comfortable underground and in the water, as they take up residence in abandoned burrows (Desbiez 2013) and are known to be strong swimmers (Hunter 2011).

Cooperative hunting strategies were hypothesized by NHs, as individuals were observed taking on different tasks in an effort to make a kill – the largest individuals were described as responsible for flushing and initial attacks, while smaller individuals wait and support subduing prey. Feeding behavior was described as frenzied and lacking distinct order, with all individuals simultaneously tearing away pieces of flesh. On two occasions, NHs intervened and opportunistically seized potential prey from bush dogs – an anecdote that may provide some insight on early inspirations for adopting wild and domesticated dogs to alleviate hunting effort.

Reproductive Behavior

Mean litter size documented here was 3.3, although four encounters included only a single pup. NH's speculated that these lone pups were part of a larger litter and were either abandoned or ventured too far away from den sites. Adult females were never encountered in the vicinity of lone pups. Bush dog reproduction has been described as aseasonal, with birth peaks in the rainy season, average gestation of 67 days, and litter sizes typically ranging from 3-6 pups but reaching up to 10 (Hunter 2011).

Of the three litters observed by NHs, each was guarded by a single female who growled and displayed her teeth when approached. Den sites of these observed litters included a hollow trunk of a fallen tree (D. DeFreitas pers. obs.), a cavity formed between rocks along a creek (K. Davis pers. comm.), and an abandoned burrow most likely excavated by *Priodontes maximus* – an observation documented previously (Desbiez 2013). In this case, the female was moving three very young pups from a burrow that was beginning to flood following a heavy rain. Females physically carried small pups, holding them in their teeth by the scruff of the neck (L. Campion pers. comm.). Den sites and maternal care have rarely been observed in the wild in this species.

Habitat Use

Bush dogs are known to use a wide variety of habitats, as verified by camera-trap captures and opportunistic encounters were recorded in savanna, bush islands, gallery forest, lowland forest, and montane forest. More of the opportunistic encounters were observed by NHs in some form of forested habitat (80%) than savanna (19%), and encounters that did occur in savanna were most often closely associated with forest edges or large forest fragments. De Souza-Lima et al. (2012) found that bush dogs used savanna habitats more than expected based on availability in similar habitat in the Pantanal. While bush dogs certainly use savanna habitat in the Rupununi, NH's speculated that use is most likely limited to dispersal between forested areas or in pursuit of prey.

Within habitat types, bush dogs were often associated with water (rivers, creeks and ponds), near habitat edges, or along the foot of mountains. The bush dog's highly carnivorous nature likely results in movement patterns dictated by the presence of prey (de Souza-Lima et al. 2012). Camera-trap data from this study indicates that sites with these attributes showed higher diversity and relative abundance of both predators and prey than other sites (pers. obs.).

Cuniculus paca are also known to favor areas near water (Michalski & Norris 2011), but our sample was also likely biased towards areas that people favor for subsistence activities. In the future, quantifying sampling efforts of NHs (in the form of time spent in the forest) may allow for more detailed habitat use analyses.

Many observations occurred within or near to areas of relatively low or intermittent human activity (traditional hunting grounds, rotational farming areas, tourism areas, logging concessions employing selective logging), suggesting some tolerance for human activity. While bush dogs were frequently observed in proximity to roads or trails, they were never observed using them to travel or hunt (they were always observed crossing perpendicular to the road). Only individuals being kept in captivity were observed in close association with villages or commercial activity.

Perceived and Observed Threats to Bush Dogs in the Rupununi

Collecting data from natural historians provides unique access to information on site specific threats to populations of species of interest that are generally not present in the quantitative datasets of scientific research. In this study, NHs identified local threats facing bush dog populations. While they closely match the range-wide issues threatening bush dogs (DeMatteo et al. 2011), the drivers and unique conditions described by NHs provide critical region-specific details necessary for developing effective management interventions.

Pet trade

Seven encounters included descriptions of bush dogs that were captured and kept as pets locally (Figure 3-3). Before the arrival of the domestic dog with the Spanish and Portuguese, bush dogs were kept as hunting dogs by the ancestors of current residents (L. Haynes pers. comm.). Stories of their legendary hunting abilities are common and often connected to the

mythical *tamona* – forest spirits that are believed to live in the high forest and usually described as the masters of animals, responsible for their proliferation and movements (Daly 2015).

Traditional beliefs dictate that not only are bush dogs very successful hunters, but also that temporarily capturing a bush dog, drawing blood from its nose, and smearing the blood on the nose of a domestic dog will transform that dog into a skilled hunter (L. Haynes pers. comm.). For those who maintain this belief, the opportunistic encounter of bush dogs, especially pups, may present an opportunity to increase hunting success. Keeping wild animals as pets is a common practice in Makushi and Wapichan cultures, with animals living in loose association with a family homestead – untethered and largely responsible for their own care (R. Roberts pers. comm.). Wild pets are often young 'orphaned' individuals that people bring into the village to raise into adulthood before the animals return to their natural habitat on their own (S. James pers. obs.). All bush dogs kept in local captivity were found as pups and raised alongside domestic dogs, with few surviving into adulthood (D. DeFreitas pers. obs.).

Bush dogs are considered personal pets of the *tamona*, and it is a widely held belief that *tamona* will punish those who harass or needlessly kill animals that they favor (A. Jackman pers. comm.). Reverence or fear of *tamona* was cited by a number of NHs as a key deterrent to harassing, killing or capturing bush dogs, while others were able to overcome this belief. While the contemporary desire to capture and keep bush dogs may be partially driven by fascination created by traditional stories of their skill at hunting wild game, the erosion of traditional taboos associated with exposure to western religion (Luzar et al. 2012) and global popular culture (Freeland 1996) may also be reducing the perceived consequences that prevented these behaviors in the past. Keeping bush dogs as pets in the Rupununi is uncommon – a practice that is

opportunistic in nature and may be driven by curiosity, as well as the erosion of traditional belief systems.

Three NHs also observed wild-caught bush dogs in the custody of international pet traders. Bush dogs were only recently protected in Guyana under the Wildlife Management and Conservation Regulations (EPA, 2009), but international trade of this species has been regulated under Appendix I of CITES since 1977. Guyana is home to a thriving legal pet trade (M. Pierre pers. obs.), but a lack of resources and capacity for enforcement also allows for illegal trade to occur. It is unclear where or to whom these individuals were destined to be sold, or what drives a market for captive bush dogs, but any formal trade in this naturally rare species is a concern.

Disease transfer from domestic canids and livestock

According to NHs, disease transfer from domestic canids was speculated to have resulted in the deaths of wild-caught individuals in captivity. An individual kept in close association with domestic canids in Rupertee Village suffered from loss of hair (in patches) and body mass preceding death, suggesting that it contracted mange (S. Andries pers. comm.). Another NH who cared for three bush dog pups after they were given to Dadanawa Ranch by a local hunter believed that they died from the bacterial disease *Leptospira* sp. (D. DeFreitas pers. obs.). As a rancher, the NH is familiar with the signs and symptoms of this disease in cattle and domestic dogs (vomiting, lethargy, loss of appetite, jaundice). Bush dogs held in captivity around domestic dogs or livestock are especially at risk of contracting diseases, but free-roaming domestic canids also form a potential vector for disease transfer to wild bush dogs.

Bush dogs are highly susceptible to diseases such as mange, leishmaniasis, parvovirus, rabies, and canine distemper, and to parasites such as *Dioctophyma renale*, *Amphimerus interruptus*, *Lagochilascaris* spp., *Spirocerca lupi*, *Toxoplasma gondii* and *Echinococcus vogeli* (DeMatteo et al. 2008, Jorge et al. 2011) – many of which can be attributed to exposure to

domestic canids. Viruses, diseases, and parasites spread quickly, killing entire packs of this highly social canid (Mann et al. 1980; DeMatteo, 2008). Domestic canids in the Rupununi live in loose association with people and are primarily used for hunting. Local dogs often form packs that hunt and scavenge independently, the vast majority of which are unvaccinated (F. Li pers. comm.). The potential for interaction between feral domestic dogs and bush dogs outside of villages in adjacent forests and savannas (packs of feral domestic dogs were observed on camera traps in this study) extends the threat of disease transfer to wild bush dog populations.

Direct and indirect impacts of roads

Bush dogs were observed crossing roads in 20% of encounters in this study. Roads can serve as both an indirect (fragment habitat, provide access to hunters/trappers) and direct (road strikes) threats to wildlife (Fahrig & Rytwinski 2009). Seven of the encounters on roads occurred along the Georgetown-Lethem highway, which serves as the primary means for transportation and commerce for the country's interior. This road is unpaved, but has been successively improved over time by annual grading, permitting increasingly higher speeds and vehicle densities. A recent environmental impact assessment of this road found a relatively low occurrence of road strikes on medium and large mammals (E. Paemelaere pers. comm.); however, two NHs reported observing bush dog road kills (including a pup).

Current plans to pave the GT-Lethem highway would dramatically increase speed and density of traffic, as well as noise, potentially leading to an increase in road strikes and further disrupting existing habitat along the roadway. Even infrequent direct mortality events from road strikes disproportionately impacts naturally rare species. Increased noise and traffic could also functionally fragment habitat leading to decreased genetic diversity at the metapopulation level (Barber et al. 2010). This is especially a concern in the Rupununi, as the GT-Lethem highway runs directly through the heart of the country's second largest protected area (Iwokrama).

NHs related nine additional descriptions of road crossings on two-track roads from the GT-Lethem highway to villages and from villages to traditional farming grounds. These roads are typically in very rough condition, supporting only low speed and vehicle density. These factors reduce the probability of collisions with wildlife; however, several NHs indicated that encounters of this species decreased following the expansion and improvement of two-track roads used by tractors to accommodate a wider range of vehicles and increase the efficiency of resource extraction (e.g. timber, agricultural products). NHs hypothesized that these secondary effects (e.g. noise associated with road construction and resource extraction, increased traffic and access provided to hunters, farmers and fisherman) were ultimately responsible for bush dogs either dispersing away from the area or shifting behavior to avoid encounters with people on these newly expanded roads.

Loss of habitat

Expansion of large-scale agriculture and inappropriate fire management serve as the greatest threats to wildlife inhabiting the cerrado savanna habitat mosaic of the Rupununi lowlands. While savanna is not prime bush dog habitat, are known to use it more than expected (DeMatteo et al. 2014), with NHs speculating that the Rupununi savannas occasionally facilitate dispersal and hunting activity. Growing interest in the development of the Rupununi as Guyana's 'agricultural frontier' threatens one of the largest intact stretches of cerrado savanna habitat (the continent's most threatened and least protected habitat type; Klink & Machado 2005; Durigan et al. 2007), as well as the forest fragments and forested corridors that maintain connectivity between intact forested areas across Guyana, Suriname, Brazil, and Venezuela. NHs indicate that growing demand for construction materials from existing large-scale agriculture operations has driven an increase in small-scale commercial logging in savanna

forests (H. Barnabas pers. comm.) – habitats that are naturally limited in diversity and biomass of timber trees.

More frequent catastrophic savanna fires were described as threats to transitional forests between forest and savanna and forest fragments, converting forest edges to savanna and primary to secondary forest. Indigenous people have been mimicking the natural regenerative properties of fire in the Rupununi savanna for centuries. However, loss of local knowledge and the interruption of predictable seasonal weather patterns by a changing climate have resulted in the increased frequency and intensity of savanna fires (N. Fredericks pers. comm.). NHs in Rupertee and Moco Moco village reported the disappearance of bush dogs following catastrophic fires that occurred in the 1980s (A. Primus pers. comm.), but more recent reports of opportunistic encounters at these locations indicate that they may have returned after forests recovered (L. Aldie pers. comm.).

Bush dogs are most frequently associated with large tracts of intact forest habitat, an asset which Guyana currently possesses, with >75% of its total land area in forest (GFC 2013). The annual deforestation rate in Guyana is relatively low, with a mean of 0.04% (range = 0.02% - 0.08%; 1990-2013), compared to a global mean of 0.52% (GFC 2012). Relatively strict regulations of the Guyana Forestry Commission (GFC) and naturally slow-growing Guiana Shield forests that support a limited number of commercially-viable species have resulted in selective logging as the most common strategy for timber extraction in Guyana. The majority of current deforestation is driven by mining activities in the country's north and northwest (GFC 2012). However, large, controversial logging concessions east of the Berbice and Rewa rivers indicate increasing pressure to exploit Rupununi resources, ultimately threatening habitat for bush dogs and other wildlife.

Conclusion

Indigenous ecological knowledge is applicable to many aspects of scientific study, but is especially valuable in cases where species are rare or elusive. A lifetime of experience in the local environment makes local natural historians trained observers, and partnerships with communities and land owners in regions where bush dogs are known to exist may help researchers unlock the secrets of this species while creating incentives to support conservation. Camera-trap captures presented here provide additional evidence of bush dogs in the wild in Guyana, but the rich dataset derived from semi-structured interviews with local natural historians provides key insights into the biology, ecology, and conservation of bush dogs that may inform the management of this little known species.

Table 3-1. Location, year, number of trap stations, number of trap nights, and number of bush dog encounters from previous camera trap studies conducted in Guyana, studies conducted by the author in bold

Site	Author	Year	Trap stations	Trap Nights	BD occ.
Eastern Kanuku Mountains, lower Kwitaro River	J. Sanderson & L. Ignacio	2002	16	160	0
Konashen Community-owned Conservation Area	J. Sanderson, E. Alexander, V. Antone, C. Yukuma	2008	20	62	0
Rewa River	R. Pickles, N. McCann, A. Holland	2011	12	218	0
Iwokrama International Centre for Rainforest Conservation & Development	A. Roopsind, T, Caughlin, H. Sambhu, J. Fragoso, J. Putz	2011	52	1,613	0
Karanambu Ranch	E. Paemelaere, E. Payan, D. McTurk	2012	67	1,972	0
Dadanawa Ranch	E. Paemelaere, E. Payan, D. DeFreitas	2013	43	1,466	0
Variety Woods & Greenheart Ltd. Charabaru Concession	E. Paemelaere	2013	36	1,593	0
Kanuku Mountains Region	M. Hallett, A. Holland, A. Roberts, M. David, A. Jackman	2013	115	4,059	2
Upper Berbice River	M. Pierre, L. Ignacio, D. Torres, E. Torres, E. Paemelaere	2014	32	1,411	0
Chenapau Village	E. Paemelaere, N. Carter, F. Carter, R. Williams	2014	41	1,204	0
South Rupununi Savanna – Kusad Mtn. & Parabara Village	E. Paemelaere, D. Fernandes, L. Ignacio, A. Johnny	2014	39	1,295	0
Apoteri Village	E. Paemelaere	2015	21	1,040	0
Bai-Shan Lin Concession	E. Paemelaere	2015	35	1,358	0
Mining District 2 Frenchman Site	J. Liddell	2016	23	151	0

Table 3-1. Continued

Demerera Timbers Limited Siparuni Concession	M. Pierre, E. Paemelaere, E. Payan	2016	33	1,236	0
Landscape-scale Study of the Rupununi Region	M. Hallett et al. (this study)	2014-2017	372	62,010	6

Table 3-2. Author, location, number of trap nights, number of occasions, and relative abundance (RAI) of bush dogs from previous camera-trap studies

Author	Study Location	# of trap nights	# of occasions	RAI
Beisiegel (2009)	São Paulo, Brazil	4,818	1	0.021
Bianchi (2009)	Mato Grosso do Sul, Brazil	2,238	1	0.045
Michalski (2010)	Alta Floresta, Brazil	6,721	2	0.030
Negrões et al. (2011)	Tocantins, Brazil	7,929	1	0.013
Bergallo et al. (2012)	Pará, Brazil	3,572	3	0.084
Fusco-Costa & Ingberman (2013)	Paraná, Brazil	4,112	3	0.073
Rocha et al. (2015)	Amazonas, Brazil	4,894	3	0.061
Ferreira et al. (2015)	Minas Gerais, Brazil	6,000	1	0.017
Meyer et al. (2015)	Panama	31,755	8	0.025
De Oliveira et al. (2016)	Brazilian Amazon	15,888	7	0.044
Hallett et al. (2017)	Kanuku Mountains, Guyana	4,059	2	0.049

Table 3-3. Distribution of opportunistic encounters of bush dogs by key variable

Variable	Number of Accounts	Percentage of Total
Behavior		
Running in single file	61	64%
Vocalizing	55	59%
Hunting	27	28%
Crossing road	20	21%
Wandering/smelling	10	11%
Resting	4	4%
Sleeping in den	3	3%
Playful interaction	2	2%
Female with pups	2	2%
Prey Species		
Cuniculus paca	18	67%
Dasyprocta leporina	3	11%
Mazama americana	2	7%
Mazama nemorivaga	1	4%
Pecari tajacu	1	4%
Tupinambis teguixin	1	4%
Sus scofra	1	4%
Habitat Type		
Lowland forest	44	46%
Upland/montane forest	21	22%
Savanna	17	18%
Bush island	8	8%
Gallery forest	5	5%
Land Use		
Indigenous Lands	65	68%
Protected Area	16	17%
Private Ranch	6	6%
State-owned Land	3	3%
Logging Concession	3	3%
Mining Concession	2	2%
Proximity to Key Resources		
Near river / creek / pond	44	24%
Near forest edge	43	23%
Traditional hunting grounds	40	22%
Near traditional farming area	31	17%
Along mountain foot	17	9%
Tourism area	8	4%
Threats		
Pet trade	10	48%
Human disturbance	6	29%
Road strike	2	10%
Disease	2	10%
Individual killed by hunter	1	5%

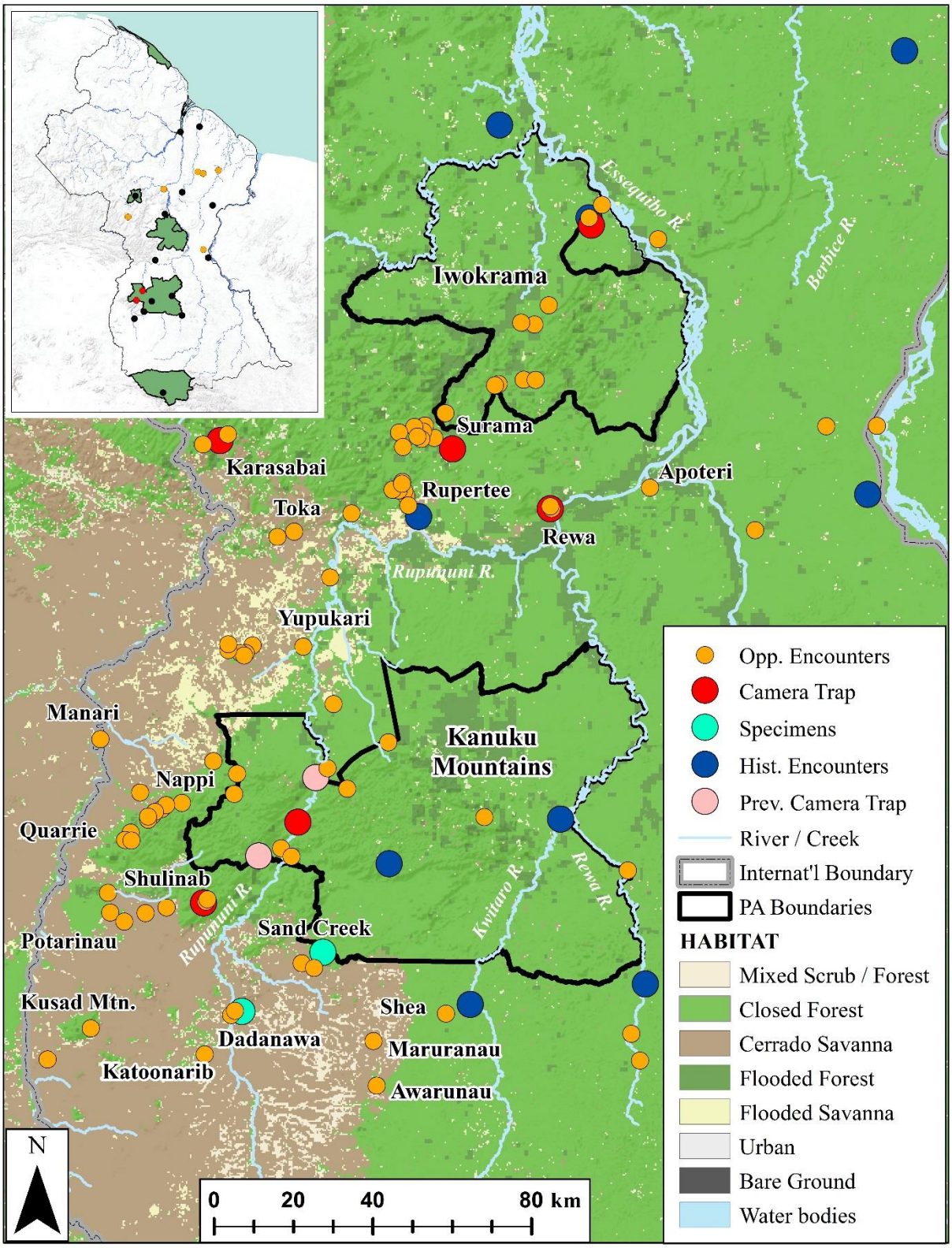

Figure 3-1. Distribution of opportunistic encounters of bush dogs in the Rupununi (ESRI 2016)

Figure 3-2. New records of bush dogs in the Rupununi Region from camera-traps (photos courtesy of Matt Hallett)

Figure 3-3. Opportunistic photographic records from the Rupununi (photos, clockwise from top right, courtesy of Meshach Pierre, Duane DeFreitas, Meshach Pierre and Ronan McDermott)

CHAPTER 4
DEVELOPING A ROBUST METHODOLOGY FOR IDENTIFYING INDIVIDUAL GIANT ANTEATERS (*MYRMECOPHAGA TRIDACTYLA*) WITH IMPLICATIONS FOR POPULATION ESTIMATION

Introduction

The giant anteater (*Myrmecophaga tridactyla*) is a large, charismatic species whose unique behavioral and physical characteristics make it a readily recognizable flagship species for Neotropical forest and savanna habitats. Despite widespread interest in its biology, ecology, and conservation, relatively little is known about this species (Bertassoni et al. 2017). Most studies on giant anteaters have focused on feeding ecology and thermoregulation, with a few studies of radio or GPS-collared individuals providing insights into home-range size and habitat use. Giant anteaters are a naturally rare species that ranges widely feeding on abundant and readily available prey – traits that have limited our understanding of their population ecology and hindering the conservation and management of this species.

The Giant Anteater

The giant anteater ranges from Nicaragua to northern Argentina, inhabiting upland and lowland tropical moist and dry forest, savanna and open grassland habitats (Eisenberg 1989). Although giant anteater populations are estimated to have decreased by >30% across their range (Miranda et al. 2014), reliable data are unavailable to determine true population densities and trends. Road strikes, uncontrolled fires, overhunting, and loss of habitat are primary threats, and have resulted in reported extirpations from Belize, Guatemala, El Salvador, and Uruguay, as well as the states of Santa Catarina, Rio de Janeiro, and Espírito Santo in Brazil (Miranda et al. 2014). Naturally low population densities, low reproductive rates, and long parental care make anteater populations vulnerable to, and ill-equipped to recover from, population declines (Rodrigues et al.

2008). As a result, they have been listed as 'Vulnerable' by the IUCN RedList of Threatened Species and under Appendix II of CITES (Miranda et al. 2014).

Feeding ecology

Giant anteaters are highly specialized predators that feed solely on ants and termites. The distribution, shape, and size of an individual's home range are highly dependent on resource availability and the state of the specific conditions in which it resides (Di Blanco et al. 2016). They fulfill their energetic and nutritional needs by selectively feeding in short bursts spread across many foraging locations with prey preference determined by the type of defense and nutritional values of potential prey (Redford 1985). A large-bodied, true mammalian myrmecophage, this species' dependence on an energetically poor diet (Redford & Dorea 1984) results in a relatively slow metabolism, and need for consistent access to an abundance of food resources (Medri et al. 2003). While ants and termites are certainly abundant in the Neotropics, an individual giant anteater may need to eat >30,000 ants and termites each day to meet its needs (Dinerstein 2013). Securing this abundance of food resources requires individual anteaters to forage over large areas for their survival.

The area that an individual animal occupies is determined by the availability of resources in that space – individuals in resource-poor areas must forage more widely than those inhabiting resource-rich regions (Schoener 1974). Home ranges (minimum convex polygons) from studies of radio and GPS-collared anteaters have varied from 0.8 – 13.5 km^2 (Miranda 2004; Di Blanco et al. 2015). Female anteaters maintain larger home ranges with more overlap (Silveira 1969; Medri & Mourão 2005; Bertassoni et al. 2017) because their distribution is thought to be determined solely by resource availability (Powell 2000), while male home ranges are largely determined by the distribution of available females (Shaw et al. 1987) because of high intraspecific competition (Braga et al. 2010). Remaining variation in home-range size may be

explained by site variation in habitat quality and resource availability, as well as the distribution of key habitat features, such as distance to foraging and resting sites (Bertassoni et al. 2017).

Habitat use

The largest anteater in the world, this species tolerates a wide range of habitats, but is found in greater association with dry, open habitats, which provide an abundance of ground-level food resources easily accessible to this species (Quiroga et al. 2016). Giant anteaters are thought to exist at the highest densities in the savannas of Brazil, Guyana, Venezuela, and Colombia (Eisenberg 1989), regions that also support highest densities of termite and ant colonies on well-drained soils (Redford 1985). Neotropical savanna and shrub habitats are not homogenous, supporting a habitat mosaic with variation in their scrub and canopy layers driven by gradients of elevation, soil moisture and nutrients (Toby-Pennington et al. 2000). These heterogeneous habitats provide giant anteaters with optimal foraging opportunities in proximity to forest edges or forested patches – refuges with sufficient cover to hide from predators, rest, and find shelter from extreme temperatures (Camilo-Alves and Mourão 2006; Mourão and Medri 2007; Desbiez and Medri 2010; Bertassoni et al. 2017; Di Blanco et al. 2017).

Forested areas may serve as particularly important refuges for this species, as their ability to thermoregulate is compromised if they are forced to rest in open habitats, making them increasingly vulnerable to predators (Camilo-Alves & Mourão 2006; Mourão and Medri 2007; Di Blanco et al. 2017). Indeed, this species, a capable swimmer, will enter water to cool its body temperature (Camilo-Alves and Mourão 2006), but primarily seeks shade in which to rest. Jaguars (*Panthera onca*) are the primary predator of adult anteaters (Silveira 2004), although anteaters make up a very small percentage of their overall diet (Cavalcanti & Gese 2010). Jaguars inhabiting semi-arid habitats – like the Caatinga, Chaco and Cerrado – reportedly prey

on giant anteaters more frequently, seemingly because of lower densities of preferred prey species (Silveira, 2004; Astete et al., 2008; Rodrigues et al., 2008; Mc Bride et al., 2010).

Cerrado savannas are the second largest ecoregion in the Neotropics (Mittermeier et al. 2005), but are also the most threatened by anthropogenic activities (Klink & Machado 2005), and the least protected (Durigan et al. 2007). Neotropical savanna habitats appear to be of particular importance to anteater conservation and management because of the unique combination of resources that they support. However, a lack of data has hindered support for prioritizing savanna habitat to support anteater conservation. Anteater abundance and population trends have never been estimated from empirical data; in part because scientists have been unable to reliable identify individual animals.

Traditional Beliefs and Anteater ID in the Rupununi

Traditional beliefs in the Rupununi region of Guyana hold that deceased acquaintances or family members who were wronged in some way before their death may take the form of the giant anteater in order to take revenge in the afterlife (L. Daly pers. comm.). Local folklore also maintains that *canaimas*, or evil spirits that may kill or physically harm people, may also take the form of the giant anteater (as opposed to its typical form as a jaguar) in an effort to fool people into a sense of complacency before attacking (G. Pereira pers. comm.). Rupununi villagers generally keep a watchful eye out for repeat visits to the area around a village by the same individual anteater (Ra. Roberts pers. comm.). As result, anteaters in close proximity to people are periodically shot (J. George pers. comm.) because they are considered a bad omen and even a threat to human life and/or property. The identification of individual anteaters by their physical attributes is a skill that is developed informally and independently through a diverse set of strategies and approaches for differentiating individuals.

Realizing that guests responded positively to stories about individual animals, guides at Karanambu Ranch applied this informal method to identifying and naming anteaters that they would repeatedly encounter during Karanambu's 'anteater safaris.' Guides make mental notes about where individuals are generally found, reproductive history of females, and any associations observed with other known individuals to help their guests connect to local wildlife and ultimately enrich their experience. Karanambu is renowned in Guyana for anteater sightings and as a result of the frequency of observation, their guides have become local anteater experts. The goal of this paper is the collaborative development of a formal method for anteater identification that brings together the process that Karanambu guides have developed for identifying individual anteaters over time with new technology for visual identification that allows this process to be standardized and replicated elsewhere.

Visual Identification of Individual Animals

Photographs represent a powerful source of data, in that they provide definitive confirmation of a species of interest at a given time and place. Increased access to inexpensive, high-quality digital cameras has created the potential for an enormous influx of data on species occurrences collected by a wide variety of actors with all levels of training and experience (Crall et al. 2013). Additionally, many species have natural markings (stripes, spots, rosettes) that are individual-specific, allowing for identification of individual animals (Karanth 1995; Arzoumanian et al. 2005; Gamble et al. 2008). The ability to recognize individual animals is a powerful tool that allows researchers to estimate population size and density, fitness, vital rates, activity patterns, inter and intra-species interactions, and life history (Bolger et al. 2012).

However, visually matching individuals is inefficient and impractical (Matthé et al. 2017), making the direct application of informal identification methods developed by practitioners inappropriate for dealing with large photo databases. Recent developments in

photo-matching algorithms have dramatically increased the accuracy and efficiency of the photo-matching process (Bolger et al. 2012). The visual identification software *HotSpotter* has successfully identified unique spot patterns in zebra (*Equus grevyi*; *E. quagga*), giraffe (*Giraffa camelopardalis reticulata*), and lionfish (*Pterois volitans*; Crall et al., 2013), Wyoming toad (*Anaxyrus baxteri*; Morrison et al. 2016), and Saimaa ringed seal (*Phoca hispida saimensis*; Zhelezniakov et al. 2015) with greater matching success than their visual ID programs using similar algorithms (Crall et al. 2013; Morrison et al. 2016).

Giant anteaters are conspicuously marked – they have a long, fan-like tail, light-colored legs that contrast with a dark-colored body, and a bold black stripe that is bordered on either side by a contrasting white stripe and extends down the midline of their flanks from throat to shoulder (Eisenberg 1989). Despite being one of the most charismatic species in the Neotropics, and one whose populations are declining and whose management has been hampered by a lack of data, individual identification using natural markings has never been formally attempted with giant anteaters. Experienced professionals from both the zoological (P. Riger pers. comm.) and eco-tourism (M. Roberts pers. comm.) fields have been informally recognizing individual anteaters for decades – typically by identifying a single characteristic trait of each individual that they repeatedly come into contact with within small populations. This paper recognizes and expands on this local expertise, to develop a formal, replicable method for identifying individuals of this species.

While previous research has provided insights into some aspects of the biology and behavioral ecology of this species, their population ecology, demographics, and distribution are still unknown. Giant anteaters are a large, conspicuous mammal that can be observed regularly in a variety of Neotropical habitats. Whether first person observations or camera-trap images,

anteater records are being accumulated across the tropics, but robust analysis of these data has not been possible to date because of their current status as an 'unmarked' species – lacking individually identifiable markings. We present a robust method for identifying individual giant anteaters, with implications for capture-recapture methodology for population estimation.

Methods

Study area

Karanambu Ranch is located in the North Rupununi savannas (Region 9 - Upper Takutu Upper Essequibo) of southwestern Guyana (Figure 4-1). The 324 km^2 privately-owned ranch, located on the western bank of the Rupununi River, was founded by the McTurk family as an outpost for the balata (natural rubber) trade in the early 1920s before shifting to a combination of cattle rearing and eco-tourism. The ranch sits within an 800,000-ha wetland complex composed of freshwater floodplains, seasonally inundated savannas, and fragments of savanna woodland connecting the Rio Branco and Essequibo watersheds that are bordered by large, unbroken tracts of pristine tropical forest in the Pakaraima and Kanuku mountains and Iwokrama forest (Mistry & Roopsind 2004).

Karanambu Ranch lands consist primarily of cerrado savanna habitat. Savanna vegetation consists largely of perennial grasses from the genus *Andropogon*, *Mesosetum*, *Paspalum* and *Trachypogon*, and a shrub layer dominated by the cayembe tree (*Curatella americana*; Shackley 1998). Shrub density varies based on soil moisture, nutrients, and history of fire, with hilltops covered by forest fragments, depressions with flooded savannas, and the boundaries of rivers, creeks, and ponds flanked by riparian forest.

Approximately 100 people reside at Karanambu Ranch on a full or part-time basis. Most reside in nearby Yupukari, Kwaimatta, and Masara villages, and are employed in eco-tourism, scientific research, wildlife conservation / management, hospitality, or livestock management

(McTurk & Spellman 2005). Karanambu maintains a herd of ~250 cattle (Dadanawa breed), and ~30 working horses (A. Holland pers. comm.).

Anteater Surveys

Images of giant anteaters were collected through three separate methods in order to test a formalized approach for identifying individual giant anteaters: (1) photos of individuals with known identifications housed in the collections of institutions accredited by the Association of Zoos & Aquariums; (2) photos from opportunistic encounters during anteater tours conducted at Karanambu Ranch, Guyana; and (3) camera-trap photos from a survey of Karanambu Ranch and neighboring Yupukari Village, Guyana.

Reference photos from AZA institutions

Photographs of captive giant anteaters residing at Association of Zoos & Aquariums (AZA) accredited zoos were obtained through the Pangolin, Aardvark & Xenarthra Taxon Advisory Group (PAX TAG) and Giant Anteater Species Survival Plan (Anteater SSP). Program leader, Stacey Belhumeur of Reid Park Zoo (Tucson, AZ), contacted staff at institutions housing giant anteaters to request photographs and information on the sex, breeding, and life history of animals in their collection. Institutions were notified that photographs provided would serve as known individuals in construction of a reference library that would aid in the development of a method for identifying individuals in a wild population.

Profile photographs (both left and right flank) of 32 individual giant anteaters (18 male, 14 female) were provided by 19 AZA accredited institutions (Appendix G) – Brevard Zoo (Melbourne, FL), Brookfield Zoo (Chicago, IL), Buffalo Zoo (NY), Cleveland Metroparks Zoo (OH), Dallas Zoo (TX), Fresno Chaffee Zoo (CA), Greensboro Science Center (SC), Houston Zoo (TX), Jacksonville Zoo (FL), Palm Beach Zoo (FL), Phoenix Zoo (AZ), Potawatomi Zoo (South Bend, IN), Reid Park Zoo (Tucson, AZ), Sacramento Zoo (CA), San Antonio Zoo (TX),

Sedgewick County Zoo (Wichita, KS), Sunset Zoo (Manhattan, KS), Turtle Back Zoo (West Orange, NJ), and Zoo Boise (ID). These images served as the reference library for training the algorithm in program *HotSpotter* in preparation for identifying individual animals in the wild population at Karanambu Ranch (Figure 4-2).

Opportunistic observations

From 2011 – 2016 giant anteaters encountered during anteater safaris were documented by Gerard Pereira, manager of the Karanambu Trust – the research and conservation arm of the ranch. Trust staff accompanies guides and tourists during this activity to provide additional information on natural history, indigenous culture, and resource management / conservation on the ranch. As part of a collaboration with the lead author that began in 2011, trust staff began to collect data on giant anteater encounters that occurred at the ranch. Photos and videos were taken of each animal along with the date, time, and GPS location (Garmin eTrex 20) of the encounter, as well as anecdotal data on behaviors observed, weather conditions, and description of sighting / locations. Multiple images from various angles were taken of each individual, with the goal of obtaining clear, unobstructed profile photos on each occasion.

Anteater safaris are a primary attraction offered by Karanambu Lodge, a certified tour operator and eco-tourism arm of Karanambu ranch. Guests are guided across Karanambu's open savannas in a 1940's Land Rover in search of giant anteaters and other wildlife. Anteater tours depart from Karanambu Lodge at 05:30, with guides in the vehicles with guests searching for anteaters along the ranch's two-track roads, while ranch vaqueros scan the areas in between on horseback. Vehicles drive slowly, while spotters search both sides of roads. Vaqueros conduct ad-hoc searches of the surrounding savanna, reducing their search area based on previous experience. Anteater tours typically last until ~09:00, when researchers and guests return for breakfast. The success rate of anteater sightings on safaris at Karanambu is ~95%. When giant

anteaters are spotted by lodge guides or ranch vaqueros, vehicles are maneuvered to put guests and researchers downwind – in the best position for prolonged encounters in proximity to the guests. In the case that the vehicles and vaqueros are some distance apart, vaqueros remain upwind at a safe distance, holding their position or walking slowly behind anteaters to direct them towards the tourists.

Care is taken by Karanambu staff to reduce stress on individual anteaters. Ideally, anteaters maintain natural behavior throughout an encounter, with only the scent and sound of human presence altering the direction of their movement. Vaqueros, guides, and guests remain quiet and chasing of anteaters is highly discouraged. Vaqueros and vehicles pull back immediately when a female with a pup is encountered.

Camera-trapping

Camera-trap photos were obtained as part of a multi-species camera-trap study of large mammals in the Rupununi Region, following well-established methods for camera trap research (Karanth & Nichols 1998; Silver 2004). Camera traps (Bushnell Trophy Cam #119447C, #119734C, #119736C, and #119837C; Bushnell®, KS, USA) were set 2-3 km apart and 30-40 cm from the ground with a single camera at each site set in proximity to observed signs of wildlife. Cameras were active 24 h per day, with a 1-second delay between captures, recording the date and time with each 3-image sequence. Due to the limited number of roads and trails, camera traps were distributed based on habitat, proximity to resources, and trail type. In total, 372 trap sites were surveyed from May 2014 – May 2017 for a total of 62,010 trap nights. Photographs utilized in this study were obtained from camera-traps set across 40 trap sites at Karanambu Ranch and Yupukari Village from June 2014 to March 2016 for a total of 7,747 trap nights (Figure 4-1).

Identification of individual anteaters

We used the visual identification program *HotSpotter* (Crall et al. 2013) to identify individual giant anteaters based on their stripe pattern. *HotSpotter* employs two algorithms, a 'one vs. one' that locates key points ("hot spots") and extracts associated 128-dimensional vector descriptors (Bolger et al. 2011), and a 'one vs. many' that identifies matching images based on a query of all descriptors available in an image database using an approximate nearest neighbor search data structure (Crall et al. 2013). Descriptor matches are scored using Local Naive Bayes Nearest Neighbor methods, an approach which simultaneously matches each descriptor in a query to its *k* nearest neighbors across all categories (McCann & Lowe 2011). *HotSpotter* queries provide ranked similarity scores, with higher scores implying more likely matches (Morrison et al. 2016).

Images were uploaded to a new database in *HotSpotter* for this project. Images of individuals with known identifications from AZA institutions were uploaded first to test *HotSpotter*'s success rate in identifying individual anteaters. *HotSpotter* requires that a rectangular region of interest (ROI) be identified for each image; we chose to focus on the horizontal stripe pattern that runs down each animal's side. Additional photos (2-3 for each animal) of AZA animals' left flanks were uploaded one at a time, ROIs identified, and queried for matches to determine the accuracy of *HotSpotter*'s matching algorithm. We repeated these steps with multiple images taken from different angles, under various lighting schemes, with various backgrounds, and with images of the right flanks of AZA animals. Queries on both the original (left flank) and mirror image of the right flank were run to determine if anteaters have identical markings on both flanks. Once a satisfactory success rate was achieved, these steps were repeated with images from camera traps and opportunistic encounters at Karanambu Ranch and Yupukari Village.

Results

The ability of program *HotSpotter* to successfully identify individual giant anteaters was tested from images of animals in the collection of AZA accredited institutions, camera-trap photos, and images taken during anteater tours at Karanambu Ranch, Guyana (Figure 4-2).

Reference Photos from AZA Institutions

Following the initial entry of 32 images of known individuals (one image of the left flank of each individual), *HotSpotter* correctly matched 93.8% (30/32) of images of the left flank of the same individual taken on a different occasion (different date/time, location within exhibit; Figure 4-3). Failed matches were caused by low-quality images (cell phone images with fewer pixels) and images with drastically different lighting (low angle morning or afternoon light). These initial matches showed very high similarity scores (>50,000), with a high density of hot spots.

Thirty-two additional images of the opposite flank of the same 32 known individuals were entered into the database in an effort to understand whether or not the giant anteater has matching flanks. The initial queries resulted in zero successful matches. However, mirror images of the opposite flank of the 32 known individuals resulted in successful matching of 84.4% (27/32) of images. These matches showed lower similarity scores (>5,000) than matches of images from the same flank, but similarity scores on matches between the left and right flank of the same individual ranked higher than similarity scores of the left flanks of different individuals (Figure 4-3).

Providing *HotSpotter* with additional images of the same individual only strengthened similarity scores and the ability of the program to successfully match images of the same individual, even increasing its ability to correctly identify images with different angles, lighting, and quality (Figure 4-3). Individual databases are classified under each animal's 'name'.

Camera-trap images

Camera-trap surveys of Karanambu Ranch and neighboring Yupukari Village resulted in 114 total photographs of giant anteaters, from 33 occasions, at 18 trap locations. Of the total sample of anteater photos, only 18 (16%) were useable for application to visual identification software. *Hotspotter* software successfully matched images of the same individual from a single sequence of images on 100% of queries, confirming the feasibility of the use of camera-trap images with visual ID software (Figure 4-4). There was only a single instance of a successful match of camera-trap photos taken of the same individual on two occasions (re-captured at a different location and time).

Variations in pose and image quality eliminated the majority of camera-trap photos in the sample from application to visual identification software. All black-and-white images (66) produced by photos taken at night with infrared flash (IR) were unusable because the lack of color washed the contrasting aspect of the anteaters stripe. Photographs of individuals walking perpendicular to camera-traps (30) were also unusable because the horizontal stripe on the anteater's flank is not visible from the front or back of the animal.

Photos from opportunistic observations

A total of 530 encounters with giant anteaters were documented at Karanambu Ranch from January 2011 – July 2016, with Karanambu Trust staff collecting GPS data (GPS locations, photographs) on 306 encounters (Figure 4-1). Images were sorted by date and further separated into cases where multiple individuals were observed on a single tour. Usable profile photos of at least one flank were obtained from all 306 encounters and usable photos of both flanks were obtained from 199 encounters.

Seventy-two photos taken from encounters that occurred in 2015 were added to the database to test the ability of *HotSpotter* to successfully ID wild individuals. Following the

initial entry of 72 images (one image of the left flank from each occasion), *HotSpotter* correctly matched 94% (68/72) of additional images of the left flank of the same individual taken during the same occasion (Figure 4-5). Unsuccessful matches were images with drastically different lighting (low angle morning or afternoon light) or that were taken at a great distance (>50 m). These initial matches showed very high similarity scores (>30,000), with a high density of hot spots. Entry of 72 mirror images of the opposite flank of the same individuals resulted in successful matching of 77.8% (56/72) of images.

Discussion

The results of this paper show, for the first time, a robust method for identifying individual giant anteaters. The conspicuous horizontal stripe along the anteater's flank serves as a unique individually-identifiable mark, which could allow researchers to track captures and recaptures of individuals and thereby provide the opportunity to estimate population densities. Ideally, presenting this method will encourage the application of this method to existing images from studies already conducted, as well as the proliferation of new capture-recapture studies of giant anteaters, considering the lessons learned from methods employed here. Key aspects of employing this method successfully include determining the region of interest (ROI), comparing opposite flanks, as well as managing issues related to image quality, image angle, and lighting.

Selecting the Region of Interest (ROI)

Local collaborators suggested three potential regions of interest which they have used to successfully identify individual anteaters in the past: (1) tail shape / size; (2) bands or markings on the wrist and forearm of forelegs; and (3) the horizontal stripe on the anteater's flank. After attempting various derivations of the regions of interest, including full body, front half only, tail only, and stripe only, the most successful matches resulted from a ROI that focused on the horizontal stripe running along the anteater's flank.

Our assumption that a combination of factors would be most useful was unfounded for application in *HotSpotter*, as the algorithm seemed to have difficulty identifying 'hot spots' over a large area (although to additional identifying characteristics may still be useful for visual ID by practitioners in small samples). Tail-only queries were also ruled out, as local collaborators suggested that this attribute may change several times over the life of an anteater. We also found that queries using both front-half and full-body ROIs were biased by hot spots identified in the vegetation or exposed rock faces in the background of the images. Issues with matching the background scenery were observed by Crall et al. (2013), but did not result in matching failures in that case. We found that this was a more prevalent issue in the photos from AZA institutions where commonalities existed in background exhibit features (rocks, turf grass, palms) between institutions. Tight cropping of the region of interest (ROI) around the anteater's stripe reduced the probability of failed matches in each of our samples.

Identifying Opposite Flanks

Issues arose with regard to matching the right and left flanks of the same animal in our sample. The *HotSpotter* algorithm ranked all of the photos of left flanks with higher similarity scores than any of the photos of right flanks, regardless of individual, suggesting that the patterns on the opposite flanks of the same individual did not match. This issue is well documented in large carnivores (O'Connell et al. 2010), motivating researchers to set camera traps in paired arrays in an effort to document the distinct patterns on both sides of the animal's body simultaneously.

However, when the image symmetry was flipped using the 'Mirror image' editing tool in *Adobe Photoshop*, we were able to dramatically increase the probability of successfully matching the opposite flanks of the same individual. It appears that the orientation of the anteater's stripe pattern was leading to failed matches, rather than the pattern of the stripe itself. Although none

of the matches between photos of the left flank and the mirror image of the right flank produced similarity scores as high as the matches of photos of left flanks from different occasions, queries of photos opposite flanks regularly awarded the highest similarity scores to the matching flanks from the same individual. The consistency with which opposite flanks were matched was satisfactory and only improved as additional images were added to the database.

Pose, Lighting Conditions, and Image Quality

Crall et al. (2013) cited issues with image angle or pose, lighting, and image quality, including focus, resolution and contrast as the primary causes of identification failures in their tests of the *HotSpotter* algorithm with various species. Images taken too far from the front, back, or top of giant anteaters could not be matched with photos of the same individual because the view of the anteater's stripe was not clear. This issue was addressed in some instances by adding correctly identified images of an individual from various angles to the database, but images with no view of the anteater's stripe are unidentifiable in the absence of a secondary characteristic (i.e. broken tail, scar). Clear profile photographs of each animal's flank are necessary for accurate identification of individuals.

Lighting was the primary issue that caused matching failures in our dataset. The *HotSpotter* algorithm was unable to match black-and-white photos from the IR flashed used by camera traps in our survey. Additionally, stripe patterns were washed out in images where the direct, low-angle morning and afternoon sun was behind the photographer. The contrast in coloration of the stripe is the key aspect that makes each stripe unique. Adding additional, correctly identified images of the same individual may help the algorithm overcome this issue, however the best approach would be to avoid setting camera traps or taking photos facing directly to the east or west, particularly around dawn and dusk.

Other issues arose with images that were taken from a relatively long distance or with cell-phone cameras. The low pixel number in these images resulted in blurry ROIs when they were clipped from the original image for analysis, and this lack of detail in the ROIs ultimately resulted in a number of identification failures. These images may need to be removed from the sample or matched to other images 'by eye' where possible. As suggested by Crall et al. (2013), most of the issues discussed in this section are manageable, but require additional human interaction to mitigate issues.

Data Collection Tools

The application of this method to existing techniques for surveying wildlife populations is a key step for estimating giant anteater populations. We applied our method to reference images of known individuals, images from camera-trap surveys, and photos from opportunistic encounters during anteater tours and will discuss issues and provide suggestions for applying this method to each.

Reference Images of Known Individuals

Our study benefitted greatly from a database of reference images graciously shared by 19 AZA-accredited institutions. Gaining access to a reference dataset of known individuals provided a critical base for training the *HotSpotter* algorithm, ultimately allowing for the identification of wild individuals at Karanambu Ranch. The creation of an accessible image database of known individual anteaters would be a valuable resource that would support of further application of this method, and is worth pursuing in the future. In general, zoo collections are a tremendous resource for researchers and practitioners seeking to inform management and conservation, and we hope that this effort will serve as an example of how collaborations can benefit both parties.

Camera-Trap Surveys

Camera-traps have proven to be an effective tool for sampling a wide variety of medium and large tropical mammals, including cryptic and naturally rare species (Tobler et al. 2008), as well as in studies employing capture-recapture methodology for estimating population densities of species with recognizable patterns (Karanath & Nichols 1998; Silver 2004). Unfortunately, images from our camera-trap survey showed limited applicability for the identification of giant anteaters using *HotSpotter*.

However, lack of success in identifying giant anteaters from camera-trap photos in this study should not deter researchers from taking up this effort in the future. Individual anteaters were successfully identified from multiple images taken during the same occasion and re-captures of the same individual from different occasions, however these successes occurred at an unacceptably low frequency. Identification of individual anteaters in camera-trap studies is possible, but adjustments would need to be made to the tools and study design of future studies to improve performance of visual identification programs and achieve robust results.

With regard to research tools, a switch from IR flash to white flash cameras may address multiple issues. No successful matches were made from the black-and-white photos taken at night by cameras employing (IR) flash – even individuals in the same photo sequence. Employing cameras that use a white flash would provide color photos with standard lighting during night occasions. Even during the day in photos taken under the forest canopy, we routinely were forced to omit photos that were too dark or too bright for analysis. White flash cameras may help alleviate this issue as well by providing a consistent source of light that illuminates the subject of each image.

In terms of study design, the camera-trap data utilized in this study came from a study primarily focused on jaguars (Hallett et al. 2017). Trap spacing (2-3 km apart) and placement

(mixed placement with some cameras set on roads and trails) may have reduced the potential for captures and re-captures of giant anteaters. The 2-3 km between cameras applied here is based on the minimum home range size observed in jaguars (10 km^2; Rabinowitz & Nottingham 1986) – standard trap spacing in jaguar studies where home range size is unknown (Silver 2004). Although 10 km^2 is similar to the maximum home range (13.5 km^2; Di Blanco et al. 2015) observed in a collared female anteater, home ranges as small as 0.8 km^2 (Miranda 2004) have also been observed. As such, reducing the distance between cameras may be necessary to increase capture and re-capture rate in studies focused on giant anteaters.

Trap placement that optimizes capture rate is also critical. Jaguars and other large carnivores have shown a preference for existing roads and trails (Harmsen et al. 2010), and as a result camera-trap studies focused on these species may disproportionately select sites along roads and trails in an effort to increase overall capture rate. Giant anteaters avoid the use of roads and trails, perhaps as a means for avoiding their primary predator (jaguars; Quiroga et al. 2016) or primary threat (road strikes; Miranda et al. 2014). We rarely observed giant anteaters on cameras set facing roads, and these few captures showed anteaters crossing perpendicular to roadways, as opposed to walking parallel to roads as observed with species known to actively use roads. Discrepancies in space use and trap placement may make the results of camera-trap studies focused on large carnivores inappropriate for characterizing the abundance or distribution of giant anteaters.

Additionally, anteaters do not appear to create game trails by traveling regular routes, resulting in low overall capture rates even at off-trail sites. These inconsistent movement patterns may have also resulted in many photos of the photos of the front or rear of individuals where the stripe is not visible. The potential for a scent or attractant placed in front of the

camera to lure and/or orient individuals in the optimal pose for obtaining profile images should be tested in future studies. Although our matching of opposite flanks provided relatively consistent results, paired camera-trap arrays would increase accuracy by providing simultaneous views of both flanks of an individual from a single event.

Visual Encounter Surveys

Visual surveys have showed limited success in the study of Neotropical mammals. Dense, remote forests obstruct visibility and provide ample cover for cryptic species. However, giant anteaters inhabiting Neotropical scrub, savanna, and grassland habitats may present a rare opportunity to employ observational techniques. Researchers suggest that giant anteaters may be most densely populated in the Llanos, Cerrado, Pantanal, and Chaco regions (Eisenberg 1989) thanks, in part, to a higher density of their favored prey (ants, termites; Redford 1985). Although this species also inhabits lowland and upland forests where observational studies may not be feasible, visual surveys may provide valuable data on the abundance and distribution of this species in these critical habitats – habitats which are also among some of the most threatened and least protected on the continent.

Our visual surveys employed vehicles with spotters slowly driving regular transects at standard speeds while vaqueros on horseback conducted ad-hoc searches informed by previous experience. Applying this method at Karanambu Ranch in the North Rupununi wetlands, anteaters were regularly observed during hours of normal activity (Shaw 1987) exhibiting natural behaviors. Although active search on horseback does flush hiding anteaters, vaqueros travelling the savannas on horseback is a common activity for a working cattle ranch, which anteaters appear to have acclimated to over time. This combination of on and off-road searches provided a successful search method, allowing for regular visual observation.

Due to concerns about the compromised ability of giant anteaters to thermoregulate (Camilo-Alves & Mourão 2006), visual surveys should be conducted at night or around dawn / dusk to minimize potential heat stress during opportunistic encounters and maximizing the potential of observing natural behaviors. Surveys in this study began before sunrise (05:30) and refrained from prolonged pursuit or excessive manipulation of natural behavior. With the anteater's poor eyesight, staying downwind keeps individuals unaware the presence of researchers / tourists, allowing approach for photo documentation and detailed observation.

Visual observation surveys may represent the ideal method for obtaining photographs that produce successful individual identification of anteaters using *HotSpotter*. Among the biggest issues impairing the ability of *HotSpotter*'s algorithm to correctly ID individuals were variations in image quality, pose, and lighting conditions. These issues can be directly addressed during visual observations by purchasing a mid to high-quality digital camera, taking multiple photos from various angles during each encounter, and putting photographers in the best position to obtain useable photographs for analysis. While every encounter may not present ideal conditions, experienced research teams and access to quality equipment will help ensure that images obtained will useful for individual identification using *HotSpotter*.

Visual surveys during this study were conducted during 'Anteater Safaris', a tourist attraction offered by Karanambu Lodge. Collaborations between researchers and practitioners have shown to promote multiple goals – boosting productivity and cutting costs of research, while supporting conservation and building capacity in local communities (Simons, 2011). The training provided to local collaborators who contributed to this study served to increase capacity among Karanambu staff, while providing data that may ultimately improve the management of anteater habitat. The revenue-generating aspect of eco-tourism in particular has shown to

increase the probability of related activities to contribute to conservation (Stem et al. 2003). As The fact that 'Anteater Safaris' are one of Karanambu's most popular activities, only increases the probability that data provided by this study will be applied to conserve anteaters on ranch lands. Increasing collaborations between researchers, citizen scientists, and tour operators at ranches and eco-lodges across the Chaco, Cerrado, Llanos, and Pantanal would create the potential to dramatically increase our understanding of giant anteaters in some of their most important habitats, while providing capacity building and income-generating opportunities for the people that are directly responsible for their stewardship. It may be exactly this type of grassroots effort that is needed to fill the knowledge gaps that are constraining efforts to effectively manage giant anteater populations into the future.

Conclusion

Giant anteaters are a charismatic, flagship species of conservation concern that inhabits Neotropical forests, savannas, and wetlands. Knowledge gaps are hindering management efforts, as actual abundance and distribution of this species are unknown. In this paper, we presented a method for identifying individual anteaters that, based on a reference dataset of captive individuals in the collections of AZA accredited institutions, showed promise when applied to a wild population at Karanambu Ranch, Guyana. The ability to successfully identify individual animals forms the necessary initial input for capture-recapture analysis – a proven method for population estimation. Photos accumulated from visual surveys, ideally in collaboration with an existing eco-tourism or citizen science efforts already in place in open habitats, in other locations across this species range should be applied further test this method. Optimizing the accuracy and efficiency of individual identification of giant anteaters is critical for applying the method developed here to population estimation.

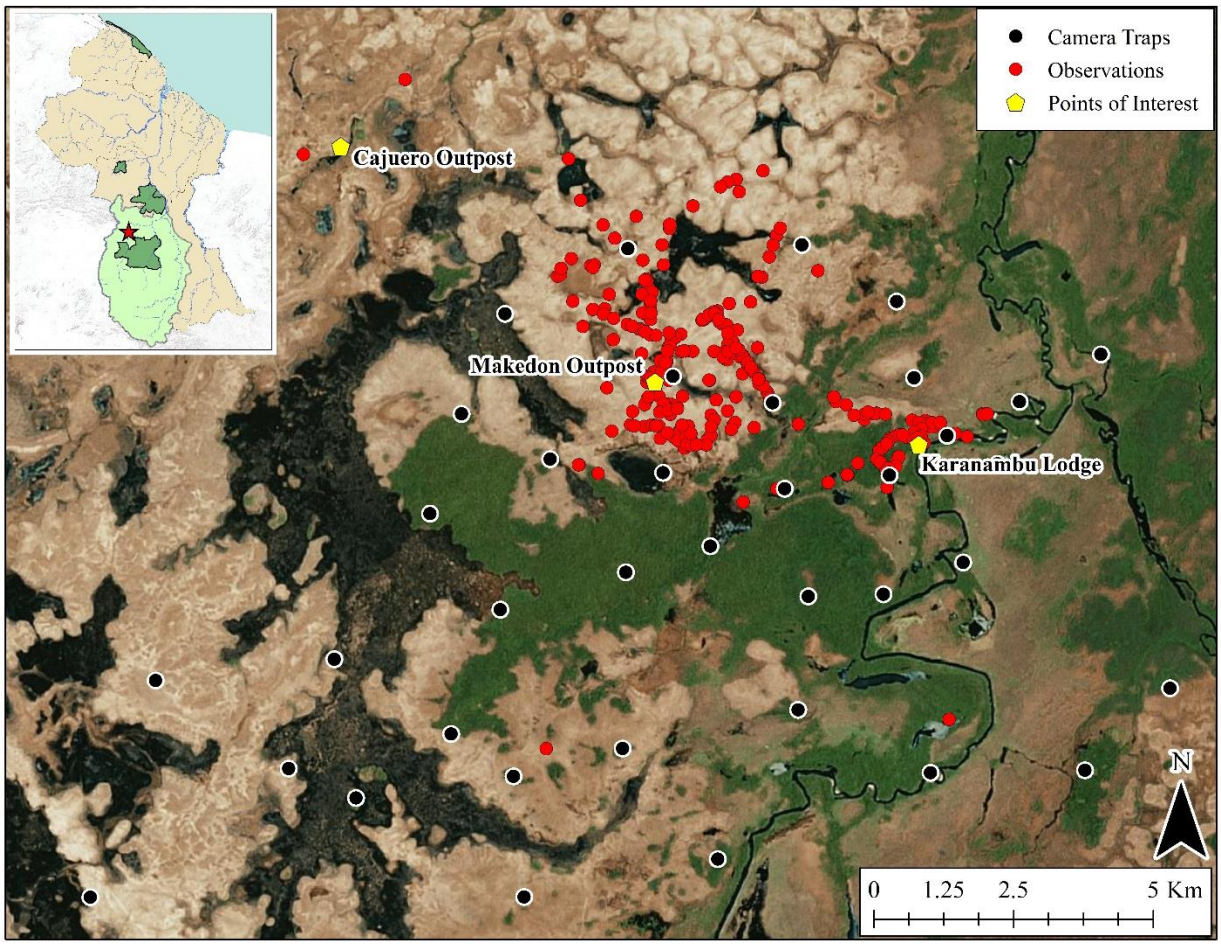

Figure 4-1. Map of camera-trap locations and opportunistic encounters with giant anteaters at Karanambu Ranch, Guyana (ESRI 2016)

Figure 4-2. Examples of images of giant anteaters from AZA institutions (top photos courtesy of Greensboro Science Center and Jacksonville Zoo & Gardens), a camera-trap survey of Karanambu Ranch and Yupukari Village (middle photos courtesy of Matt Hallett), and opportunistic encounters during anteater tours at Karanambu Ranch (bottom photos courtesy of Gerard Pereira)

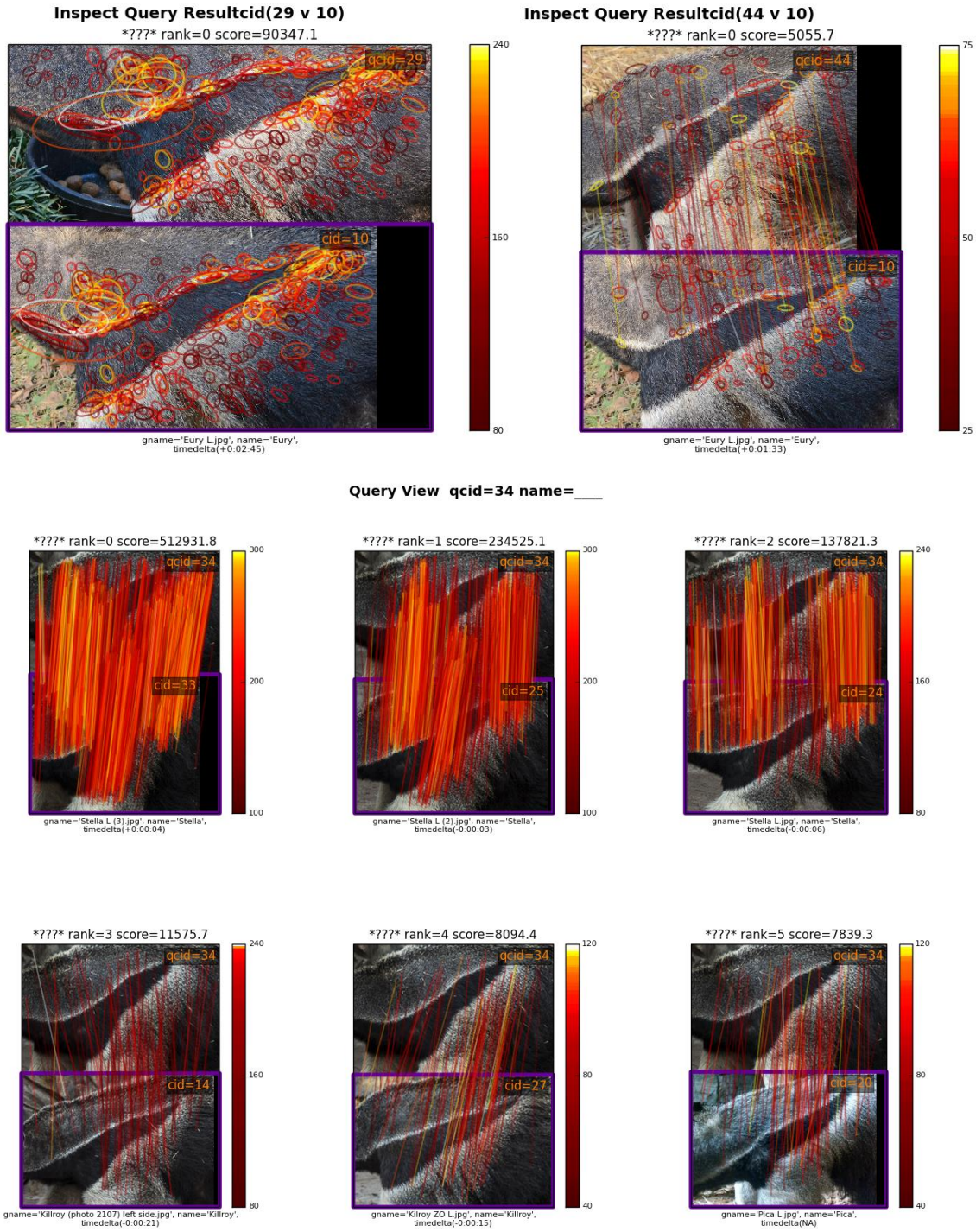

Figure 4-3. Example results from queries of known individuals from AZA accredited institutions. Shown here is an example of a successful identification of (a) the same individual from two separate images of the left flank (top left), (b) the same individual from an image of the left flank and mirror image of the right flank (top right), and (c) an individual to several images previously identified in the database (including images of both flanks); photos courtesy of Greensboro Science Center and Jacksonville Zoo & Gardens

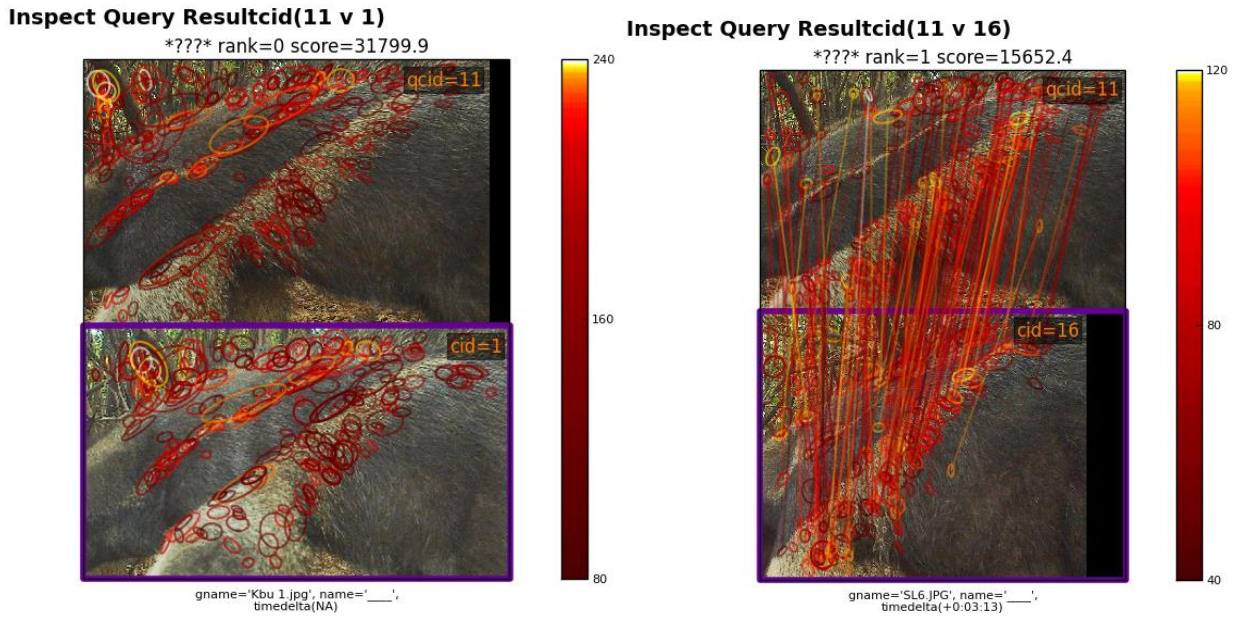

Figure 4-4. Example results from queries of camera-trap images obtained during a survey of Karnambu Ranch and Yupukari Village. Shown here is an example of a successful identification of (a) the same individual from two images from the same sequence (left) and (b) a re-capture of the same individual at a second trap location (right); photos courtesy of Matt Hallett

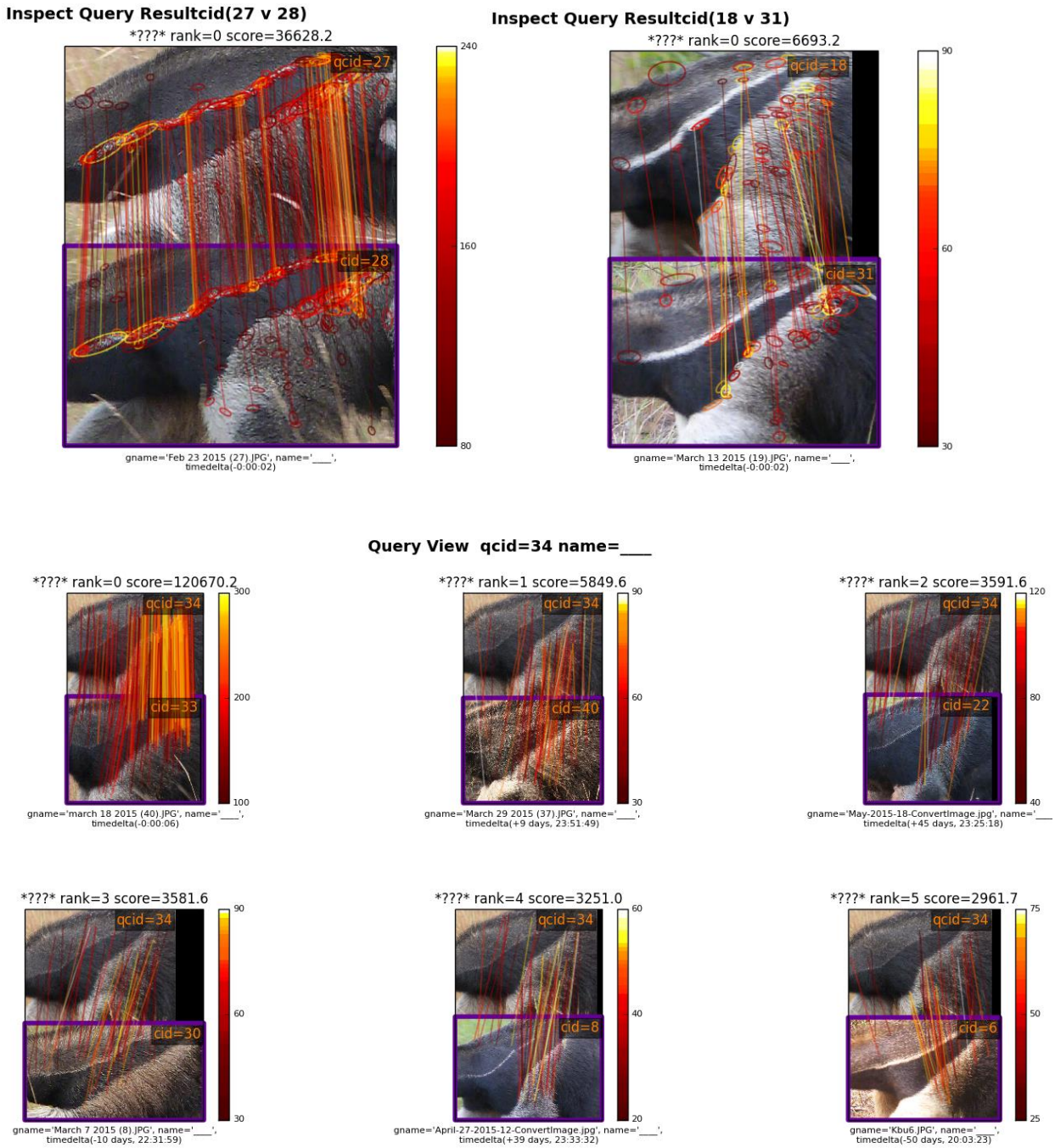

Figure 4-5. Example results from queries of photos from opportunistic encounters during anteater tours at Karanambu Ranch. Shown here is an example of a successful identification of (a) the same individual from two images taken during a single encounter (top left); (b) a re-capture of the same individual on separate occasions at different locations (top right); and (c) an individual from two images previously identified in the database (including images of both flanks); photos courtesy of Gerard Pereira

CHAPTER 5
CONCLUSIONS

While some policies that exclude communities from natural resources in the name of conservation still exist, most of the current ideas about the community's role in conservation have changed radically. Communities are now the locus of conservation thinking and driving bottom-up approaches to conservation and management (Agrawal and Gibson 1999). However, community-based conservation is rife also with its own set of unique challenges to overcome. Idealized images of coherent, long standing, localized sources of authority that are tied to what are assumed to be sustainable resource management regimes (Brosius et al. 1998) are just that – idealized (Berkes 2004).

The vision of community – as the centerpiece of conservation and resource management – is attractive. However, communities are not merely static groups of isolated people. In reality, they are multidimensional, cross-scale, social-political units or networks that can be elusive and are constantly changing over time (Carlsson 2000). Communities do not act as simple, uniform agents that either conserve or despoil, instead they should be viewed as congregations of unique individuals with their own interests and motivations that respond to pressures and incentives and are embedded in larger systems (Berkes 2004). With the realization that communities are difficult to define, we set out to design a project that build the confidence and capacity to allow communities to define themselves.

In previous efforts to engage communities in research, conservation, and management, the focus on what or who community is are generally focused by forces from outside of the community that are attempting to define and organize it. Many such projects have fallen short of meeting their objectives because community-based initiatives should be based on local-level solutions to issues identified by the communities themselves (Leach et al. 1999). Very simply,

this means that communities should derive their own solutions to their own problems. Previous projects failed to invest in capacity building, instead building systems which are developed, run and maintained by outsiders with members of communities receiving only residual benefits (Reed 2008). Passive benefits also have a history of being unequally allocated or not allocated at all (Child 1996). As a result, community compensation for participation in conservation has become a source of criticism of community-based conservation as a concept and in practice (Kiss 2004).

Studies have also shown that the conception of local incentives purely in terms of economic benefits is too narrow, too simplistic, and potentially counterproductive (Berkes 2004). Incentives are multidimensional. Equity and empowerment are often more important than monetary incentives (Reed 2008). Decision-making processes should be legitimate, accountable, inclusive, and that take into account multiple stakeholders and interests are highly valued (Berkes 2004). We attempted to circumvent the shortcomings and capitalize on success of previous projects by designing a project based around locally relevant issues (Figure 1-1) that provides fair compensation, gives careful consideration into how we engage with communities, is transparent about decision making, promotes participation, and invests heavily in capacity building and leadership development (Figure 1-2).

Implementation and results to date

The goal of this dissertation was to engage Rupununi communities in a learning process for conservation and management. While the focus of chapter two was informed by issues that communities themselves defined as important, the design of the project was set before the project began to provide a structure that would facilitate learning and growth through participation. While the data generated by our camera-trap project is certainly important, open sourcing the remaining chapters of this dissertation made effective engagement and capacity building a

central tenant that would ultimately decide our fate. Certainly, the contribution of local collaborators makes landscape-scale research feasible and efficient, but it also gave community members a chance to contribute to research in a way that their knowledge was recognized and they were provided with opportunities to participate at a high level. Information gained through this type of experiential learning provides the context that directs the formation of values and behavior with participants progressing from action, to understand the consequences of that action, to generalization of these consequences in a broader context (Tuss 1996).

Participants often grow complacent with project over a period of time and request new avenues to maintain engagement (Evans et al. 2005). This aspect creates both a challenge and an opportunity. Participatory action research provides an outlet for leaders that emerge from the process to take on greater responsibility and ownership over their own development. Effective PAR projects should respond to the experiences and needs of the community, foster collaboration between researchers and community research activities, and promote common knowledge and increases community awareness (Finn 1994). From the outset of this project we provided local collaborators with a clear path and incentives for leadership development, with increased responsibility resulting in increased autonomy, compensation, and recognition.

As participants gained interest and confidence in working with the camera trapping project, we provided them with additional responsibility, autonomy, and opportunities to contribute to decision making. As participants progressed in skills and confidence, we provided training and leadership development opportunities to allow them to experience research while building towards independent action and eventually the development of their own questions. The key to building this kind of capacity was structuring activities in such a way that skills, knowledge, and understanding progressed from simpler cases to more complex. Integrating

research and training allowed data collection and community development to occur simultaneously, as community members are allowed to assume more participation and ownership over research when they were ready.

As participants began to master the tasks related to our camera trap project, they were encouraged to start asking their own questions, based on their own interests or the interests and needs of their community. Research has shown that when participants design and implement their own studies, they develop a strong vested interest in finding answers to their own questions and implementing the results (National Research Council 1997). While our initial engagement focused on increasing understanding of ecological processes (chapter two), chapters three and four represent community-directed initiatives.

Research, conservation, and development are not mutually exclusive. Though rarely documented in the literature, research is known to generate interest in biodiversity that may lead to increased conservation and management. Much of this may depend on facilitation, but research strategies that emphasize participation are gaining traction in ecological research all over the world. Engaging stakeholders in the research process involves the development of a shared learning process that could change conservation behaviors in participants and inspire conservation planning and action in communities. We believe that this dissertation provides an example of how research can be utilized as a tool to engage communities of resource users – simultaneously increasing scientific understanding, contributing to conservation outcomes, and building capacity in communities who often have access to few such opportunities.

Applications for Community-driven Management

The scaffolded interaction and collaboration utilized in this project was intended to provide a structure for building capacity through participatory research and towards community-driven natural resource management. When local communities are empowered to manage their

own resources, a new approach to science and management can be created (Berkes 2004), but transitioning from participation in research to resource management informed by data collection involves providing a centralized organizational infrastructure that is specifically designed to promote individual, community and regional science-based management via an interactive feedback loop (Cooper et al. 2007). Hence, in the future this project will be entering a new phase in which we will begin developing the necessary structures that will facilitate the translation of the results presented here into action.

Adaptive management is the application of scientifically informed natural resource management strategies whose recommendations are iteratively evaluated and revised to improve outcomes and have shown to be an effective means for organizing citizens, research and resource management activities to achieve cumulative, positive impacts on biological diversity (Cooper et al. 2007). Our emphasis on experience, interpretation, reflection, and the co-production of knowledge were specifically designed to prepare community members for integration into adaptive management. Empowering a community to take ownership over itself and its own development could perhaps be the greatest achievement of participatory action research, but only time will tell if the approach presented here will be successful in getting there.

APPENDIX A
JAGUAR CAPTURE DATA

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
BHI13	01140129	Lowland	1/14/2017	12:35	Male	12
BHI14	01060113	Lowland	1/6/2017	20:30	Male	8
BHI14	03230712	Lowland	3/23/2017	11:32	Female (with cubs)	9
BHI5	08160563	Montane	8/16/2016	16:28	Male	11
BHI5	09060892	Montane	9/6/2016	16:52	Male	11
BHI5	09080932	Montane	9/8/2016	15:19	Male	8
BHI5	09240090	Montane	9/24/2016	6:20	Female	10
BHI5	11250820	Montane	11/25/2016	16:51	Male	12
BHI5	04070594	Montane	4/7/2017	19:04	Male	11
BHI6	06180377	Lowland	6/18/2016	8:51	Female	10
BHI6	07050083	Lowland	7/5/2016	4:13	Male	11
BHI6	07150232	Lowland	7/15/2016	15:41	Female	10
BHI6	07270467	Lowland	7/27/2016	23:25	Male	11
BHI6	08160899	Lowland	8/16/2016	19:00	Male	11
BHI6	04020828	Lowland	4/2/2017	22:05	Female	10
BHI6	05130739	Lowland	5/13/2017	20:57	Female	10
BHI8	09030162	Bush Island	9/3/2016	1:46	Female	9
DAD1	EK000764	Gallery	3/16/2016	16:33	Female	1
DAD10	EK001495	Gallery	12/1/2015	17:57	Female	1
DAD10	EK001498	Gallery	12/1/2015	19:04	Female	1
DAD10	EK002236	Gallery	1/10/2016	8:33	Female	3
DAD10	EK002487	Gallery	1/18/2016	4:46	Male	2
DAD10	EK002553	Gallery	1/20/2016	18:38	Female	3
DAD10	EK002742	Gallery	1/27/2016	6:50	Female	1

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
DAD10	EK002767	Gallery	1/27/2016	19:36	Female	1
DAD10	EK003463	Gallery	2/19/2016	4:05	Female	1
DAD10	EK003529	Gallery	2/21/2016	8:16	Female	1
DAD2	EK001766	Bush Island	4/15/2016	23:32	Male	50
DAD3	EK000271	Gallery	2/17/2016	21:37	Female	1
DAD7	EK000418	Gallery	11/22/2015	20:44	Female	1
DAD7	EK000470	Gallery	11/24/2015	10:20	Male	2
DAD7	EK001135	Gallery	12/13/2015	2:26	Female	1
DAD7	EK001289	Gallery	12/13/2015	17:30	Female	1
DAD8	PICT0133	Gallery	11/24/2015	23:47	Female	3
DAD8	PICT0659	Gallery	1/27/2016	2:00	Female	3
DAD8	PICT0674	Gallery	2/3/2016	6:50	Female	3
DAD9	EK000085	Gallery	12/5/2015	18:23	Male	2
KBAI1	03100280	Gallery	3/10/2016	5:12	Female	13
KBAI1	03110343	Gallery	3/11/2016	2:01	Female	13
KBAI1	03200728	Gallery	3/20/2016	19:24	Male	14
KBAI1	04030283	Gallery	4/3/2016	3:31	Female	13
KBAI1	04120860	Gallery	4/12/2016	18:29	Female	13
KBAI10	EK000130	Lowland	3/24/2016	8:07	Female	13
KBAI17	PICT0742	Lowland	12/14/2016	10:40	Male	14
KBAI17	PICT0751	Lowland	12/14/2016	15:06	Male	14
KBAI17	PICT0757	Lowland	12/15/2016	18:52	Male	14
KBAI17	PICT0768	Lowland	12/16/2016	18:23	Male	14
KBAI17	PICT0769	Lowland	12/17/2016	17:15	Male	14
KBAI17	PICT0775	Lowland	12/17/2016	22:21	Male	14
KBAI17	PICT0778	Lowland	12/17/2016	23:18	Male	14
KBAI2	09270737	Savanna	9/27/2016	2:56	n/a	15
KBAI2	10010800	Savanna	10/1/2016	21:14	Male	14

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
KBAI5	03150057	Lowland	3/15/2016	9:35	Female	13
KBAI5	08010170	Lowland	8/1/2016	10:19	Female	13
KBAI9	EK000307	Savanna	8/3/2016	21:58	Male	14
KBU1	EK000637	Bush Island	3/5/2015	11:42	Female	27
KBU11	EK000001	Bush Island	4/6/2015	1:21	Male	26
KBU11	EK000008	Bush Island	4/16/2015	4:15	Male & Female	26 & 27
KBU16	PICT0065	Gallery	12/28/2014	18:40	Male	26
KBU16	EK000028	Gallery	3/30/2015	17:37	Male	26
KBU17	PICT0144	Gallery	10/13/2014	1:00	Male	28
KBU17	PICT0148	Gallery	10/13/2014	8:50	Male	28
KBU17	PICT0205	Gallery	10/22/2014	8:08	Female	27
KBU17	PICT0211	Gallery	10/23/2014	10:20	Male	28
KBU17	PICT0214	Gallery	10/23/2014	14:59	Male	28
KBU17	PICT0221	Gallery	10/24/2014	2:14	Male	28
KBU17	PICT0405	Gallery	11/29/2014	20:06	Male	28
KBU17	PICT0406	Gallery	12/1/2014	6:27	Male	28
KBU17	PICT0485	Gallery	12/18/2014	13:37	Female	27
KBU17	PICT0633	Gallery	1/28/2015	18:33	Male	28
KBU17	PICT0641	Gallery	2/3/2015	19:05	Male	28
KBU17	PICT0679	Gallery	2/8/2015	20:53	Male	28
KBU17	PICT0682	Gallery	2/12/2015	2:20	Male	28
KBU17	PICT0844	Gallery	2/25/2015	21:22	Male	28
KBU19	PICT0122	Bush Island	5/1/2015	1:37	Female	27
KBU2	PICT0389	Bush Island	12/29/2015	22:45	Male	26
KBU2	PICT0457	Bush Island	11/15/2015	20:26	Male	26
KBU2	PICT0468	Bush Island	11/17/2015	21:29	Female	25
KBU2	PICT0476	Bush Island	11/19/2015	23:11	Female	25

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
KBU2	PICT0561	Bush Island	12/1/2015	2:42	Male	26
KBU20	PICT0004	Gallery	3/1/2015	5:48	Male	28
KBU20	PICT0067	Gallery	3/30/2015	18:18	Male	28
KBU20	PICT0568	Gallery	2/4/2016	21:38	Male	28
KBU5	PICT0174	Bush Island	7/12/2014	18:14	Female	25
KBU5	PICT0114	Bush Island	1/15/2015	13:06	Female	27
KBU5	PICT0100	Bush Island	6/22/2015	22:07	Male	26
KBU5	PICT0187	Bush Island	7/25/2015	19:11	Female	25
KBU5	PICT0193	Bush Island	7/29/2015	18:24	Male	26
KBU5	PICT0220	Bush Island	8/14/2015	6:54	Male	26
KBU5	PICT0303	Bush Island	9/17/2015	1:58	Male	26
KBU5	PICT0010	Bush Island	10/31/2015	23:29	Male	26
KBU5	PICT0142	Bush Island	12/10/2015	0:28	Male	26
KBU5	PICT0683	Bush Island	1/13/2016	23:21	Male	26
KBU6	EK000093	Gallery	4/27/2015	2:30	Male	29
KBU6	PICT0151	Gallery	2/23/2016	4:57	Male	28
KBU7	PICT0049	Gallery	11/13/2015	22:17	Male	28
KBU7	PICT0052	Gallery	11/17/2015	20:38	Female	27
KBU7	PICT0065	Gallery	12/4/2015	18:44	Male	26
KBU7	PICT0067	Gallery	12/15/2015	17:54	Male	26
KBU7	PICT0073	Gallery	12/27/2015	20:09	Male	26
KBU7	PICT0078	Gallery	1/6/2016	15:32	Male	26
KBU7	PICT0086	Gallery	1/17/2016	0:13	Male	26
KBU7	PICT0100	Gallery	2/1/2016	23:18	Male	26
KBU7	PICT0149	Gallery	3/2/2016	21:39	Male	29
KBU7	PICT0154	Gallery	3/3/2016	5:40	Male	29
KBU9	EK000034	Gallery	11/10/2014	20:36	Male	26
KBU9	EK000060	Gallery	11/13/2015	18:39	Female	24

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
KBU9	EK000119	Gallery	12/5/2015	6:00	Male	28
KBU9	EK000163	Gallery	1/14/2016	5:34	Male	28
KBU9	EK000174	Gallery	1/21/2016	15:57	Male	24
KBU9	EK000195	Gallery	1/25/2016	5:03	Female	25
KBU9	EK000205	Gallery	2/2/2016	0:13	Female	25
KMPA12	11050887	Lowland	11/5/2016	0:25	Female	37
KMPA12	11230104	Lowland	11/23/2016	5:58	Female	37
KMPA13	02240040	Riverine	2/24/2017	16:11	Male	40
KMPA14	09210463	Riverine	9/21/2016	18:07	Male	40
KMPA14	09270538	Riverine	9/27/2016	14:19	Male	40
KMPA14	10220751	Riverine	10/22/2016	21:46	Male	40
KMPA14	10250786	Riverine	10/25/2016	11:46	Male	40
KMPA14	10300809	Riverine	10/30/2016	0:26	Male	39
KMPA14	11240019	Riverine	11/24/2016	7:33	Male	40
KMPA14	11260029	Riverine	11/26/2016	0:08	Male	40
KMPA14	12130161	Riverine	12/13/2016	3:25	Male	39
KMPA14	12250270	Riverine	12/25/2016	9:25	Male	39
KMPA14	02060647	Riverine	2/6/2017	20:44	Male	39
KMPA14	02100689	Riverine	2/10/2017	14:41	Male	39
KMPA14	02210922	Riverine	2/21/2017	7:22	Male	40
KMPA14	03090232	Riverine	3/9/2017	2:58	Male	40
KMPA14	03170374	Riverine	3/17/2017	13:01	Male	40
KMPA14	03200431	Riverine	3/20/2017	17:34	Male	40
KMPA14		Riverine	3/20/2017	18:10	Female	41
KMPA14	03210437	Riverine	3/21/2017	6:18	Female	41
KMPA14	03260524	Riverine	3/26/2017	20:26	Male	40
KMPA14	04030646	Riverine	4/3/2017	19:27	Female	41
KMPA14	04210863	Riverine	4/21/2017	7:20	Female	41

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
KMPA14	04250905	Riverine	4/25/2017	18:38	Male	40
KMPA14	05180133	Riverine	5/18/2017	10:36	Female	41
KMPA14	06040287	Riverine	6/4/2017	9:52	Male	40
KMPA14	06050294	Riverine	6/5/2017	10:55	Male & Female	40 & 41
KMPA14	06050299	Riverine	6/5/2017	17:34	Female	41
KMPA14	06060308	Riverine	6/6/2017	6:49	Male	40
KMPA16	04230812	Montane	4/23/2017	19:41	Male	39
KMPA17	01250854	Montane	1/25/2017	14:33	Female	38
KMPA17	05130448	Montane	5/13/2017	3:40	Female	38
KMPA17	06100711	Montane	6/10/2017	3:38	Male	39
KMPA18	09010205	Lowland	9/1/2016	9:15	Female	38
KMPA18	01260953	Lowland	1/26/2017	0:20	Female	38
KMPA2	EK000350	Riverine	7/11/2014	14:56	Male	43
KMPA2	11130422	Riverine	11/13/2016	3:45	Female	42
KMPA22	08210076	Montane	8/21/2016	8:33	Male	44
KMPA22	09040177	Montane	9/4/2016	5:41	Female	41
KMPA22	11250519	Montane	11/25/2016	14:32	Male	44
KMPA22	02100581	Montane	2/10/2017	11:33	Male	44
KMPA23	09280986	Lowland	9/28/2016	12:45	Male	44
KMPA23	09280987	Lowland	9/28/2016	14:58	Male	44
KMPA23	09300004	Lowland	9/30/2016	6:20	Male	44
KMPA23	10110199	Lowland	10/11/2016	5:01	Female	37
KMPA23	11200097	Lowland	11/20/2016	0:25	Male	44
KMPA23	05020058	Lowland	5/2/2017	4:24	Female	37
KMPA23	05060084	Lowland	5/6/2017	4:00	Male	44
KMPA23	05140131	Lowland	5/14/2017	23:32	Male	44
KMPA29	11010356	Montane	11/1/2016	14:23	Female	42

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
KMPA30	05190566	Riverine	5/19/2017	10:42	Male	43
KMPA5	05120487	Montane	5/12/2017	9:03	Male	43
KMPA7	01300748	Montane	1/30/2017	5:33	Female	42
KMPA8	04290608	Lowland	4/29/2017	6:22	Female	42
MAP10	EK000194	Lowland	7/9/2014	7:45	Male	47
MAP10	EK000204	Lowland	7/10/2014	12:44	Male	47
MAP10	EK000580	Lowland	8/20/2014	8:29	Male	47
MAP10	EK002413	Lowland	12/21/2014	15:32	Male	49
MAP10	EK000253	Lowland	1/26/2015	15:25	Female	48
MAP12	EK000433	Montane	7/10/2015	6:14	Female	48
MAP3	EK001130	Montane	8/11/2015	19:49	Male	47
MAP3	EK001722	Montane	9/26/2015	2:02	Female	46
MAP4	PICT0680	Montane	7/26/2015	21:12	Female	45
MAP5	EK000981	Lowland	1/5/2016	8:38	Male	47
MAP6	EK004453	Riverine	1/8/2016	18:41	Female	45
REW10	03300924	Lowland	3/30/2016	13:14	Female	35
REW10	03310005	Lowland	3/31/2016	13:55	Male	34
REW14	EK000547	Montane	8/11/2016	5:39	Female	36
REW15	EK001063	Montane	8/6/2016	9:27	Female	36
REW16	EK000909	Montane	6/21/2016	13:05	Male	33
REW16	EK001771	Montane	8/5/2016	15:27	Female	36
REW16	EK002264	Montane	9/4/2016	10:04	Male	33
REW2	02270055	Riverine	2/27/2016	17:05	Male	30
REW2	07180373	Riverine	7/18/2016	2:08	Male	30
REW2	11230729	Riverine	11/23/2016	23:19	Female	31
REW2	02280762	Riverine	2/28/2017	2:53	Female	31
REW3	EK000340	Riverine	3/22/2016	8:38	Female	32
REW5	EK000426	Lowland	4/19/2016	11:51	Male	33

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
REW5	EK000555	Lowland	9/8/2016	12:44	Male	30
REW5	EK000647	Lowland	9/16/2016	6:14	Male	30
REW5	EK000539	Lowland	2/2/2017	0:40	Male	30
REW6	05280329	Montane	5/28/2016	3:18	Female	35
REW6	02220335	Montane	2/22/2017	16:27	Male	34
REW7	03240307	Lowland	3/24/2016	2:54	Male	33
REW8	EK000069	Gallery	3/1/2016	16:01	Male	33
REW8	EK006924	Gallery	3/24/2016	6:32	Male	33
REW8	EK006953	Gallery	4/5/2016	22:30	Male	33
REW8	EK006955	Gallery	4/7/2016	9:05	Male	33
REW8	EK006965	Gallery	4/20/2016	6:04	Male	35
REW9	EK004156	Lowland	9/17/2016	11:12	Male	33
REW9	EK004552	Lowland	11/21/2016	18:46	Male	33
REW9	EK000177	Lowland	1/7/2017	17:28	Male	33
REW9	EK001170	Lowland	3/2/2017	9:04	Male	33
REW9	EK001345	Lowland	3/24/2017	0:32	Female	31
RH10	EK000169	Riverine	12/12/2015	10:13	Female	21
RH11	EK000791	Lowland	2/25/2016	17:44	Female	21
RH12	EK006918	Montane	3/2/2016	7:07	Male	20
RH14	EK000309	Lowland	12/23/2015	3:20	Male	20
RH16	EK000056	Riverine	12/6/2015	22:22	Male	16
RH16	EK000203	Riverine	2/7/2016	22:19	Male	16
RH16	EK000221	Riverine	2/23/2016	4:58	Male	16
RH16	EK000233	Riverine	3/1/2016	8:38	Male	16
RH16	EK000243	Riverine	3/5/2016	17:57	Male	16
RH16	EK000251	Riverine	3/5/2016	18:40	Male	16
RH16	EK000267	Riverine	3/6/2016	11:43	Male	16
RH16	EK000275	Riverine	3/6/2016	17:12	Male	16

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
RH16	EK000281	Riverine	3/7/2016	7:41	Male	16
RH16	EK000291	Riverine	3/8/2016	7:15	Male	16
RH16	EK000296	Riverine	3/8/2016	8:34	Male	16
RH16	EK000314	Riverine	3/8/2016	17:41	Male	16
RH16	EK000373	Riverine	3/25/2016	10:35	Male	17
RH18	EK000995	Lowland	3/30/2016	3:50	Female	18
RH19	EK001556	Riverine	1/31/2016	18:38	Female	18
RH2	EK002846	Riverine	4/8/2016	4:50	Female	19
RH20	EK008395	Lowland	2/11/2016	17:31	Female	18
RH5	EK000388	Lowland	12/17/2015	21:51	Male	22
RH6	EK000875	Lowland	3/6/2016	10:37	Female	21
RH6	EK000923	Lowland	3/9/2016	17:52	Female	21
RH8	EK000124	Montane	12/4/2015	7:55	Female	73
RH9	EK001604	Riverine	2/1/2016	16:41	Male	20
RUP11	04230433	Bush Island	4/23/2017	4:36	Female	6
RUP11	04230441	Bush Island	4/23/2017	15:04	Female	6
RUP11	04240492	Bush Island	4/24/2017	0:53	Female	6
RUP12	04130789	Bush Island	4/13/2017	20:01	Male	7
RUP12	04290850	Bush Island	4/29/2017	5:10	Male	7
RUP2	12290240	Lowland	12/29/2016	7:57	Male	4
RUP2	01150642	Lowland	2/3/2017	12:01	Male	4
RUP2	01280813	Lowland	2/16/2017	5:06	Male	5
RUP2	02070883	Lowland	2/26/2017	1:51	Male	5
RUP2	02170228	Lowland	3/8/2017	6:36	Male	5
SH1	EK001228	Gallery	3/14/2016	14:23	Male	65
SH10	EK000103	Gallery	11/7/2015	23:31	Female	68
SH10	EK000313	Gallery	11/29/2015	19:45	Female	67
SH10	EK000433	Gallery	12/16/2015	6:07	Female	68

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
SH10	EK001264	Gallery	1/29/2016	0:26	Female	68
SH10	EK001283	Gallery	1/31/2016	19:06	Female	68
SH10	EK001439	Gallery	2/20/2016	5:36	Female	67
SH12	PICT0053	Savanna	11/13/2015	5:46	Male	66
SH12	PICT0098	Savanna	12/15/2015	3:08	Male	69
SH15	EK000985	Montane	8/18/2016	11:55	Male	70
SH15	EK002354	Montane	11/23/2016	22:12	Male	70
SH15	EK003029	Montane	2/18/2017	1:17	Male	70
SH17	EK001545	Lowland	10/23/2016	22:57	Female	71
SH18	EK003425	Montane	1/30/2017	22:46	Male	70
SH18	EK003893	Montane	3/13/2017	19:57	Male	70
SH19	EK000226	Savanna	10/5/2016	19:29	Female	71
SH20	EK000140	Savanna	6/25/2016	0:17	Female	71
SH21	EK000371	Bush Island	7/23/2016	22:17	Female	71
SH21	EK000416	Bush Island	8/14/2016	20:15	Female	71
SH21	EK000608	Bush Island	2/6/2017	5:06	Male	70
SH22	11240968	Montane	11/24/2016	0:10	Male	70
SH22	11240990	Montane	11/24/2016	20:14	Male	70
SH22	01150419	Montane	1/15/2017	19:07	Male	70
SH22	03200332	Montane	3/20/2017	8:21	Female	72
SH22	04030606	Montane	4/3/2017	21:54	Male	70
SH22	04040611	Montane	4/4/2017	4:33	Male	70
SH4	EK000100	Gallery	11/17/2015	6:32	Male	65
SH8	EK000213	Savanna	11/11/2015	19:07	Female	67
SH8	EK000372	Savanna	11/30/2015	9:02	Male	66
SH8	EK000379	Savanna	12/2/2015	4:54	Male	66
SH8	EK000591	Savanna	1/20/2016	10:03	Female	67

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
SH8	EK000651	Savanna	1/22/2016	23:19	Female (with cub)	67
SH8	EK001224	Savanna	2/3/2016	23:51	Male	65
SH8	EK001263	Savanna	2/14/2016	6:38	Female	68
SH8	EK001428	Savanna	2/17/2016	19:14	Female	67
SH8	EK001431	Savanna	2/17/2016	21:12	Female	67
SH8	EK001434	Savanna	2/18/2016	0:03	Female	68
SH8	EK001491	Savanna	2/20/2016	7:51	Male	66
SH8	EK004173	Savanna	4/11/2016	19:15	Female	68
SH9	EK000111	Gallery	11/14/2015	5:18	Male	66
SH9	EK000329	Gallery	12/29/2016	18:57	Female	68
SH9	EK001269	Gallery	2/29/2016	5:22	Male	66
SM11	EK000245	Gallery	6/23/2016	21:29	Male	51
SM11	EK000739	Gallery	7/26/2016	19:28	Male	51
SM11	EK000859	Gallery	7/29/2016	19:36	Male	51
SM11	EK001021	Gallery	8/4/2016	22:33	Male	51
SM11	EK001051	Gallery	8/11/2016	18:00	Female	53
SM11	EK001093	Gallery	8/19/2016	4:42	Male	51
SM11	EK000172	Gallery	2/25/2017	20:40	Male	52
SM11	EK000278	Gallery	3/20/2017	13:58	Male	52
SM11	EK000282	Gallery	3/20/2017	16:51	Male	52
SM11	EK000286	Gallery	3/21/2017	1:01	Male	52
SM11	EK000289	Gallery	3/21/2017	6:11	Male	52
SM14	EK000085	Bush Island	1/25/2017	18:30	Male	55
SM15	06130050	Bush Island	6/13/2016	23:47	Male	55
SM15	09050832	Bush Island	9/5/2016	17:49	Male	55
SM15	09060844	Bush Island	9/6/2016	16:47	Female	55
SM15	09070852	Bush Island	9/7/2016	3:47	Male	52

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
SM15	09140893	Bush Island	9/14/2016	15:28	Male	55
SM15	09160905	Bush Island	9/16/2016	19:53	Male	52
SM15	09230964	Bush Island	9/23/2016	17:31	Male	55
SM15	09290027	Bush Island	9/29/2016	23:25	Male	55
SM15	09290043	Bush Island	9/29/2016	23:56	Male	55
SM15	10060047	Bush Island	10/6/2016	16:33	Male	55
SM15	10130079	Bush Island	10/13/2016	22:21	Male	55
SM15	10190131	Bush Island	10/19/2016	19:57	Female	54
SM15	10190151	Bush Island	10/19/2016	22:45	Male	55
SM15	10240174	Bush Island	10/24/2016	2:04	Male	55
SM15	10280499	Bush Island	10/28/2016	16:15	Male	55
SM15	11090547	Bush Island	11/9/2016	18:15	Male	55
SM15	11150601	Bush Island	11/15/2016	7:52	Male	55
SM15	12070811	Bush Island	12/7/2016	7:36	Male	55
SM15	12150848	Bush Island	12/15/2016	16:51	Female	53
SM15	01280308	Bush Island	1/28/2017	7:17	Male	55
SM15	02070375	Bush Island	2/7/2017	17:17	Male	55
SM15	02240508	Bush Island	2/24/2017	3:58	Male	55
SM15	02260616	Bush Island	2/26/2017	3:34	Male	55
SM15	03110704	Bush Island	3/11/2017	22:24	Male	55
SM15	03170800	Bush Island	3/17/2017	4:48	Female	54
SM15	04170033	Bush Island	4/17/2017	18:51	Male	55
SM15	05080767	Bush Island	5/8/2017	20:37	Male	55
SM4	EK000197	Gallery	12/16/2015	5:13	Male	51
SM4	EK000280	Gallery	12/17/2015	1:56	Male	51
SM5	EK000200	Bush Island	11/19/2015	4:40	Female	53
SM5	EK000684	Bush Island	12/5/2015	5:12	Female	53
SM5	EK000703	Bush Island	12/5/2015	14:38	Female	53

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
SM5	EK000715	Bush Island	12/6/2015	17:36	Female	53
SM5	EK000787	Bush Island	12/11/2015	8:58	Female	53
SM5	EK000796	Bush Island	12/11/2015	9:34	Female	53
SM5	EK001842	Bush Island	2/13/2016	9:02	Female	53
SM5	EK002330	Bush Island	2/24/2016	5:23	Female	54
SM5	EK000202	Bush Island	6/11/2016	6:57	Female	54
SM5	EK000362	Bush Island	10/16/2016	4:00	Female	54
SM5	EK000655	Bush Island	12/11/2016	7:41	Female	53
SM6	EK002089	Bush Island	1/3/2016	12:47	Female	53
SM6	EK002099	Bush Island	1/3/2016	21:54	Female (with cub)	53
SM6	EK002105	Bush Island	1/4/2016	19:32	Female (with cub)	53
SM6	EK002139	Bush Island	1/8/2016	19:48	Female	53
SM6	EK002473	Bush Island	2/10/2016	17:23	Male	52
SM6	EK003274	Bush Island	3/20/2016	9:00	Male	52
SM6	EK003346	Bush Island	3/26/2016	18:27	Female	53
SM6	EK003364	Bush Island	4/5/2016	5:23	Male	52
SM7	EK000297	Gallery	1/18/2016	17:51	Female	53
SM7	EK000369	Gallery	1/30/2016	9:07	Male	52
SM7	EK000373	Gallery	1/30/2016	22:51	Male	52
SM8	EK000056	Bush Island	7/19/2016	3:46	Male	51
SM8	EK000067	Bush Island	8/5/2016	10:18	Male	52
SM8	EK000238	Bush Island	10/9/2016	3:06	Male	52
SUR10	EK001525	Lowland	10/16/2015	10:38	Female	62
SUR10	EK002453	Lowland	12/24/2015	2:36	Female	62
SUR10	EK002714	Lowland	1/2/2016	22:15	Female	61

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
SUR10	EK002759	Lowland	1/5/2016	7:38	Female (with cubs)	61
SUR10	EK002923	Lowland	1/11/2016	14:31	Female (with cubs)	61
SUR10	EK002945	Lowland	1/12/2016	9:18	Female	63
SUR10	EK002997	Lowland	1/15/2016	9:12	Female	63
SUR10	EK003173	Lowland	1/21/2016	22:35	Female	61
SUR10	EK003177	Lowland	1/22/2016	7:36	Female	61
SUR11	EK002256	Lowland	9/15/2015	15:11	Male	57
SUR11	EK000389	Lowland	3/3/2016	8:38	Male	57
SUR11	EK005218	Lowland	5/17/2016	11:00	Female	61
SUR11	EK005334	Lowland	5/20/2016	16:58	Male	59
SUR11	EK007321	Lowland	7/11/2016	6:11	Female	61
SUR12	EK000703	Riverine	1/21/2016	8:17	Male	57
SUR12	EK000706	Riverine	1/21/2016	9:03	Male	57
SUR12	EK000712	Riverine	1/21/2016	10:51	Male	57
SUR12	EK000715	Riverine	1/21/2016	16:42	Male	57
SUR15	EK000623	Lowland	8/1/2016	6:31	Male	57
SUR15	EK000752	Lowland	8/13/2016	3:03	Male	60
SUR15	EK000932	Lowland	8/23/2016	22:10	Male	57
SUR15	EK000938	Lowland	8/24/2016	1:35	Male	60
SUR15	EK000942	Lowland	8/24/2016	16:55	Male	60
SUR15	EK001634	Lowland	9/25/2016	15:44	Female	61
SUR15	EK002064	Lowland	10/26/2016	2:27	Male	57
SUR15	EK002243	Lowland	11/13/2016	18:53	Male	57
SUR15	EK002318	Lowland	11/23/2016	22:35	Male	60
SUR15	EK002460	Lowland	12/2/2016	18:03	Female	62
SUR15	EK002465	Lowland	12/2/2016	22:35	Male	60

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
SUR16	EK000440	Lowland	8/26/2016	15:52	Male	57
SUR16	EK000618	Lowland	9/28/2016	5:33	Male	64
SUR16	EK000913	Lowland	10/26/2016	1:54	Male	57
SUR16	EK000930	Lowland	10/28/2016	9:45	Male	64
SUR16	EK000935	Lowland	10/28/2016	14:08	Male	64
SUR16	EK000939	Lowland	10/29/2016	2:58	Male	64
SUR16	EK000944	Lowland	10/29/2016	3:46	Male	57
SUR16	EK000947	Lowland	10/29/2016	18:13	Male	57
SUR17	EK000253	Lowland	8/12/2016	22:59	Female	63
SUR18	EK001043	Lowland	9/4/2016	21:07	Female	62
SUR18	EK001053	Lowland	9/5/2016	15:23	Female	63
SUR18	EK002036	Lowland	11/25/2016	15:20	Female	62
SUR20	EK000089	Lowland	7/22/2016	1:52	Male	60
SUR24	EK002156	Lowland	10/11/2016	0:57	Male	60
SUR24	EK002328	Lowland	10/23/2016	10:56	Female	63
SUR24	EK002399	Lowland	10/26/2016	23:56	Female	63
SUR24	EK002442	Lowland	10/31/2016	20:47	Male	60
SUR24	EK003225	Lowland	12/3/2016	13:28	Female	62
SUR3	EK000480	Lowland	8/9/2015	7:10	Male	56
SUR3	EK000760	Lowland	8/24/2015	19:50	Male	57
SUR3	EK002205	Lowland	11/24/2015	1:41	Female	58
SUR3	EK002222	Lowland	11/25/2015	3:57	Male	57
SUR3	EK002348	Lowland	12/7/2015	17:25	Male	57
SUR3	EK003494	Lowland	2/19/2016	23:46	Female	58
SUR3	EK000149	Lowland	2/21/2016	7:28	Female	58
SUR3	EK000285	Lowland	2/24/2016	12:59	Male	56
SUR3	EK000932	Lowland	3/26/2016	21:41	Female	58
SUR3	EK001041	Lowland	4/2/2016	15:13	Male	57

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
SUR3	EK001166	Lowland	4/8/2016	4:43	Female	58
SUR3	EK001292	Lowland	4/10/2016	22:10	Male	57
SUR3	EK002446	Lowland	5/28/2016	23:38	Male	56
SUR4	EK001445	Lowland	8/5/2015	4:01	Female	58
SUR4	EK004370	Lowland	5/23/2016	3:35	Male	57
SUR7	EK000413	Montane	8/17/2015	14:54	Male	56
SUR7	EK000619	Montane	9/23/2015	14:05	Male	59
SUR8	EK001407	Lowland	8/29/2015	20:10	Male	56
SUR8	EK002639	Lowland	11/25/2015	19:10	Female	58
SUR8	EK003189	Lowland	1/28/2016	2:36	Female	58
SUR9	EK000166	Lowland	7/27/2015	0:32	Male	57
SUR9	EK000722	Lowland	8/19/2015	21:24	Male	57
SUR9	EK000932	Lowland	8/28/2015	17:39	Mlae	57
SUR9	EK000974	Lowland	8/29/2015	21:04	Male	57
SUR9	EK001139	Lowland	9/10/2015	15:44	Male	56
SUR9	EK001280	Lowland	9/23/2015	19:10	Male	60
SUR9	EK001301	Lowland	9/24/2015	17:14	Female	58
SUR9	EK001336	Lowland	9/27/2015	22:30	Male	60
SUR9	EK002223	Lowland	11/10/2015	15:19	Male	59
SUR9	EK002424	Lowland	11/25/2015	1:46	Female	58
SUR9	EK002456	Lowland	11/29/2015	9:48	Female	58
SUR9	EK002572	Lowland	12/11/2015	4:03	Female	58
SUR9	EK000285	Lowland	3/8/2016	1:29	Male	60
SUR9	EK000355	Lowland	3/14/2016	10:55	Male	57
SUR9	EK000430	Lowland	3/19/2016	7:28	Male	57
SUR9	EK001311	Lowland	5/13/2016	8:01	Male	59
YUP1	PICT0305	Bush Island	8/31/2014	15:58	Female	25
YUP1	PICT0049	Bush Island	7/28/2015	18:14	Female	25

APPENDIX A Continued

Site	Image ID	Habitat	Date	Time	Sex	Indiv. ID
YUP2	EK000485	Bush Island	11/4/2014	1:20	Male	24
YUP9	EK000532	Gallery	11/16/2015	17:25	Male	24
YUP9	EK000890	Gallery	1/22/2016	22:50	Female	23
YUP9	EK001011	Gallery	2/4/2016	5:47	Male	24
YUP9	EK001103	Gallery	2/19/2016	1:14	Male	24
YUP9	EK001128	Gallery	2/21/2016	1:25	Male & Female	23 & 24
YUP9	EK001146	Gallery	2/25/2016	23:37	Male	24

APPENDIX B
R CODE FROM CHAPTER 1 STATISTICAL ANALYSIS

```
jag=read.csv("Jag_trap2.csv", header=T)
head(jag)

cor.test(jag$Trap.Nights, jag$Rel..Abund)
hist(jag$Rel..Abund)

cor.test(jag$Elevation,jag$Habitat)
plot(jag$Elevation,jag$Habitat, label=T)

head(jag)
kruskal.test(Rel..Abund~Habitat, data=jag)
warnings()
boxplot(Rel..Abund~Habitat, data=jag)

install.packages("FSA", dep=T)
library(FSA)

test=dunnTest(Rel..Abund~Habitat, data=jag)
test


###test for differences in RAI between trail types

jag=read.csv("Jag_trap2.csv", header=T)
head(jag)


head(jag)
kruskal.test(Rel..Abund~Trail.Type, data=jag)
boxplot(Rel..Abund~Trail.Type, data=jag)

install.packages("FSA", dep=T)
library(FSA)

test=dunnTest(Rel..Abund~Trail.Type, data=jag)
test

## Use linear modeling (logistic regression)

corjag=jag[c(14,16:21)]
head(corjag)
corjag2=as.matrix(corjag)
cor(corjag2)
```

APPENDIX B continued

```
?corr
# Null model
null_mod=glm(Presence~1, family="binomial", data=jag)
summary(null_mod)
# Full model
full_mod=glm(Presence~Elevation+Bush.Island+Gallery+Lowland+Montane+Savanna+Riverin
e+Hunter_pa, family="binomial", data=jag)
summary(full_mod)
# Remove riverine(not enough presences to include)
mod_vr1=glm(Presence~Elevation+Bush.Island+Gallery+Lowland+Montane+Savanna+Hunter_
pa, family="binomial", data=jag)
summary(mod_vr1)
# Remove montane
mod_vr2=glm(Presence~Elevation+Bush.Island+Gallery+Lowland+Savanna+Hunter_pa,
family="binomial", data=jag)
summary(mod_vr2)
#Remove lowland
mod_vr3=glm(Presence~Elevation+Bush.Island+Gallery+Savanna+Hunter_pa,
family="binomial", data=jag)
summary(mod_vr3)
#Remove gallery
mod_vr4=glm(Presence~Elevation+Bush.Island+Savanna+Hunter_pa, family="binomial",
data=jag)
summary(mod_vr4)

exp(-0.621378)/(1+exp(-0.621378))
#Remove bush island
mod_vr5=glm(Presence~Elevation+Savanna+Hunter_pa, family="binomial", data=jag)
summary(mod_vr5)
AIC(mod_vr5)

stepAIC(full_mod)

model.avg(mod_vr5,mod_vr4,mod_vr3)
library(AICcmodavg)
selection=model.sel(null_mod,full_mod,mod_vr1,mod_vr2,mod_vr3, mod_vr4, mod_vr5,
rank="AIC")
as.data.frame(selection)
??model.sel


## Jaguar Activity Patterns

library(overlap)
```

APPENDIX B continued

```
data("kerinci")
head(kerinci)

class(kerinci$Zone)

#convert decimal time to radians
timeRad <- kerinci$Time * 2 * pi

tig2 <- timeRad[kerinci$Zone == 2 & kerinci$Sps == 'tiger']
densityPlot(tig2, rug=TRUE)

#Test with jaguar data
jags=read.csv("jag_caps_hab.csv", header=T)
head(jags)

jtime_rad=jags$Time_dec * 2 * pi

#Activity patterns on roads vs. other trail types in lowland
#Subset data, calculate time in radians for data subset
jag_lowland=subset(jags, jags$Habitat=="Lowland")
jag_low_time_rad=jag_lowland$Time_dec * 2 * pi
#Roads
jag_roads <- jag_low_time_rad[jag_lowland$Trail_type=="Road" & jag_lowland$Sp_ID ==
'JAG']
densityPlot(jag_roads, rug=T,adjust=.5, main="Lowland - Roads", ylim=c(0,0.1))
#Other trail types
jag_other<- jag_low_time_rad[jag_lowland$Trail_type!="Road" & jag_lowland$Sp_ID ==
'JAG']
densityPlot(jag_other, rug=T,adjust=.5, main="Lowland - Other", ylim=c(0,0.1))
#compare roads versus other trail types--the overlap
par(mfrow=c(1,1))
min(length(jag_roads),length(jag_other))
lowland_trail_ovr=overlapEst(jag_roads,jag_other, type="Dhat1")
overlapPlot(jag_roads,jag_other,adjust=.5, main="", ylim=c(0,.08))
legend('topleft', c("Roads", "Other"), lty=c(1,2), col=c(1,4), bty='n')
#Bootstrap
#Resample roads
roads_boot <- resample(jag_roads, 10000)
#Resample females
other_boot <- resample(jag_other, 10000)
#Bootstrap
jag_roads_other_boot <- bootEst(roads_boot, other_boot, type="Dhat1") # takes a few seconds
#Calculate mean overlap
( BSmean <- mean(jag_roads_other_boot) )
```

APPENDIX B continued

```
#generate CIs (use basic0)
bootCI(lowland_trail_ovr, jag_roads_other_boot)

#Activity patterns on creek beds vs. other trail types in gallery
#Roads
jag_gallery=subset(jags, jags$Habitat=="Gallery")
jag_gal_time_rad=jag_gallery$Time_dec * 2 * pi

#Creek beds
jag_creek <- jag_gal_time_rad[jag_gallery$Trail_type=="Dry Creek Bed" & jag_gallery$Sp_ID
== 'JAG']
densityPlot(jag_creek, rug=T,adjust=.5, main="Gallery - Creek Beds", ylim=c(0,0.1))
#Other trail types
jag_gal_other<- jag_gal_time_rad[jag_gallery$Trail_type!="Dry Creek Bed" &
jag_gallery$Sp_ID == 'JAG']
densityPlot(jag_gal_other, rug=T,adjust=.5, main="Gallery - Other", ylim=c(0,0.1))
#compare creek beds versus other trail types--the overlap
par(mfrow=c(1,1))
min(length(jag_creek),length(jag_gal_other))
gallery_trail_ovr=overlapEst(jag_creek,jag_gal_other, type="Dhat1")
overlapPlot(jag_creek,jag_gal_other,adjust=.5, main="", ylim=c(0,.11))
legend('topleft', c("Creek Beds", "Other"), lty=c(1,2), col=c(1,4), bty='n')
#Bootstrap
#Resample creek beds
creek_boot <- resample(jag_creek, 10000)
#Resample other
gal_other_boot <- resample(jag_gal_other, 10000)
#Bootstrap
jag_creek_other_boot <- bootEst(creek_boot, gal_other_boot, type="Dhat1") # takes a few
seconds
#Calculate mean overlap
( BSmean <- mean(jag_creek_other_boot) )
#generate CIs (use basic0)
bootCI(gallery_trail_ovr, jag_creek_other_boot)

#Hunting pressure in lowland and gallery habitats
#Subset data
low_hab=subset(jags,jags$Habitat=="Lowland")
low_time_rad=low_hab$Time_dec * 2 * pi
#density plot for captures in combined lowland and gallery habitats where hunted
jag_low_hunted <- low_time_rad[low_hab$Hunted == "Yes" & low_hab$Sp_ID == 'JAG']
densityPlot(jag_low_hunted, rug=T,adjust=.5, main="Lowland hunted", ylim=c(0,0.1))
#density plot for captures in combined lowland and gallery habitats where NOT hunted
jag_low_no_hunt <- low_time_rad[low_hab$Hunted == "No" & low_hab$Sp_ID == 'JAG']
```

APPENDIX B continued

```
densityPlot(jag_low_no_hunt, rug=T,adjust=.5, main="Lowland not hunted", ylim=c(0,0.1))

#compare hunted versus not hunted in lowland habitat
par(mfrow=c(1,1))
min(length(jag_low_hunted),length(jag_low_no_hunt))
low_hunt_no_hunt=overlapEst(jag_low_hunted,jag_low_no_hunt, type="Dhat1")
overlapPlot(jag_low_hunted, jag_low_no_hunt,adjust=.5, main="")
legend('topright', c("Hunted", "Not Hunted"), lty=c(1,2), col=c(1,4), bty='n')
#Bootstrap
#Resample gallery
low_hunt_boot <- resample(jag_low_hunted, 10000)
#Resample females
low_nohunt_boot <- resample(jag_low_no_hunt, 10000)
#Bootstrap
jag_lowhunting_boot <- bootEst(low_hunt_boot, low_nohunt_boot, type="Dhat1") # takes a few
seconds
#Calculate mean overlap
( BSmean <- mean(jag_lowhunting_boot) )
#generate CIs (use basic0)
bootCI(low_hunt_no_hunt, jag_lowhunting_boot)


par(mfrow=c(3,2))
#density plot for captures in Bush Island habitat
jag_BI <- jtime_rad[jags$Habitat == "Bush Island" & jags$Sp_ID == 'JAG']
densityPlot(jag_BI, rug=T,adjust=.5, main="Bush Island", ylim=c(0,0.1))
#Lowland
jag_Low <- jtime_rad[jags$Habitat == "Lowland" & jags$Sp_ID == 'JAG']
densityPlot(jag_Low, rug=T,adjust=.5, main="Lowland", ylim=c(0,0.1))
#Montane
jag_Mon <- jtime_rad[jags$Habitat == "Montane" & jags$Sp_ID == 'JAG']
densityPlot(jag_Mon, rug=T,adjust=.5, main="Montane ", ylim=c(0,0.1))
#Gallery
jag_Gal <- jtime_rad[jags$Habitat == "Gallery" & jags$Sp_ID == 'JAG']
densityPlot(jag_Gal, rug=T,adjust=.5, main="Gallery", ylim=c(0,0.1))
#Riverine
jag_Riv <- jtime_rad[jags$Habitat == "Riverine" & jags$Sp_ID == 'JAG']
densityPlot(jag_Riv, rug=T,adjust=.5, main="Riverine", ylim=c(0,0.1))
#Savanna
jag_Sav <- jtime_rad[jags$Habitat == "Savanna" & jags$Sp_ID == 'JAG']
densityPlot(jag_Sav, rug=T,adjust=.5, main="Savanna", ylim=c(0,0.1))


#compare gallery and riverine
```

APPENDIX B continued

```
par(mfrow=c(1,1))
min(length(jag_Gal),length(jag_Riv))
galriv=overlapEst(jag_Gal,jag_Riv, type="Dhat4")
overlapPlot(jag_Gal, jag_Riv,adjust=.5, main="")
legend('topleft', c("Gallery", "Riverine"), lty=c(1,2), col=c(1,4), bty='n')
#Bootstrap
#Resample gallery
Gal_boot <- resample(jag_Gal, 10000)
#Resample females
Riv_boot <- resample(jag_Riv, 10000)
#Bootstrap
jag_galriv <- bootEst(Gal_boot, Riv_boot, type="Dhat4") # takes a few seconds
#Calculate mean overlap
( BSmean <- mean(jag_galriv) )
#generate CIs (use basic0)
bootCI(galriv, jag_galriv)

#compare lowland and montane
par(mfrow=c(1,1))
min(length(jag_Low),length(jag_Mon))
##Less than 50 samples, use Dhat1
lowmon=overlapEst(jag_Low,jag_Mon, type="Dhat1")
overlapPlot(jag_Low, jag_Mon,adjust=.5, main="")
legend('topleft', c("Lowland", "Montane"), lty=c(1,2), col=c(1,4), bty='n')
#Bootstrap
#Resample gallery
Low_boot <- resample(jag_Low, 10000)
#Resample females
Mon_boot <- resample(jag_Mon, 10000)
#Bootstrap
jag_lowmon <- bootEst(Low_boot, Mon_boot, type="Dhat1") # takes a few seconds
#Calculate mean overlap
( BSmean <- mean(jag_lowmon) )
#generate CIs (use basic0)
bootCI(lowmon, jag_lowmon)


#compare lowland and riverine
par(mfrow=c(1,1))
min(length(jag_Low),length(jag_Riv))
##Less than 50 samples, use Dhat1
lowmon=overlapEst(jag_Low,jag_Riv, type="Dhat1")
overlapPlot(jag_Low, jag_Riv,adjust=.5, main="")
legend('topleft', c("Lowland", "Riverine"), lty=c(1,2), col=c(1,4), bty='n')
```

APPENDIX B continued

```
#Bootstrap
#Resample gallery
Low_boot <- resample(jag_Low, 10000)
#Resample females
Riv_boot <- resample(jag_Riv, 10000)
#Bootstrap
jag_lowriv <- bootEst(Low_boot, Riv_boot, type="Dhat1") # takes a few seconds
#Calculate mean overlap
( BSmean <- mean(jag_lowriv) )
#generate CIs (use basic0)
bootCI(lowmon, jag_lowriv)

#compare lowland and bush island
par(mfrow=c(1,1))
min(length(jag_Low),length(jag_BI))
##Less than 50 samples, use Dhat1
lowmon=overlapEst(jag_Low,jag_BI, type="Dhat4")
overlapPlot(jag_Low, jag_BI,adjust=.5, main="")
legend('topleft', c("Lowland", "Bush Island"), lty=c(1,2), col=c(1,4), bty='n')
#Bootstrap
#Resample gallery
Low_boot <- resample(jag_Low, 10000)
#Resample females
BI_boot <- resample(jag_BI, 10000)
#Bootstrap
jag_lowbi <- bootEst(Low_boot, BI_boot, type="Dhat4") # takes a few seconds
#Calculate mean overlap
( BSmean <- mean(jag_lowbi) )
#generate CIs (use basic0)
bootCI(lowmon, jag_lowbi)


#### Looking at between sex differences
par(mfrow=c(2,1))
#Males only--all habitats (general activity pattern)
jag_male <- jtime_rad[jags$Sex == "Male" & jags$Sp_ID == 'JAG']
densityPlot(jag_male, rug=T,adjust=.2, main="Male Jaguar Captures", ylim=c(0,0.08))

#Females
jag_female <- jtime_rad[jags$Sex == "Female" & jags$Sp_ID == 'JAG']
densityPlot(jag_female, rug=T,adjust=.2, main="Female Jaguar Captures")
##Overlap test
min(length(jag_male),length(jag_female))
## Over 50, use type=Dhat4
```

APPENDIX B continued

```
par(mfrow=c(1,1))
mf2est=overlapEst(jag_male,jag_female, type="Dhat4")
overlapPlot(jag_male, jag_female,adjust=.2, main="")
legend('topleft', c("Males", "Females"), lty=c(1,2), col=c(1,4), bty='n')


#Bootstrap males
maleboot <- resample(jag_male, 10000)
dim(maleboot)
#Bootstrap females
femaleboot <- resample(jag_female, 10000)
dim(femaleboot)

jag_mac <- bootEst(maleboot, femaleboot, type="Dhat4") # takes a few seconds
( BSmean <- mean(jag_mac) )
#generate CIs
bootCI(mf2est, jag_mac)
bootCIlogit(mf2est, jag_mac)
```

APPENDIX C

KEY CHARACTERISTICS OF BUSH DOG, CRAB-EATING FOX, AND DOMESTIC DOG

	Bush Dog	Crab-eating Fox	Domestic Dog
Size:	HB: 610 - 750 mm; T: 110 - 130 mm; HF: 110 – 120 mm; EE: 40 – 51 mm; WT: 5 – 7 kg	HB: 590 - 765 mm; T: 22 - 41 mm; HF: 132- 165 mm; EE: 66 -80 mm; WT: 4.5-8.5 kg	HT: 380 – 570 mm; WT: 10 - 18 kg, (variable based on breed)
Legs / Feet:	Legs very short, black or dark brown in coloration, webbed feet	Feet and lower legs usually brown, darker than body coloration, feet not webbed	Long legs and relatively large feet, in proportion with body length, feet not webbed
Head:	Broad, bear-like head, short muzzle, small brown eyes	Pointed, fox-like head, muzzle darker brown than cheeks	Head relatively small compared to body, long and rounded snout, coloration same as body
Ears:	Short, rounded ears	Medium-sized, thinly haired, without thick pale hair on inner rim, pointed, upright	Ear shape and position variable, used to communicate emotional state, often pointed at tip, sometimes drooping
Body:	Small stocky dog unlike any other canid with a long cylindrical body, very short legs	Medium-sized fox, elongated body, relatively short legs, full tail	Body length in proportion with head and legs, variable based on breed
Coat:	Long and soft fur, coloration varies from blonde to dark brown, usually pale brown to tawny yellow around the head and neck, darkening gradually to dark brown hindquarters and tail, sometimes white spot on chest	Course fur, upper body dark grizzled grey with light to heavy black streaks, mid back with streak from head to tail, neck tawny orange, underparts cream to buff – dark bristly appearance	Single coat of course guard hair, often with counter shading – darker coloration on back and lighter coloration on underparts

APPENDIX C continued

Tail:	Short, stumpy tail, black in coloration and thickly furred	Moderately bushy, shorter than hind leg, black at the tip	Thin, straight tails, generally used to communicate emotional state
Call:	Groups communicate with high-pitched whining, yap while chasing prey	"Sings" with tonal cry	Short, yapping barks
Key Attribute:	Short bushy tail, webbed feet, broad head, short ears, cylindrical body	Long, bushy tail, relatively short legs, small feet, pointy snout	Long, thin tail, relatively long legs, large feet

APPENDIX D
SPECIES IDENTIFICATION SLIDES

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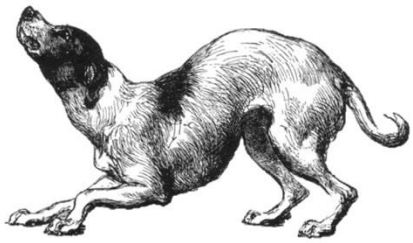

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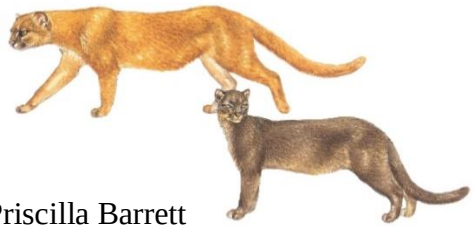

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[adapted from Hunter, L., & Barrett, P. (2011). *Carnivores of the world*. Princeton University Press, New Jersey.]

APPENDIX D continued

[adapated from www.arkive.og]

APPENDIX D continued

[photos courtest of Matt Hallett]

APPENDIX E
BUSH DOG INTERVIEW DATA SHEET

Witness Name: _____ **Village:**_____

Verbal Consent? Y / N

Signed Consent: I, _____(name) hereby acknowledge that I have provided a truthful account of a firsthand encounter with bush dogs (*Speothos venaticus*) in the Rupununi, Guyana. I understand that this account will be reproduced in a scientific publication with proper recognition given to me by name in the form of (*Name*, pers. comm.).

_____ Date: _____

Date of Encounter (or nearest estimate):

_____

Season: Rainy / Dry (circle one)

Description of weather conditions:

_____

_____

Time of day: Day / Night / Dawn / Dusk / Morning / Midday / Afternoon

Anyone else that can confirm sighting? Y / N **Name:** _____

GPS Location: _____ **Sighting In:** Forest / Savanna

Location Near To: River / Creek / Road / Trail / Village / Farm / Hunting Spot / Other

Description of Location:
_____

APPENDIX E continued

How many animals: _____

Length of encounter: _____

Interactions: Vocalizations / Sniffing / Feeding / Tail wagging / Biting / Growling / Hunting

Noticeable Behaviors:

_____

_____

Description of animal:

_____

_____
____

APPENDIX F
BUSH DOG INTERVIEW DATA

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
Jul-12	Iwokrama ICRCD	4.6529	-58.6848	Screaming Piha trail near Iwokrama Field Station	Lowland Forest	3	Running through forest away from forest edge/station clearing	B. Lim / T. Horsley
Aug. 2013	Iwokrama ICRCD	4.6238	-58.7140	GT-Lethem Road near 3-mile check point	Lowland Forest	1	Crossing road	M. Davis
N/A	Iwokrama ICRCD	4.4266	-58.8055	GT-Lethem road at Bamboo Creek	Lowland Forest	4	Crossing road	B. Allicock
N/A	Iwokrama ICRCD	4.3834	-58.8378	GT-Lethem Road near Big Turu Creek	Lowland Forest	4	Running alongside road	K. Singh
N/A	Iwokrama ICRCD	4.2590	-58.8620	Iwokrama forest along mtn. foot near Atta Lodge	Lowland Forest	2	Pursuing *Ciniculus paca*	P. Allicock
N/A	Iwokrama ICRCD	4.2583	-58.8349	Iwokrama forest along mtn. foot near canopy walkway	Lowland Forest	6	Pursuing *Ciniculus paca*	P. Allicock
N/A	Iwokrama ICRCD	4.3876	-58.8679	Iwokrama forest in Big Turu Creek, not far from GT-Lethem road	Lowland Forest	2	Pursuing *Dasyprocta leporina*	K. Singh
2016	Iwokrama ICRCD	4.2490	-58.9190	GT - Lethem Road just after turn off for canopy walkway, photographed near bridge	Lowland Forest	4	Protographed crossing GT - Lethem Highway	R. McDermott

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
2017	Iwokrama ICRCD	4.2460	-58.9270	GT - Lethem Road just after turn off for canopy walkway	Lowland Forest	6	Observed crossing GT - Lethem Highway	G. Sway
2010	Iwokrama ICRCD	4.1832	-59.0396	GT-Lethem Road near south gate	Lowland Forest	2	Two pups found dead alongside road, suspected road kill	A. Roopsind
N/A	Surama Village	4.1547	-58.0623	GT-Lethem road near Surama Gate	Lowland Forest	3	Crossing road	D. Allicock
2012	Surama Village	4.1279	-59.0646	GT-Lethem road near Surama Junction	Lowland Forest	2	Crossing road	S. James / L. Haynes
N/A	Surama Village	4.1554	-59.0855	Traditional farming areas near Surama Pond	Lowland Forest	5	Pursuing *Ciniculus paca*	M. Captain
2004	Surama Village	4.1419	-59.0902	Tractor road near traditional farming grounds	Lowland Forest	5	Pursuing *Ciniculus paca*	F. Milton
Sept. 2013	Surama Village	4.1526	-59.1096	Tractor road near traditional farming grounds	Lowland Forest	4	Crossing road	K. Singh
Aug. 2013	Surama Village	4.1397	-59.1443	Surama forests in Pakaraima Mountains near Sabba Creek	Montane Forest	6	Pursuing *Ciniculus paca*	B. Allicock
Jan. 2014	Surama Village	4.1073	-59.1354	Crossing savanna from mtn. forest through Camodi Bash (swamp)	Savanna	4-6	Crossing road	F. Buckley
N/A	Surama Village	4.1250	-59.0938	Running through the forest near Surama Creek	Lowland Forest	3-5	Running in single file line through forest	E. Allicock
2004	Surama Village	4.1308	-59.1025	Road/culvert leading into Surama, over creek near forest/savanna edge	Lowland Forest	4	Crossing road leading into village	K. Singh

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
1977	Rupertee Village	3.9754	-59.1233	Tractor road near traditional farming grounds	Savanna	1	Crossing road	E. Vanlong
1979	Rupertee Village	4.0095	-59.1449	Tractor road near traditional farming grounds	Montane Forest	12	Crossing road	S. Andries
N/A	Rupertee Village	3.9969	-59.1278	In savanna crossing between mountain forests	Savanna	1	Crossing road	M. Vanlong
1999	Rupertee Village	4.0076	-59.1323	Tractor road near traditional farming grounds	Montane Forest	3-6	Crossing road; Barking	G. Duarte
2004	Rupertee Village	4.0095	-59.1449	Tractor road near traditional farming grounds	Montane Forest	4	Crossing road	J. Sciptio
1994	Rupertee Village	4.0105	-59.1588	Creek bed in forested area near traditional farming grounds	Montane Forest	2	Crossing dry creek bed	C. Vanlong
2012	Rupertee Village	4.0284	-59.1369	Traditional hunting grounds in high forest far from village (back dam)	Montane Forest	10	Drinking water from a small and mostly dry creek bed	J. Vanlong
N/A	Rupertee Village	4.0239	-59.1377	Forested area near bush mouth near village and traditional farming area	Lowland Forest	8	Crossing road; Pursuing *Ciniculus paca*	J. Vanlong
N/A	Rupertee Village	3.9754	-59.1233	Found near small pond and traditional farming grounds	Montane Forest	1	Found pup raised as pet for 1 year; died in captivity in Lethem	J. Vanlong
1970's	Apoteri Village	4.0152	-58.5764	Captured along traditional balata harvesting route	Lowland Forest	1	Found pup raised as pet; died in captivity	S. Andries

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
N/A	Rewa Village	3.9680	-58.7990	Lowland forest area near traditional farming grounds	Lowland Forest	3-6	Running through forest	C. Haynes
~2010	Rewa Village	3.9730	-58.8020	Lowland forest area near traditional farming grounds	Lowland Forest	4	Running through the forest in a single file line, barking as they ran	C. Edwards
N/A	Berbice River	3.9195	-58.3381	Animals captured near Berbice River, held in East Bank Demerara	Lowland Forest	8	Animals captured and transferred to exporter on the coast	W. Melville
Nov. 2013	Yakarinta Village	3.9575	-59.2518	GT-Lethem road near Yakarinta Junction	Savanna	3	Running alongside road	V. Edwards
N/A	Aranaputa Village	3.9044	-59.4195	Near village crossing an open area between mountain forests	Savanna	4-7	Pursuing *Dasyprocta leporina*	V. Hamilton
2000	Toka Village	3.9160	-59.3816	Rocky area near village, forest edge, mountain foot and small stream	Savanna	5	Sleeping with pups in hole btw. rocks; Growled when disturbed	K. Davis
2007	Karasabai Village (Kaibaiku)	4.1355	-59.5318	Crossing a swampy area in savanna btw. montane forest and bush island	Savanna	4-6	Pursuing *Mazama americana*	K. Davis
~2010	Karasabai Village	4.1130	-59.5880	Traditional hunting grounds in Pakaraima Mountains above farming grounds	Montane Forest	3	Running through the forest, Sniffing along the ground	A. Albert

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
Mar. 2012	Kwaimatta Village	3.8131	-59.3006	Along Rupununi River near traditional farming grounds	Gallery Forest	4	Running along Rupununi River; Some biting/growling noises	H. Ambrose
N/A	Yupukari Village	3.6564	-59.3611	Along Awarikuru Lake near traditional farming grounds	Gallery Forest	3	Running in single file line along hill foot	H. Ambrose
2013	Quattata Village	3.6595	-59.4760	In bush island along a creek on hill top near Old Dutch Fort	Bush Island	5	Wandering – Sniffing along the ground; Playful interactions	M. Mandook
N/A	Quattata Village	3.6419	-59.4913	Near large bush island on hill top near Old Dutch Fort	Savanna	2	Walking in open savanna along forest edge	M. Mandook
N/A	Markanata Village	3.6420	-59.5030	Marakanata bush island near bush edge and close to a pond	Bush Island	3	Pursuing *Mazama americana*	M. Mandook
N/A	Markanata Village	3.6370	-59.4950	Middle of Markanata bush island near small creek	Bush Island	1	Running through forest; Sniffing along the ground	M. Mandook
2017	Markanata Village	3.6490	-59.5310	Running through long grass along Pirara Creek	Savanna	5	Pursuing *Sus scofra* sow with piglets, kill observed, individuals chased off by observer on horseback	J. Fidel
N/A	Markanata Village	3.6620	-59.5310	Savanna area between several large bush islands, ~2 mi from main road	Savanna	5	Crossing road	F. Li
2008	Nappi Village	3.3696	-59.5110	Traditional hunting area in mountains near Maipaima Lodge	Montane Forest	6	Pursuing *Ciniculus paca*	D. Aldie

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
N/A	Nappi Village	3.3981	-59.5645	Along forest edge, bush mouth area near traditional farming grounds	Savanna	4	Running in savanna along the forest edge	G. Fredericks
2013	Nappi Village	3.3239	-59.5175	Running along a flat hill top behind Nappi Mountain	Montane Forest		Running through the forest, Sniffing along the ground	M. David
Feb. 1983	Manari Ranch	3.4479	-59.8202	Traditional hunting area along the Takutu River and Manari Creek	Gallery Forest	4	Pelt of an individual shot by hunter who encountered group along creek	C. Melville
N/A	Katoka Village	3.5270	-59.2925	Along Simoni Creek in traditional hunting grounds	Lowland Forest	5	Pursuing *Mazama nemorivaga*	K. Edwards
N/A	Kanuku Mountains Protected Area	3.3820	-59.3060	Along the Rupununi River near the mouth of Hiari Creek	Gallery Forest	4	Pursuing *Ciniculus paca*	B. Lawrence
N/A	Kanuku Mountains Protected Area	3.4408	-59.1687	Along Simoni Creek far from any use areas	Lowland Forest	3	Running along riverbank on Simoni Creek	K. Mandook
N/A	Kanuku Mountains Protected Area	3.3358	-59.2614	Along Mapari Creek in tourism area near traditional farming grounds	Montane Forest	3-6	Sitting in understory vegetation along the riverbank	D. DeFreitas
1976-1978	Kanuku Mountains Protected Area	3.2717	-58.9512	Simoni Creek head near traditional balata, fishing and hunting grounds	Lowland Forest	3-5	Pursuing *Ciniculus paca*	R. Merriman

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
2008	Moco Moco Village	3.3037	-59.6358	High forest traditional hunting area near Kumaka Falls	Montane Forest	1	Wandering – Sniffing along the ground with head down	L. Piash
2009	Moco Moco Village	3.2898	-59.6816	Near traditional farming grounds south of village at Raguaga Falls	Montane Forest	4	Pursuing *Tupinambis teguixin*	K. Ambrose
2011	Moco Moco Village	3.2989	-59.6714	Traditional farming grounds at Raguaga Falls	Lowland Forest	1	Pursuing *Ciniculus paca*	K. Ambrose
Mar. 2013	Moco Moco Village	3.2754	-59.7027	Along mountain foot near Moco Moco creek	Montane Forest	3	Wandering – Sniffing along the ground and in the air	C.S. Williams
2012	Moco Moco Village	3.2835	-59.6969	Traditional framing grounds near Moco Moco creek	Lowland Forest	4	Female moving 3 pups from den site	L. Campion
N/A	Moco Moco Village	3.3274	-59.7306	Open savanna between Moco Moco and Lethem	Savanna	2	Walking across savanna towards forest, recently pursued prey	L. Campion
2008	Moco Moco Village	3.2661	-59.7123	Along Cruza Creek in traditional hunting grounds	Montane Forest	2	Wandering – Sniffing along the ground and in the air	L. Aldie
Dec. 2013	Moco Moco Village	3.2732	-59.7126	Along Cruza Creek in traditional hunting grounds	Montane Forest	3-4	Vocalizations and tracks identified leading to den site	L. Aldie
Jan. 1985	Quarrie Village	3.2369	-59.7518	Along creek near traditional farming grounds and forest/savanna border	Lowland Forest	5	Pursuing *Ciniculus paca*	F. Raymundo

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
N/A	Quarrie Village	3.2203	-59.7644	Traditional hunting area near small creek and farming grounds	Lowland Forest	4	Pursuing *Ciniculus paca*	K. Peter
N/A	Quarrie Village	3.2191	-59.7499	Traditional hunting area near small creek and farming grounds	Lowland Forest	3-5	Pursuing *Ciniculus paca*	P. Morari
N/A	Parikwarnau Village (Imprenza)	3.1008	-59.8033	Traditional hunting area near creek and isolated mountain	Gallery Forest	2	Pursuing *Pecari tajacu*	C. Melville
N/A	Parikwarnau Village (Imprenza)	3.0563	-59.7980	Traditional hunting area near creek and isolated mountain	Savanna	4	Crossing savanna between mountain forest and creek	C. Melville
N/A	Shulinab Village	3.0552	-59.7184	Savanna near village and bush edge, animal run down and hand caught	Savanna	1	Animal captured and kept in captivity shortly and released	M. Malcom
~2005	Shulinab Village	3.0810	-59.5810	Traditional hunting area near farming grounds	Montane Forest	8	Pursuing *Ciniculus paca*	G. Bell
~2010	Shulinab Village	3.0860	-59.5780	Traditional hunting area near farming grounds	Montane Forest	4	Running through the forest in a single file line	G. Bell
N/A	Meriwau Village	3.0675	-59.6704	Traditional hunting grounds near forest edge of Kanuku Mountains	Savanna	1	Pursuing *Ciniculus paca*	G. Peter
N/A	Sand Creek Village	3.2017	-59.4113	Along Rupununi River and mtn. foot near traditional farming grounds	Montane Forest	3-4	Pursuing *Ciniculus paca*	A. Jackman

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
N/A	Sand Creek Village	3.1829	-59.3877	Along Rupununi River and mtn. foot near traditional farming grounds	Montane Forest	6-8	Pursuing *Dasyprocta leporina* near a foot trail along the Rup. R.	B. Phillips
1980	Potarinau Village	3.0360	-59.7663	Traditional hunting ground near farming area	Lowland Forest	2	Pair mating/fighting; Young adult male captured, held in captivity	J. George
1980's	Kusad Mountain	2.7948	-59.8421	Traditional farming areas at the foot of Kusad Mountain	Lowland Forest	4	Pursuing *Ciniculus paca*	J. George
1980's	Dog mountain	2.7247	-59.9401	Traditional grazing area near small mountain named for bush dogs	Bush Island	5	Running along mountain foot	J. George
Late 1990's	Katoonarib Village	2.736	-59.584	Several bush dogs kept in the village as pets	Bush Island	3	Several individuals held in local captivity	A. Wilson
1960's	Dadanawa Ranch	2.824741	-59.524431	Pups found along trail to Kwitaro River; raised to adults at the ranch	Lowland Forest	4	Four pups kept as pets; survived into adulthood; deposited as specimens in Natural History Museum in London	
~2005	Dadanawa Ranch	2.824741	-59.524431	Pups found in hollow log near Kwitaro River; kept at ranch as pets alongside dom. dogs	Lowland Forest	3	Three pups kept as pets; did not survive until adulthood; believed to have contract *Leptospirosis* sp.	

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
N/A	Rupunau Village	2.9415	-59.3646	Traditional hunting grounds in bush islands on hill tops near the village	Bush Island	4	Pursuing *Ciniculus paca*	L. Ignacio
N/A	Rupunau Village	2.9313	-59.3367	Traditional hunting grounds in bush islands on hill tops near the village	Bush Island	3	Wandering – Sniffing along the ground and in the air	L. Ignacio
1960's	Shea Village	2.8280	-59.0380	Pups encountered along a trail from village to traditional fishing grounds along Kwitaro R.	Lowland Forest	4	Found pups raised as pets; died in captivity as adults at Dadanawa Ranch; deposited as specimens	S. Brock
N/A	Awarunau Village	2.6654	-59.1947	Animal caught in bush island on a hill near the village	Bush Island	1	Found pup raised as pet; died in captivity	T. Griffith
N/A	Maruranau Village	2.7662	-59.2021	Animal found near village	Savanna	1	Animal found near village, kept in local captivity for some time	G. Pereira
N/A	Kwitaro River	2.8343	-59.5156	Animals found in a hollow log near the Kwitaro River	Lowland Forest	3	Found pups raised as pets; died in captivity at Dadanawa Ranch	D. DeFreitas
N/A	Bamboo Creek (Rewa River)	3.1512	-58.6263	Lowland forest along river bank ~70 miles up Rewa River	Lowland Forest	3-4	Standing on high riverbank along the edge of Bamboo Creek	D. Laurentino
2005	Rewa River	2.7825	-58.6186	Lowland forest along river bank near the head of the Rewa River	Lowland Forest	8	Standing near Rewa River on a small sand bank	A. Holland
N/A	Rewa River	2.7220	-58.5990	Lowland forest along river bank near the head of the Rewa River	Lowland Forest	3-5	Running along riverbank on Rewa River	D. DeFreitas

APPENDIX F continued

Date	Site	Lat	Long	Location	Habitat	# of ind.	Behavior	Observer
N/A	DTL Logging Concession	4.5757	-58.5581	Logging road in privately held concession – near Essequibo River	Lowland Forest	3-6	Crossing logging road	H. James
2008	Mango Landing (Region 8)	5.3080	-58.9360	Found along mining access road as pups, given to wildlife trader with facility on the East bank of the Demerara	Lowland Forest	4	Bush dogs discovered as pups, adult not observed nearby; Observed being held by an international wildlife trader	M. Pierre
N/A	Paramakatoi Village (Region 8)	4.7777	-59.6213	Animal captured in Pakaraima Mtns., held in Paramakatoi Village	Montane Forest	1	Found pup raised as pet; died in captivity	E. Edwin
2015	Bai Shan Lin Concession (Region 10)	4.1539	-58.1773	Lowland forest within Bai Shan Lin logging concession	Lowland Forest	3	Crossing logging road during biodiversity survey	L. Ignacio
N/A	Dubulay Ranch (Region 10)	5.6680	-57.8880	Open intermediate savanna in Dubulay Ranch	Savanna	2	Running through open savanna in the middle of the day	A. Mendes
N/A	Berbice Road (Region 10)	5.6370	-58.2830	Lowland forest along Berbice Road	Lowland Forest	2	Crossing the Berbice Road	A. Mendes
N/A	Berbice Road (Region 10)	5.6060	-58.1780	Berbice Road near Dubulay Ranch	Lowland Forest	1	Adult bush dog found dead along road, suspected road kill	A. Mendes

APPENDIX G
IDENTIFICATION OF KNOWN INDIVIDUAL ANTEATERS FROM AZA INSTITUTIONS

Institution	Anteater Name	Sex	# of photos	Positive ID (Y/N)	Reason for incorrect ID	Photo Credits
Brevard Zoo	Abner	Male	3	Yes	n/a	Kerry Sweeney
Brevard Zoo	Boo	Female	4	Yes	n/a	Kerry Sweeney
Brookfield Zoo	Lupito	Male	2	Yes	n/a	n/a
Buffalo Zoo	Delilah	Female	2	Yes	n/a	n/a
Buffalo Zoo	Haji	Male	2	Yes	n/a	n/a
Cleveland Metroparks Zoo	Amendi	Male	2	Yes	n/a	n/a
Cleveland Metroparks Zoo	Kutter	Male	2	Yes	n/a	n/a
Cleveland Metroparks Zoo	Pica	Female	2	Yes	n/a	n/a
Dallas Zoo	Jimi	Male	2	Yes	n/a	n/a
Dallas Zoo	Tullah	Female	2	Yes	n/a	n/a
Fresno Chaffee Zoo	Caliente	Male	2	Yes	n/a	Meghan Kelly
Greensboro Science Center	Eury	Male	5	Yes	n/a	n/a
Houston Zoo	Olive	Female	3	Yes	n/a	n/a
Houston Zoo	Pablo	Male	3	Yes	n/a	n/a
Houston Zoo	Rio	Female	4	Yes	n/a	n/a
Jacksonville Zoo & Gardens	Killroy	Male	4	Yes	n/a	John Reed
Jacksonville Zoo & Gardens	Stella	Female	7	Yes	n/a	John Reed
Palm Beach Zoo	Cruz	Male	3	Yes	n/a	n/a
Palm Beach Zoo	Odelia	Female	3	Yes	n/a	Nancy Nill
Phoenix Zoo	Beaker	Male	11	Yes	n/a	Carrie Flood

APPENDIX G continued

Institution	Anteater Name	Sex	# of photos	Positive ID (Y/N)	Reason for incorrect ID	Photo Credits
Potawatomi Zoo	Jo Hei	Male	7	Yes	n/a	n/a
Reid Park Zoo	Curl Tail	Male	3	Yes	n/a	n/a
Reid Park Zoo	Sophia	Female	3	Yes	n/a	n/a
Sacramento Zoo	Amber	Female	2	Yes	n/a	n/a
San Antonio Zoo	Sprout	Female	5	No	Low pixel images	n/a
San Antonio Zoo	Humphrey	Male	7	Yes	n/a	n/a
Sedgewick County Zoo	Ibini	Female	5	Yes	n/a	Steve Jones
Sedgewick County Zoo	Matteo	Male	4	Yes	n/a	n/a
Sunset Zoo	Angelina	Female	5	Yes	n/a	n/a
Turtle Back Zoo	Barques	Male	15	No	Low pixel images	n/a
Zoo Boise	McCauley	Male	2	Yes	n/a	n/a
Zoo Boise	Gloria	Female	2	Yes	n/a	n/a
TOTALS	32	18 M 14 F	128		n/a	

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BIOGRAPHICAL SKETCH

Matthew Thomas Hallett was born and raised in Chicago, Illinois. He received a Bachelor of Arts in biology with minors in environmental studies and political science from the College of Charleston in 2005 and a Master of Arts in zoology with a concentration in community-based conservation from Miami University in 2009. He previously worked in public education at the zoos and aquariums in the U.S. and in research and community-based conservation in Kenya, South Africa, Malaysian Borneo, and Guyana. Experiences in the field have inspired Matt to consistently pursue work that falls at the intersection of humans and nature with the challenge of developing creative solutions that maximize the benefits to both.