Chimpanzees in the Island of Gold:
Impacts of artisanal small-scale gold mining on chimpanzees (*Pan troglodytes verus*) in Fongoli, Senegal

by

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DEDICATION

To my mother, Ellen Slentz.

For helping to make my dreams become a reality

and

In memory of

Saiba Keita

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ACKNOWLEDGMENTS

When I first decided to go back to graduate school I was given the advice that if I wanted to study chimpanzees I needed to meet Jill Pruetz. I was directed to a conference and ushered in front of her to make a rather awkward introduction of myself. Twelve years later, I cannot thank Jill enough for her support and confidence in me and my work, especially during trying moments that Senegal can so often produce. I would also like to thank my committee members for their support and guidance, through proposal and committee changes, and especially in my decision to continue my doctoral program from the far reaches of the Upper Peninsula.

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ABSTRACT

Despite its historical and global pervasiveness, little quantitative research has been conducted on artisanal small-scale gold mining (ASGM) and terrestrial wildlife. Using an ethnoprimatological approach, this body of work evaluates the impacts of anthropogenic activity associated with ASGM on a community of savanna chimpanzees (*Pan troglodytes verus*) living in a complex and coupled human and natural system. Research was conducted in Senegal where the recent intensification of ASGM has increased the local human population, polluted, and degraded the environment, and threatens the habitat of critically endangered West African savanna chimpanzees. To quantify the impacts of ASGM, we analyzed 10 years of chimpanzee observational data from the Fongoli Savanna Chimpanzee Project (FSCP) database related to human-chimpanzee encounters, chimpanzee behavior, and habitat use. During the study period, ASGM increased from a few seasonal miners to seven intensively mined sites and shifted local livelihoods from non-timber resource collection to gold mining. As ASGM increased, we found corresponding increases in human-chimpanzee encounters and human-initiated interactions. Chimpanzee behavior related to ASGM was complex and varied with spatial and temporal scales. At the level of home range, we observed a shift in ranging patterns toward the largest mine during initial and low-level activity. As mining expanded and increased in intensity, the home range shifted away, resulting in the avoidance of preferred land cover types and the use of poorer quality habitat types. The expansion of the largest mine also blocked previously used travel routes to feeding patches**.** At the finer scale of mining areas, mining activity increased the apes' use of anthropogenic areas, particularly on weekdays when miners were absent. The presence of miners did not change chimpanzee use of forested and woodland areas adjacent to mining sites, however. When at the ASGM sites, the apes inspected materials left by the miners and drank water from mining pits, perhaps assessing the novel disturbance and potential risks. However, risks associated ASGM activities (i.e. mercury toxicity, exposure to human fecal pathogens, degradation of forest resources, and risks associated with uncovered and abandoned pits) are likely to go unperceived by chimpanzees and may pose a more insidious threat to chimpanzee conservation in the form of an ecological trap.

CHAPTER I

INTRODUCTION: WEST AFRICAN CHIMPANZEES

Chimpanzees (*Pan troglodytes*) range across the equatorial belt of Africa longitudinally from Uganda to Guinea Bissau and latitudinally from Tanzania to Senegal (Figure 1). The species is subdivided into four subspecies (Fischer et al., 2006), although some phylogenetic approaches suggest the possibility of six (Gonder et al., 2011). West African chimpanzees (*P.t. verus*) show the greatest genetic differentiation among the subspecies, with a split from eastern chimpanzees (*P.t. schweinfurthii*) approximately 500,000 years ago. This, along with distinctly different behavioral traits (Yamakoshi, 2004), has led to some speculation on the possibility of splitting *Pan troglodytes* into two separate species (Boesch, 2009; Last, 2012).

Much of our understanding of *Pan* grew out of foundational studies of the east African chimpanzee subspecies living in the closed canopy forests and woodlands of Tanzania. At the Gombe Research Center in Tanzania, Goodall (1986) studied tool use, community structure, social relationships, and aggression. In other parts of Tanzania, Japanese researchers including Kinji Imanishi and his students established other foundational study sites that, like Gombe, continue today (e.g. Mahale). Toshisada Nishida continued the work of Imanishi and founded the Mahale field site in 1965, making it the second longest run chimpanzee research site next to the Gombe Stream Research Center project, which began in 1960 (Goodall, 1986). During the same time period, Vernon Reynolds, Frankie Reynolds and Yukimara Sugiyama began studying the chimpanzees of Uganda (Reynolds and Reynolds, 1965; Sugiyama, 1968) and describing the fission-fusion social organization of the species (Reynolds, 2005).

In the late 1960s, research began in West Africa, first at Bossou, Guinea (Sugiyama, 1981) followed by sites in Cote d'Ivoire (Tai National Park – Boesch and Boesch-Achermann, 2000) and Senegal (Mt. Assirik in Niokolo-Koba National Park – McGrew et al., 1981) in the 1970s. Senegal stands out from the other sites, as it is the northern most extent of the chimpanzee geographic range as well as the hottest and driest environment (Hunt and McGrew, 2002). Previous research had also begun in savanna environments in East Africa in the 1970s (Ugalla – Itani, 1978). Although the chimpanzees at Mt. Assirik were not habituated during the four-year study (1976-1979), differences between these and forest chimpanzees were apparent (Tutin et al., 1983; McGrew et al., 1981; Baldwin et al., 1982). The savanna vegetation, rainfall and temperature were so drastically different from other chimpanzee study sites that more studies of savanna chimpanzees followed (Moore, 1996; Hunt and McGrew, 2000; Pruetz et al., 2002) but with varying levels of success in habituating subjects.

Researchers returned to Mt. Assirik in 2000 to conduct nest surveys and population density estimations. Results indicated a chimpanzee population density of 0.13 chimpanzees per km^2, an increase from the population density estimate of 0.09 chimpanzees per km^2 in the earlier, 1970s studies (Pruetz et al., 2002). In 2015, a new chimpanzee field site was started at Mt. Assirik with the goal to habituate the resident chimpanzee community (S. Lindshield and S. Bogart, pers. comm). Although our knowledge of savanna chimpanzees is growing, a disparity between studies of forested and savanna chimpanzees remains (Lindshield, 2014). As of 2014, 13 long-term (> 10 years of continuous study) field sites had been established to study chimpanzees (Wilson, et al., 2014). Only one of these study sites, Fongoli, occurs in a savanna ecosystem.

Senegal's savanna chimpanzees

West African chimpanzees range from the Dahomey Gap in Ghana to the southeastern corner of Senegal. The subspecies has been extirpated from The Gambia, Benin, Togo, and Burkina Faso (Kormos et al., 2003; Ginn, 2013). In Senegal, the chimpanzee population was most recently estimated at around 300 individuals (Carter et al., 2003), but this number is likely an underrepresentation. As survey efforts have been more extensive and research activities increased, new chimpanzee communities have been discovered and known communities are better understood. Since the 2003 report on West African chimpanzees (Kormos et al., 2003), some countries have seen population estimates increase as research methods and coverage improve (Sierra Leone – Carlen et al., 2011; Liberia – Tweh et al., 2014), while other countries have seen dramatic declines (Côte d'Ivoire – N'Goran et al., 2013) or confirmed extirpation (Burkina Faso – Ginn, 2013).

Using updated publications and information available, I estimate the population of Senegal's chimpanzees is likely closer to 500-1200 individuals, not considering any possible growth or decline in population. Rather, as research presence has increased across the country more chimpanzee communities have been identified and, as research methods have diversified (e.g. camera traps – Boyer-Ontl and Pruetz, 2014), details of the density and demographics of groups have improved. To reach the updated population estimate, I calculated group estimates for areas with confirmed chimpanzee presence (Table 1). Some of the sites listed in Carter et al. (2003) have been studied further and more information is now available on contiguousness of the chimpanzee communities (e.g. chimpanzee nests at Fongoli, Ngari and Djendji belong to the same chimpanzee community, while Bantankilin is a separate community). Other chimpanzee communities have also since been identified and added to the list. Using known group sizes for Drambos (Boyer-Ontl and Pruetz, 2014), Balengoma (Boyer-Ontl and Pruetz, 2014), and Fongoli (Pruetz et al., 2016), I calculated an average chimpanzee group size of 29 individuals. For areas with confirmed chimpanzee communities but unknown population estimates I used the calculated average. For areas where few nests have been observed, I used the minimum possible group size as an estimate. Minimum possible group size was set at 13 (the smallest estimated group size in Senegal from the Nathia community - Gaspersic and Pruetz, 2011) and the maximum possible group size was set at 32 (the largest known group size in Senegal from the Fongoli community). For Angafou, Nathia and Bandafassi, I calculated group size based on the reported average dry season party size from Gaspersic and Pruetz (2011) relative to the dry season party size at Fongoli with a known community size.

In 2000, Pruetz expanded study of Senegalese chimpanzees from the Nikola Koba National Park into unprotected areas and established the Fongoli field site (Pruetz et al, 2001). At Fongoli, Pruetz et al. (2002) found chimpanzees living in close proximity to people and competing for food and water resources. The research site was established in April 2001, and Pruetz and her team began the process of habituation to study the behavior of savanna chimpanzee behavioral ecology, as well as their relationship to their human neighbors and the anthropogenic environment. Focal follows of habituated chimpanzees at Fongoli began in early 2005 and striking differences between forest and savanna chimpanzee behavior emerged. The research at Fongoli directly addresses these differences and suggests that understanding the diversity of chimpanzee ecological adaptations may help to shed light on the earliest hominins' behavioral ecology in similar habitats (Pruetz and Bertolani, 2009).

The most obvious difference between the forest and savanna habitats is the amount of evergreen canopy cover. This ecological difference results in behavioral differences between chimpanzee communities, particularly in thermoregulatory behaviors. The open habitat of the savanna, paired with a long dry season, creates a hot environment with few areas for respite. Chimpanzees in Senegal have adjusted to this hot, dry, open environment by cooling themselves in pools of water (Pruetz and Bertolani, 2009), being active in the cooler temperatures of the nighttime (Pruetz and Bertolani, 2009; Boyer-Ontl and Pruetz, 2014), and entering caves where temperatures are cooler (Pruetz 2007; Boyer Ontl and Pruetz, in review). While nighttime activity is not unique to Senegalese or savanna dwelling chimpanzees in general (Krief et al., 2014), chimpanzees in Senegal appear to expand their temporal niche to forage and socialize during the late dry season when temperatures are highest (Pruetz, in prep.), rather than exhibit crop-raiding behavior (Krief et al., 2014) or wake because of disturbances (Zamma 2014), as has been seen in East African forest-dwelling chimpanzees. However, soaking in water has only been observed in Senegal (Pruetz 2007; Pruetz and Bertolani, 2009; Boyer Ontl and Pruetz, 2014), and evidence of cave use has only been seen in Senegal and Mali.

The Fongoli chimpanzees' ranging and grouping behavior reflects the hot, dry, and open environment (Pruetz and Bertolani, 2009). Compared to chimpanzee communities in forest environments, the community ranges over a larger area (see Chapter 5, Table 1). The range is used cyclically with the seasons and the availability of water and food resources (Lindshield et al., 2017). As water becomes scarce in the dry season, the chimpanzees travel and socialize in smaller groups, remaining in closer proximity to the few year-round water sources and foraging on depleted food resources around water sources (Pruetz and Bertolani, 2009). In the heat of the day, the apes rest in closed canopy gallery forests and travel more frequently in the cooler moments early and later in the day (Pruetz and Bertolani, 2009). As water availability becomes more abundant on the landscape during the rainy season, the community seeks out available fruit resources in larger traveling parties (Pruetz and Bertolani, 2009).

Other research conducted at the Fongoli field site has covered a diverse array of topics. Bogart and Pruetz (2011) found that Fongoli chimpanzees forage for termites throughout the year and spend more of their foraging time feeding on termites than East African chimpanzees that fish for termites seasonally. Additionally, Fongoli chimpanzees build more ground nests (Stewart et al., 2007) and lower arboreal nests than the chimpanzees in Niokolo-Koba National Park, suggesting that nesting building may have an anti-predator component (Pruetz et al., 2008). The Fongoli chimpanzees have been observed hunting mammalian prey with spear-like tools (Pruetz and Bertolani, 2007; Pruetz et al., 2015), informing important comparative models to understand how early hominins may have hunted in a similar environment.

The Fongoli chimpanzee community, like most of the chimpanzees in Senegal, lives outside of the country’s largest protected area and the only one in which chimpanzees are found, the Niokolo-Koba National Park. Chimpanzees here exist in a human dominated landscape with relatively high levels of disturbance compared to other long-term chimpanzee research sites (Pruetz and Bertolani, 2009, Wilson et al., 2014 but see Hockings et al. 2015). These two factors, ecologically distinct habitat and human presence, influenced the creation of the FSCP and have shaped the direction of the project's on-going research (Pruetz, 2014).

Ethnoprimatology

The discipline of anthropology has been subdivided to account for the various facets of human society including culture (cultural anthropology), evolution (biological anthropology), language (linguistics), and cultural pre-history (archaeology). The study of non-human primates (hereafter referred to as primates) falls within the realm of biological anthropology, as humans are taxonomically primates. Primatologists recognize that human culture and ecology are often inseparable from the culture and ecology of non-human primates, thus revealing a limitation of the dissected discipline and the bridge between the biological and social (Hill and McLennan, 2016). Our study subjects are defined ecologically, culturally, and spiritually as separate from humans, but as evolutionary kin and ecologically sympatric species (Sponsel, 1997; although see Imanishi, 1941 for Eastern perspective on primate-human relationship). Our understanding of human behavior, evolution, and health relies heavily on primate models. In field studies and conservation, the study of primates is intertwined with the lives of local and indigenous people. Whether collaborating with human communities for conservation purposes, identifying the anthropogenic changes to the landscape, or assessing the cultural and historical relationships between humans and primates, the perspective of the primatologist is often dual – biological and cultural – thus reaching across anthropological disciplines.

This duality and the complex relationship between humans and other primates warrant its own discipline. The field of ethnoprimatology comprises a holistic study of the interactions and interrelationships between humans and primates (Sponsel, 1997; Fuentes, 2012), acknowledging their long history of sympatry and that they have adapted or adjusted to one another's presence and altered each other's environment. Throughout history and today, people have perceived primates as sacred beings, companions, pests, food, and commodities (Sponsel, 1997; Fuentes and Wolfe, 2002; see Chapter 4 for review). However, as human population increases, primate populations are coming into contact with humans more frequently, changing human-primate dynamics and threatening the survival of most primate species (Estrada et al., 2017).

Anthropogenic activity and West African chimpanzees

As globalization increases, anthropogenic change is rapidly expanding. Across Africa suitable habitat for great apes has declined in the past 30 years, much of it due to an increase in human impacts (Junker et al., 2012). Industrialized agriculture, logging, metal and mineral mining, petroleum extraction, and associated infrastructure have become the greatest threat to primate habitat and species survival (Estrada et al. 2017). The impacts on great apes have been devastating in some regions (Redmond, 2001; Hicks et al., 2010; Halloran et al., 2014) and disruptive but behaviorally defining in others, particularly in terms of ranging behavior and foraging activity (Hickey et al. 2013; McLennan, 2008; Krief et al., 2014). The threats to chimpanzees and other great apes are diverse, as are the people living alongside these populations, resulting in unique situations for each country and region where humans and great apes coexist (Hockings et al., 2015). Here, I focus my review on the literature of anthropogenic impacts on West African chimpanzees.

Mali

Chimpanzees inhabit the southwestern corner of Mali where the country borders Senegal and Guinea. Although Mali may be home to one of West Africa's largest contiguous populations of chimpanzees (Duvall et al., 2003), little research has been conducted there, particularly with respect to anthropogenic impacts on chimpanzee communities. Most research has taken place in the Bafing Biosphere Reserve, which is the only protected area with confirmed presence of chimpanzees in the country (Duvall, 2008; Granier and Martinez, 2004). The region has a low human population density, and most people are tolerant or indifferent towards chimpanzees (Granier and Martinez, 2004). Agriculture poses the greatest threat to chimpanzee habitat in Mali, as people rarely hunt the apes, reportedly for medicinal purposes rather than for bushmeat (Duvall et al. 2003). Both industrial and artisanal gold mining are extensively practiced in southwestern Mali, particularly along the Falémé River that borders Senegal, and chimpanzee surveys are lacking in the area. In 2011, an estimated 50% of the chimpanzees' range in Mali was covered by mining licenses, and conservationists are working to establish a Bafing-Falémé Transboundary Protected Area (IUCN/PACO, 2012).

Guinea Bissau

In Guinea Bissau, anthropogenic disturbances include logging, agriculture, and illegal hunting for the pet trade and medicinal purposes (Hockings and Sousa, 2011; Sa et al., 2012). In Cantanhez National Park local beliefs protect the chimpanzees from hunting, but the increasing human population may cause human-chimpanzee conflict to rise (Hockings and Sousa, 2011). Chimpanzees in this area eat at least 10 different crop species and the raiding of orange (*Citrus sinensis*) crops has, on a few occasions, resulted in retaliatory killings of chimpanzees (Hockings and Sousa, 2011). The most prevalent agriculture crop in the region is the cashew (*Anacardium occidentalis*), and although chimpanzees do not harm the nut when crop raiding they can damage the trees (Carvalho et al., 2013; Hockings and Sousa, 2011). In addition, extensive cashew plantations are reducing suitable chimpanzee habitat and viable nesting trees (Carvalho et al., 2013).

Guinea

The Republic of Guinea is home to the largest density of chimpanzees in West Africa (Kormos et al., 2003). At the Bossou field site in the Republic of Guinea, people and chimpanzees have coexisted amicably for generations due to the local cultural belief system (Yamakoshi, 2011). In recent years, however, as the human population has increased and agriculture has become more widespread, conflicts between humans and chimpanzees have increased (Hockings et al., 2010). Conflicts include chimpanzee attacks on humans during periods of fruit scarcity and increased crop raiding. Eleven attacks by chimpanzees took place over a 14-year period (Hockings et al., 2010). Crop raiding in Bossou makes up nearly 10% of the chimpanzee feeding time (Hockings et al., 2009).

Nearby, in the Nimba Mountains, human density is also increasing along with slash and burn agriculture (Granier and Martinez, 2011). The forest is subsequently becoming more fragmented. Corresponding to increased agriculture pressures is the rise in uncontrolled bushfires that reduce forest canopy coverage (Granier and Martinez, 2011). In contrast to the Bossou site, people living in the Nimba Mountains hunt chimpanzees extensively for bushmeat and medicinal purposes and perform retaliatory killings in response to crop raiding (Granier and Martinez, 2011). The Nimba area is also known for its iron stores, which have been targeted by international mining companies (Granier and Martinez, 2011). Gold deposits and artisanal small-scale gold mining (ASGM) activity are prevalent farther north toward the Senegal-Guinea border (Dessertine, 2016).

Sierra Leone

In 2011 a population and habitat viability assessment (PHVA) was performed for the chimpanzee population of Sierra Leone (Carlsen et al., 2012). Anthropogenic threats identified during the workshops were mining, logging, farming, fires, plantations, city development, cattle ranging, bushmeat, and retaliatory killings. The team determined areas of low and high vulnerability (within protected areas and outside protected areas, respectively) and their associated threats. In areas of low vulnerability, the greatest threat to the country's apes was direct hunting, whereas for high vulnerability areas the greatest threat was deemed habitat loss (Carlsen et al., 2012). In northern and eastern Sierra Leone, ASGM is a considerable part of peoples' livelihoods and, in the Tonkolili district, miners range from self-supported informal miners to paid, licensed miners (Cartier and Burge, 2011).

Research on chimpanzees has also been conducted at the Tonkolili field site in the center of the country (Halloran et al., 2014). Chimpanzees and people in this area compete over oil palm (*Elais guineensis*) crops, which has resulted in retaliatory killings of chimpanzees. The apes at this site also reportedly raided mangos (*Mangifera indica*), and pineapples (*Ananas comosus*). Much of this competition and conflict had arisen since the onset of the nation's civil war in 1991, which shifted the livelihoods of the community from beekeeping and livestock herding to agriculture (Halloran, 2016).

Liberia

The forest of Liberia has been deemed the most suitable habitat for chimpanzees in West Africa based on environmental and anthropogenic variables (Junker et al., 2012). Although the human impacts are relatively low, the country's chimpanzees are still threatened by logging, mining, and hunting for bushmeat and the pet trade. The extractive industries in Liberia are largely artisanal; however, international investors have showed renewed interest in the country's resources since the end of the civil war (Tweh et al., 2014). A national wide survey by Tweh et al. (2014) found hunting to be the most frequently encountered human threat to Liberia's chimpanzees. Artisanal small-scale gold mining occurs in the Sapo National Park in southeastern Liberia, but the impacts related to wildlife, and particularly chimpanzees, have not been quantified (Small, 2012; Arcus Foundation, 2014).

Côte d'Ivoire

Taï National Park located along the Liberia-Côte d'Ivoire border in southwestern Côte d'Ivoire is the largest remaining expanse of Guinean forest in West Africa. However, the area surrounding the national park is becoming increasingly fragmented as a result of the expansion of human settlements and associated agriculture there since the 1980s (Koné et al., 2008). Despite being outlawed, primate hunting is widespread in the country, as are illegal logging activities (Boesch-Ackermann and Boesch, 1995). In the

1990s and early 2000s, the chimpanzee population saw a dramatic decline likely due to a 50% increase in human population in the country during the same period (Campbell et al., 2008). In a more recent survey, a similar decline in chimpanzee population was seen within the Taï National Park (N'Goran et al., 2013). The study attributed the population decline to increased human activity, indicated by areas of deforestation for farming and plantations and evidence of poaching with traps and guns. One of the signs of human activity recorded was artisanal gold mining. In Côte d'Ivoire, gold mining is a common livelihood, with women having a prominent role in such work (Stork et al., 2015).

Ghana

A small chimpanzee population is thought to remain in southwestern Ghana, along the border of Côte d'Ivoire. A survey of 14 protected reserves found chimpanzee presence in only five (Danquah et al., 2012). The population estimate for the country is around 200 individuals. Reports of crop raiding were rare but occurred in cocoa (*Theobroma cacao*) fields when people were not present in the afternoons. Hunting activity was observed in protected areas throughout the study area, with nearly 50% of observations related to wire snares. Other threats to the Ghanaian chimpanzee population include timber extraction, agriculture and the illegal pet trade of chimpanzee infants (Danquah et al., 2012). In a separate survey of the Subri River Forest Reserve, chimpanzees were not observed or detected by signs, but hunters retold accounts of observing and killing chimpanzees (Buzzard and Parker, 2012). The same study also indicated the presence of artisanal small-scale gold mining within chimpanzee inhabited areas.

Summary

Much of our knowledge of chimpanzees has derived from studies on East African forest dwelling communities (see also Boesch and Boesch Achermann, 2000). With the expansion of research into the savannas of West Africa, our understanding of chimpanzee behavior and ecology has also expanded. Living at the edge of their global range, the chimpanzees of Senegal illustrate how great apes can adapt to live in a hot, dry, and open environment, and have provided insight into how early hominins subject to pressures associated with similar environments may have also lived.

The study of primatology bridges disciplines from human evolution to primate ecology, and encompasses both biological and social disciplines. This is particularly important as a theoretical base for which to study primates living outside of protected areas and in close proximity to human communities, as is the case with most savanna chimpanzee study sites. Ethnoprimatology brings these two disciplines together to investigate how humans and non-human primates interaction and relate.

Across West Africa, people and chimpanzees inhabit the same geographic space and often compete over the same resources. Much has been written on the conversion of chimpanzee habitat to agriculture in West Africa and the resulting human-ape conflict over crop raiding. While most of the human-chimpanzee relationships in West Africa are related to agriculture and crop raiding, each country’s culture and history ultimately defines the interactions and conservation status of their respective chimpanzee populations. Overall, little quantitative research has taken place on the impacts of artisanal resource extraction, explicitly gold mining, within chimpanzee habitat despite its presences in most West African chimpanzee range countries. As gold prices have remained elevated over the past 10 years and gold mining continues to expand, there is an urgency to understand the impacts of this extractive industry on endangered primates. This dissertation strives to fill this gap in the literature by providing an assessment of the impacts of ASGM activity within the home range of chimpanzees in Senegal.

Dissertation structure

This dissertation on the impacts of ASGM on the chimpanzees at Fongoli analyzed data collected on 1761 observation days comprising over 10,300 hours of observation from 2005 through 2014. This dataset was compiled using all digitally scanned data books as of January 2015. An additional 30 days of observation were included in analyzes of human-chimpanzee encounters as these data were compiled directly from field notebooks that were not digitally scanned. These 30 days were not used in analysis on ranging or habitat use as information on location was not available. The datasets use in analyses for Chapters Five and Six on ranging and habitat selection, respectively, included 627 days of observation previously entered by Dr. Jill Pruetz, employees of the FSCP, volunteers, and students, as well as 544 days of observations entered for the purpose of this study. The remaining 560 days in the digitally scanned database were not analyzed due to time constraints. To assure a robust sample, efforts were made to provide for each year of the study period, at minimum, an equal amount of coverage for each season to that of the pre-mining dataset from years 2005 through 2007. For each data chapter I have further sub-selected from the dataset based on availability of pertinent variables (i.e. location data and focal subject).

To introduce the study, I provide an overview of ASGM in Chapter Two, situating the practice in geography, history, and its environmental impacts. In addition, I provide a synopsis of the ASGM sites that have emerged on the landscape at the Fongoli field site between 2008 and 2014. Chapter Three explores and details the coupled human and natural system that makes up the Fongoli field site through an analysis of interacting social, natural and global systems. In Chapter Four, I examine the impacts of shifting community livelihoods and changes in human-chimpanzee encounters over a nine-year study period. Chapters Five and Six explore the impacts of ASGM on the behavior of the Fongoli chimpanzee community related to ranging and habitat use, respectively. The final chapter summarizes my findings and discusses their relevance to direct learning of novel disturbances and chimpanzee conservation.

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Table 1.1 Estimates of chimpanzee communities across the Kedougou region of Senegal

Region Name	**Site Name**	**Ave./ Estimate**	**Min.**	**Max.**	**Source**
Falémé/ Eastern Kedougou	Drambos	28◆	28	32	Boyer-Ontl and Pruetz, 2014
	Balengoma	27◆	27	32	Boyer-Ontl and Pruetz, 2014
	Dalafing	29	13	32	K Boyer Ontl, unpublished
	Lingeya	13✧	13	32	K Boyer Ontl, unpublished
	Garaboureya	29	13	32	Carter et al. 2003
	Bofeto	29	17⋆	32	Boyer Ontl and Pruetz, in review
	Nafadji 1	29	13	32	S Ndiaye, unpublished; K Boyer Ontl, unpublished
	Nafadji 2	29	13	32	K Boyer Ontl, unpublished
	Sarouja	29	13	32	K Boyer Ontl, unpublished
	Noumafoukha	29	13	32	K Boyer Ontl, unpublished
	Bountou	13✧	13	32	K Boyer Ontl, unpublished
Northern Kedougou/ Southern Bakel	Kayan	29	13	32	Oelze et al., 2016
	Kheremakhono	29	13	32	S Ndiaye, unpublished; Nests, K Boyer Ontl, unpublished
	Makhana/Massawa	29	13	32	Ndiaye et al., in review
	Sandingkounda	29	13	32	Ndiaye et al., in review
Central Kedougou	Fongoli	32*	32	32	Pruetz and Herzog, in review
	Diaguiri	29	13	32	Ndiaye, pers. comm.
	Kanoumering	29	13	32	Ndiaye et al., in review
	Bantan	13✧	13	32	Pruetz, unpublished data
	Baniom	29	13	32	Ndiaye et al., in review
	Angafou	15†	13	32	Gaspersic and Pruetz, 2011
	Mako	29	13	32	L. Badji
	Baitalaye	29	13	32	Ndiaye et al., in review
	Dadeya/Kedougou	29	13	32	S Ndiaye, unpublished
	Spires	29	13	32	Ndiaye et al., in review
South Central Kedougou	Nathia	13†	13	32	Gaspersic and Pruetz, 2011
	Bandafassi	21†	13	32	Gaspersic and Pruetz, 2011
	Dindefello	50	50	50	L. Pacheco, pers. comm.
	Segou	29	13	32	Kormos et al. 2003

Table 1.1 Continued

Region Name	Site Name	Ave./ Estimate	Min.	Max.	Source
South Central Kedougou	Fongolimbi - Thiomboukoure	29	13	32	Kormos et al. 2003
	Fongolimbi - Kosiray	29	13	32	Kormos et al. 2004
Western Kedougou	Diara	29	13	32	Ndiaye et al., in review
	Ethiolo 1	29	13	32	Ndiaye et al., in review
	Ethiolo 2	29	13	32	Ndiaye et al., in review
Niokolo-Koba National Park	Mt Assirik	29	13	32	Pruetz et al., 2011
	Antenne/Park Ranger Post	29	13	32	Pruetz et al., 2012
	Northern Border	29	13	32	Ndiaye et al., in review
Totals		887	553	1202	

* = known group size from observation
□ = known group size from camera trap images
⚹ = known group size from fresh nest counts
† = estimates calculated based on reported average dry season group size relative to average dry season group size at Fongoli
✧ = observations suggest small group
29 = average number of chimpanzee individuals from Balengoma, Drambos, and Fongoli
13 = minimum estimate from estimate at Nathia
32 = maximum from average community size at Fongoli

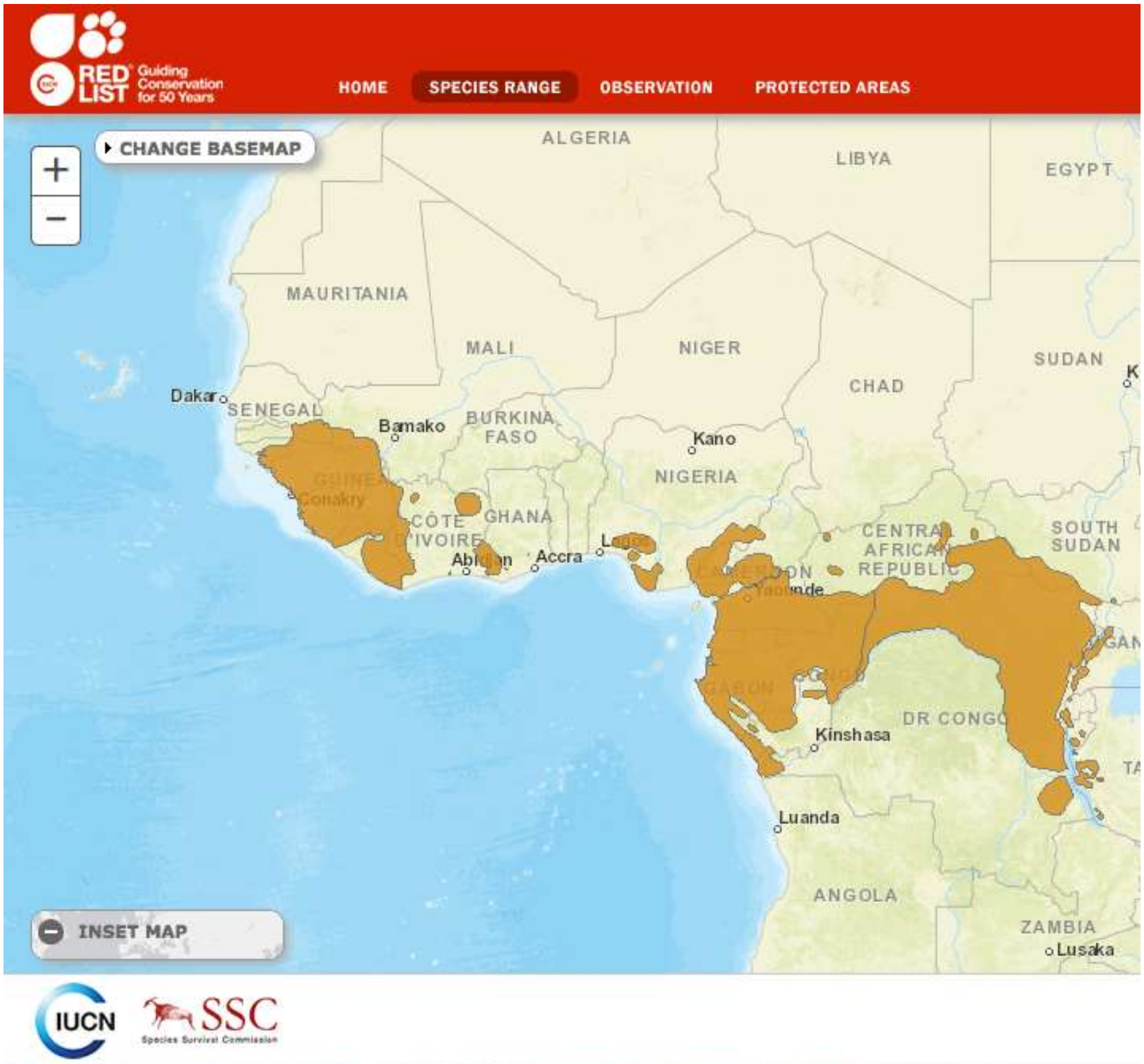

Figure 1.1 Geographical distribution of *Pan troglodytes* (Humle et al., 2016)

CHAPTER II

ARTISANAL SMALL-SCALE GOLD MINING IN CONTEXT

"Africa is on the verge of an unprecedented mining boom" (Edwards et al., 2014)

A frontier is a moving line, an evolving conquest of land, space and resources. The American frontier has been described as "the meeting point between savagery and civilization" (Turner, 1920: 3), where resources were claimed or conquered by those with economic, colonial or governmental power. In the 1990s, resource frontiers were seen as areas where natural resources are extracted to support a growing global demand for raw materials (Carvalho and Gertler, 1990; Armstrong, 1991; Tsing, 2003). These frontiers are not static, constantly evolving and advancing in space and time. A resource frontier may initially possess a single marketable resource drawing corporate extraction industries, small-scale investors, and illegal prospectors. However, as market conditions change, resources previously viewed as secondary or tertiary may rise to the top. Others may have a diverse resource base with many abundant and profitable resources (Carvalho and Gertler, 1990).

Armstrong (1991: 69) describes resource frontiers as "not simply a line or even zone but a dynamic process of spatial interaction in which unoccupied resource-rich regions are incorporated into national economic space." Note that Armstrong refers to these frontiers as unoccupied, much in the same way that Turner (1920) referred to the American conquest of the Western Frontier. Yet, many of these frontiers were and are inhabited by indigenous communities. Anna Lowenhaupt Tsing (Tsing, 2003; Tsing,

2005) captures the energy of the evolving resource frontier in Indonesia in her writing, specifically addressing the conflict between the indigenous communities and the incoming prospectors who "wrest landscape elements from previous livelihoods and ecologies to turn them into wild resources, available for the industries of the world" (Tsing, 2003:5100).

West Africa has many resources that draw outside interest, including agricultural land, fisheries, timber, oil, metals and minerals, which spatially overlap areas of habitation of humans and wildlife. In the past 10 years elevated gold prices have drawn much attention to West Africa and the expanding gold mining industry (Edwards et al., 2014). Gold mining activities have increased in many West African nations, including Burkina Faso, Ghana, Guinea, Mali, and Senegal. The frontier has drawn both large and small-scale mining activity from both regional and international prospectors.

In Senegal, chimpanzees and gold mining are found only in the southeastern region of the country (Figure 1). Their co-occurrence is not coincidence but relates to the geological formations characterizing West Africa. Much of the region is comprised of the West African craton (WAC), a large, stable rock formation formed in the late Archean and early Proterozoic eons and part of the Precambrian basement rock of Africa. The portion of the WAC within Senegal's geopolitical boundary is known as the Kédougou-Kénieba Inlier (KKI). The inlier is comprised of volcanic rock including large areas of granitic rock known to host gold as well as other metal and mineral deposits (Lawrence et al., 2013).

Ecologically, the KKI area of Senegal is known today as the Shield ecoregion and includes the Department of Kedougou as well as portions of the Departments of

Tambacounda and Kolda. The complexity of the folded volcanic and sedimentary rocks creates a diverse landscape of hills, valleys and plateaus making this southeastern region drastically different from the rest of Senegal (Stancioff et al, 1986). The diverse geology leads to diversity of soils, plants, and animals, making southeastern Senegal the most biodiverse region in the country. The species richness and vegetative diversity creates suitable habitat for chimpanzees (McGrew et al., 1981; Lindshield, 2014).

West Africa's story of gold

Artisanal gold mining has a long history and tradition in West Africa, likely dating back before the Common Era, with trade routes arising around 300 CE between the Mediterranean and West Africa (Gewald, 2010; Garrard, 1982). Much of the gold traded with Arabic and European nations came from the "Island of Gold", a seemingly legendary location now presumed to include southeastern Senegal and southwestern Mali (MacIntosh, 1998; Levtzion, 1973). Historically known as the Bambuk, this gold producing area was located within the two regions straddling the Falémé River: Kedougou in Senegal and Kayes in Mali (Curtin, 1973; Figure 2). During the 12th Century this gold bearing region was under the control of the Ghana Empire. Although much of the ancient Empire of Ghana, from 400 CE to 1200 CE, was centered in southeastern Mauritania and western Mali, the southern border extended into southeastern Senegal and included the Bambuk goldfields (Levtzion, 1973). In the mid-1500s the goldfields of Bambuk were the target of a battle between the leader of the Denianke Dynasty of northern Senegal and the Mali Empire, and remained under the control of the Mali Empire until its fall in 1600. Although some authors dispute the location of the famous and mythicized "Island of Gold" (McIntosh, 1981), the historical importance of gold in southeastern Senegal and western Mali cannot be denied (Huysecom et al., 2012). Ultimately, it was the lure of gold that brought Europeans into West Africa to secure access to both ends of the Saharan gold routes (Barbier, 2011) and today, international mining concessions have been established throughout the region.

Modern gold rush and the environmental impacts

Gold mining in Senegal has traditionally been the work of agriculturalists (Gewald, 2010; Persaud et al., 2017). In this region, farmers would turn to gold mining in shallow "placer" mines during the long dry season, when crops cannot be cultivated. Placer mines are locations where small particles of heavy minerals, including gold, become superficial deposits in sandy areas, often in streambeds. Here, agriculturalists were able to collect gold using simple technologies that were associated with their livelihood (Gewald, 2010).

The tradition of supplemental gold mining in Senegal has continued through the centuries. Today this method of gold mining is referred to as artisanal small-scale gold mining or ASGM. The broad definition of ASGM is that of labor-intensive gold mining that uses rudimentary tools. The practice often does not take care to provide safety measures or environmental protections (Mining Minerals and Sustainable Development Project [MMSD], 2002). In Senegal today, most mines are shallow deposits that are reached by digging a shaft by a team of workers that include rope pullers, diggers, and shaft owners (Persaud et al., 2017). The system of shafts has changed little over time (Figure 3). Once the gold laden rock is retrieved from the shaft, it is processed by people who crush the rock, either by hand or machine, and then washed with mercury or simply water. Finally, it is sold to gold buyers and traders (Persaud et al., 2017). As of 2014, the government of Senegal had provided permits to 27 international companies and nine Senegalese mining companies to explore and exploit the regions gold deposits (ITIE, 2014; Figure 4).

There are four different types of ASGM categories: seasonal, permanent, rush-type, and shock-push (Hruschka and Echavarria, 2011). Senegal's traditional supplemental mining fell in the category of seasonal, where mining activities coincide with seasons outside of the cultivation window to supplement annual incomes. Permanent ASGM refers to year-round mining activity that miners engage in on a full-time basis, although it is not unheard of for miners to continue other occupations like herding or farming. Rush-type ASGM occurs when large migrations of people are attracted to a concentrated area of a newly discovered deposit. Migrants are often lured by an illusion of riches that may be obtained at the new site. Rush type areas often develop into established settlements, with the miners functioning as settlers, as has been seen in areas of Senegal including Bantako and Kharakhena (Doucouré, 2014; K Boyer Ontl, pers. obs.). The last type of ASGM, shock-push, is a result of economic loss or instability related to a specific event (e.g. natural disaster, conflict, or loss of jobs in other sectors). This poverty-driven type of ASGM is often a last resort for poorly educated and itinerant individuals.

In the 1970s, Senegal experienced a gold rush that resulted in far reaching environmental and social impacts (Savornin et al., 2007). The surge of gold prices over the past 10 years has again resulted in a resurgence of traditional gold mining in the country (Prause, 2016). With the increased mining, southeastern Senegal has seen a surge of transnational migration, population, health crises, and environmental degradation

(Government of Senegal, 2011). Negative impacts on the environment are not new to mining. As early as the 16th century, Agricola (1950 [1556]) wrote about concerns of the environmental impacts of early artisanal mining, documenting deforestation, water contamination and wildlife extirpation. However, environmental impacts only became a core concern for mining operations in the mid-1980s (Bridge, 2004). Southeastern Senegal's mining zone has always been dynamic, but today's modern globalized economy and society exacerbate the mining sector's impacts, which are far-reaching and include mercury pollution, sanitation issues, and deforestation, among other impacts.

ASGM frequently involves unregulated use of mercury to extract gold from ore through mercury-gold amalgamation (Harada et al., 1997; Ogola et al., 2002), a practice that dates back to medieval times (Agricola, 1950 [1556]). This process includes adding mercury to crushed ore and water. The gold binds to the mercury creating mercury-gold amalgams, which are then separated out using a gravity method and sluice box. The mercury laden water is often released into nearby water sources. The amalgams are then heated to vaporize the mercury and leave behind concentrated gold. Another method to separate gold from the surrounding substrate uses a gravity method that washes the gold in shallow pans or a calabash, a dried gourd. Although this method does not employ mercury or other toxic elements, it is not suitable for all types of gold deposits, particularly when the gold is presented in fine particles or if it is not fully liberated from the host rock. .

Although data are lacking, ASGM is considered one of the largest contributors to global mercury pollution (Wade, 2013; Telmer and Veiga, 2009). There have been extensive studies on the impact of mercury pollution on the environment and on human health (Wade, 2013; Nweke and Sanders, 2009; van Straaten, 2000; Olivero-Verbel et al., 2011; Malm et al., 1996; Lusilao-Makiese et al., 2013; Cheng et al., 2009), including those conducted in southeastern Senegal (Niang et al., 2014a; Niane et al., 2014b; Gerson et al., in prep.). The use of mercury in gold mining has serious health risks to wildlife and humans, especially regarding environmental toxicity (Wade, 2013). Mercury is a highly toxic element that can be harmful to the lungs, nervous system, immune system, digestive system and kidneys if inhaled in vapor form (World Health Organization, 2007). Minamata disease in human infants is caused by the uptake of large quantities of mercury from food resources causing neurological defects in a developing infant brain, such as mental retardation, deafness and blindness, and cerebral palsy (Clifton, 2007; Ogola et al., 2002). Most studies have been done in captive animals or on affected people. Whether the same effects can be found in chimpanzees is unknown, but as our closest living relative it is likely they would be susceptible to similar impairments and health impacts. In general, studies have not indicated whether or not mercury pollution has affected wildlife living alongside ASGM sites.

In addition to mercury, sanitation issues are a major concern at ASGM sites (Long et al., 2013; Small, 2012). Mining sites often have low hygienic standards that lead to widespread infectious diseases including typhoid and dysentery (Bose-O’Reilly et al., 2010; Spiegel and Veiga, 2005). With no pit latrines available, defecation occurs on the outskirts of the mines, often without regard to waterways or runoff areas. Poor sanitation increases the possibility of zoonotic and anthroponotic disease transmission around ASGM sites. Zoonotic diseases such as enteroviruses, including polio, can be transmitted via consumption of water contaminated with fecal material (Wallis and Lee, 1999).

Chimpanzees are vulnerable to infection from human polio strains (Dowdle and Birmingham, 1997) and in 1966 wild chimpanzees suffered from a polio-like outbreak at Gombe, Tanzania soon after the chimpanzees were habituated to humans (Goodall, 1986). Although no polio-like symptoms have been seen in the Fongoli chimpanzees, the threat of fecal-oral viral transmission exists. A health concern also exists for the pastoralist communities that also depend on wild water resources. Another health concern is African sleeping sickness caused by *Trypanosoma brucei gambiense*, which is spread via the tsetse fly across much of West and Central Africa. Studies show that artisanal mining sites with open water can lead to increased tsetse infestations, particularly during the dry season when water is scarce (Franco et al., 2014). Chimpanzees are also susceptible to infection from *T. brucei*, although some individuals may have a resistance and act as a host or reservoir for the disease (Jirku et al., 2015). More research is needed to address the risk of disease transmission between humans and great apes at ASGM sites.

Deforestation associated with mining arises from clearing trees to accommodate mine shafts (Small, 2012) and to provide wooden support structures in tunnels underground (S. Keita, pers. comm.). Straight hardwood trees (e.g. *Pterocarpus erinaceus*) with a diameter of approximately 10-15 cm are selected for support structures (B. Damfakha, pers. comm.). At the Fongoli field site, people from the nearby town of Kedougou cut trees with larger diameters (> 20 cm) to supply building needs in the growing urban center. Loss of vegetation can lead to habitat loss, invasive plant and animal species, and soil erosion during the rainy season (Arcus Foundation, 2014). In

Senegal, the loss of *P. erinaceus* may affect chimpanzee nesting and feeding locations (Ndiaye et al., 2013).

Other indirect impacts of ASGM impacting wildlife are the bushmeat and illegal pet trade. As artisanal gold mining began at the Bili-Uele field site in the Democratic Republic of Congo (DRC), researchers documented an increase in the illegal sale of chimpanzee orphans and chimpanzee bushmeat in the markets (Hicks et al., 2010). A similar impact was seen in Kahuzi-Biega National Park in the DRC as artisanal mining for coltan began. In Kahuzi-Biega, miners hunting emptied the forest of large mammals including East lowland gorillas (*Gorilla beringei graueri*) and chimpanzees (*P. t. schweinfurthii*) (Redmond, 2001).

Artisanal gold mining takes place in nearly all of the West African chimpanzee range countries: Senegal, Mali, Guinea, Ghana, Liberia, Sierra Leone and Cote d'Ivoire, excluding only the small country of Guinea Bissau where gold deposits are minimal. The increase in mining activity in the chimpanzees' home range is expected to alter how apes use the landscape (Hockings & Humle, 2009), but there has been little research showing the actual impacts. More information is known regarding the impacts of agricultural landscapes on ape ranges. For resource extraction, the majority of research in great ape habitat focuses primarily on logging and timber extraction (Clark et al., 2009; Granier & Martinez, 2011; Laporte et al., 2007; Morgan & Sanz, 2007). When mining activity is addressed in the literature it most often refers to large-scale industrial mining and infrequently addresses artisanal and small-scale mining (Hockings and Humle, 2009; Arcus Foundation, 2014). Reports of ASGM activities in ape areas are limited (McMahon et al., 2000; Arcus Foundation, 2014), and assessments of their impacts on great apes are even fewer (Hicks et al., 2010). Much of what is reported on ASGM comes from technical reports from non-governmental organizations and intergovernmental organizations, which frequently compile data on a global or multinational scale (McMahon et al., 1999; MMSD, 2002; Villegas et al., 2012; Arcus Foundation, 2014). Thus, quantitative studies on the impacts of ASGM on great ape behavior are missing from peer-reviewed literature. In this study we help to fill the gap by addressing how ASGM sites are spatially and temporally distributed within the chimpanzees' home range and the impact they have on chimpanzees' ranging behavior.

ASGM in Fongoli Senegal

Prior to 2008 in the region of Kedougou, gold mining was estimated to occur in more than 70% of the region's villages (Alvarez and Heemskerk, 2008). The specific details of gold mining's long history in Fongoli, Senegal are largely unknown, but the landscape holds some clues. Hills and hummocks of past gold mining endeavors stretch along the banks of the Fongoli stream. Although the vegetation has returned, the scars of mining remain. At the onset of research at the Fongoli Savanna Chimpanzee Project (FSCP), small pockets of seasonal ASGM activity occurred with a few people mining during the dry season (Pruetz, unpublished data). The most recent mining activity at Fongoli runs along the Fongoli stream and its tributaries. From 2008 through 2013, seven mining areas were established within the home range of the Fongoli chimpanzee community (Table 1; Figure 5). Information about history and evolution of the seven mining areas was extracted from FSCP data book entries, informal talks with miners from Fongoli, personal observations, and LANDSAT 7 satellite imagery.

Oundoundou mine

The first mining site to appear since the 2008 global economic shift was the Oundoundou mine. Located along the hillsides of the Oundoundou ravine, the mining area began with people digging shafts and exploring the streambed area for gold. This area originated as a seasonal mine but became a permanent ASGM site in 2008. By the end of 2008 and into early 2009, hundreds of people from neighboring villages were mining the hillside (K. Boyer Ontl, per obs.; Figure 6). The mine continued to function along the lower portion of the valley through 2010 with little expansion (Table 2). In 2011, mining slowed at the original location and began to expand along the eastern portion of the valley toward the Fongoli stream. Local mining companies and small-scale international investors began excavating with large machinery along the eastern edge. As gold prices reached their maximum at the end of 2011 and into 2012, excavation along the top of the ridge began. In 2013 and 2014 trenches were dug along the upper ridge and mining activity intensified along the original valley (Figure 7).

Kerouani mine

Mining began in 2011 along the Kerouani stream at low levels. By 2012, a dirt vehicle track was cut from the Fongoli-Petit Oubadji road down to the stream to access the area. The Kerouani mining area did not expand like the Oundoundou mine, but rather became a series of pits running the length of the mine, many of them remaining under the closed canopy of the stream's gallery forest and woodland covers, undetectable from satellite imagery. This area included a women's calabash mine where gold was washed using the gravity method (F. Camara, pers. comm.). In 2014, the area was abandoned, and most of the people searching for gold in the Kerouani moved to the Oundoundou mine to continue exploration. For the majority of the lifetime of this mining area, the ASGM activity remained largely seasonal; however, during 2012 people began using the area on a full time basis.

Coucoukoto and Wolokoto mines

The mining areas of Coucoukoto and Wolokoto began in 2012. Both areas were located near the conflux of the Kerouani and Fongoli streams. These mines were short lived, from 2012 through 2013, and included machinery to excavate for the gold suggesting permanent full time use of the area during its period of activity.

Ngari Camp and Niakora mine

The mining areas at Niakora and Ngari are located at the edges of the Fongoli chimpanzee community range in areas infrequently visited by the apes. Niakora is located 1.5 km from the village of Tinkoto, along the national highway. The Niakora mining area was initiated in late 2011, continued through 2013 and closed by 2014. The Ngari mining camp is located 1.5 km from the village of Ngari and began operating in 2013. The mine was owned by an Italian mining company and remained active in 2014. Both Ngari and Niakora mining areas were actively mined with excavators and other large machinery, and the rock was hauled with large dump trucks.

Djendji mine

Mining along the Gambia River near the village of Djendji began in 2010 as a seasonal mine with traditional small-scale mining with rudimentary tools (Figure 8). In 2013, an international mining company began exploration along the river and continued through 2014 (Figure 9). The mining area includes machinery to crush the rock, large scale sluicing machines, generators and backhoes. Despite the industrial presence, individual miners continue to process gold along the borders of the river and in the outskirts of the Djendji village. The footprint of the Djendji mining area has remained relatively small over the years.

Summary

This chapter explores the history of artisanal gold mining in West Africa and its cultural importance for the region. Although ASGM has a deep and rich history in Senegal and elsewhere in West Africa, today's global forces that drive extraction and compound local threats may not allow the critical ecosystem to rebound as it once did. Southeastern Senegal is located in a resource frontier where natural capital is being transformed into economic capital by and for local human communities. The resulting environmental impacts affect the nation's chimpanzee communities through deforestation, the influx of mercury toxins in the ecosystem, the spread of zoonotic diseases, and the growing risk of illegal harvesting of apes. Today in Senegal, researchers, non-profit organizations, and governing bodies are working to conserve the country's remaining chimpanzee population. The impacts of gold mining are now considered among the species' greatest threats in Senegal. Successful efforts to conserve chimpanzees and their habitat will need to include an understanding of the dynamic history and culture surrounding gold mining in southeastern Senegal as well as the impacts of the modern global economy.

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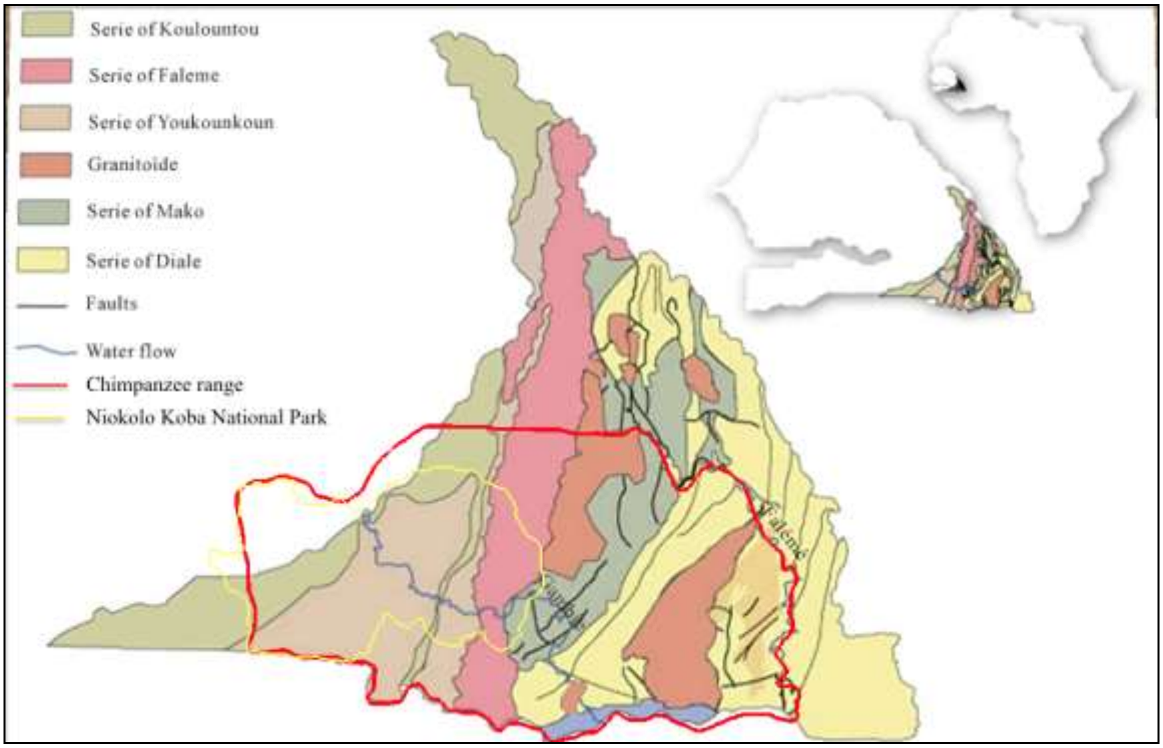

Figure 2.1 Geological features associated with gold bearing ore in Senegal. Chimpanzee range correlates with the country's metal deposits and is outlined in red. Image adapted from Sarr et al., 2013.

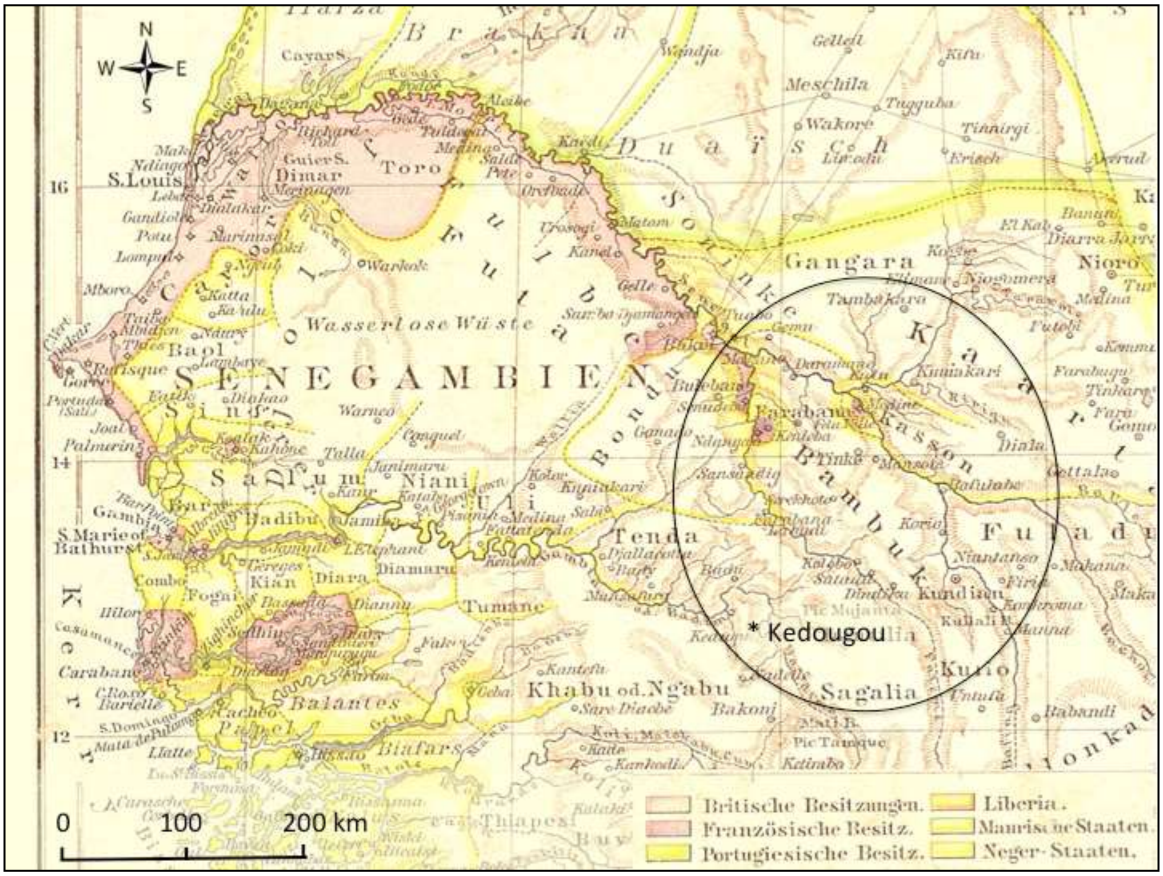

Figure 2.2 Bambuk goldfields of western Mali and southeastern Senegal circled in black, with location of the regional capital Kedougou indicated. Adapted from Allgemeiner, 1881.

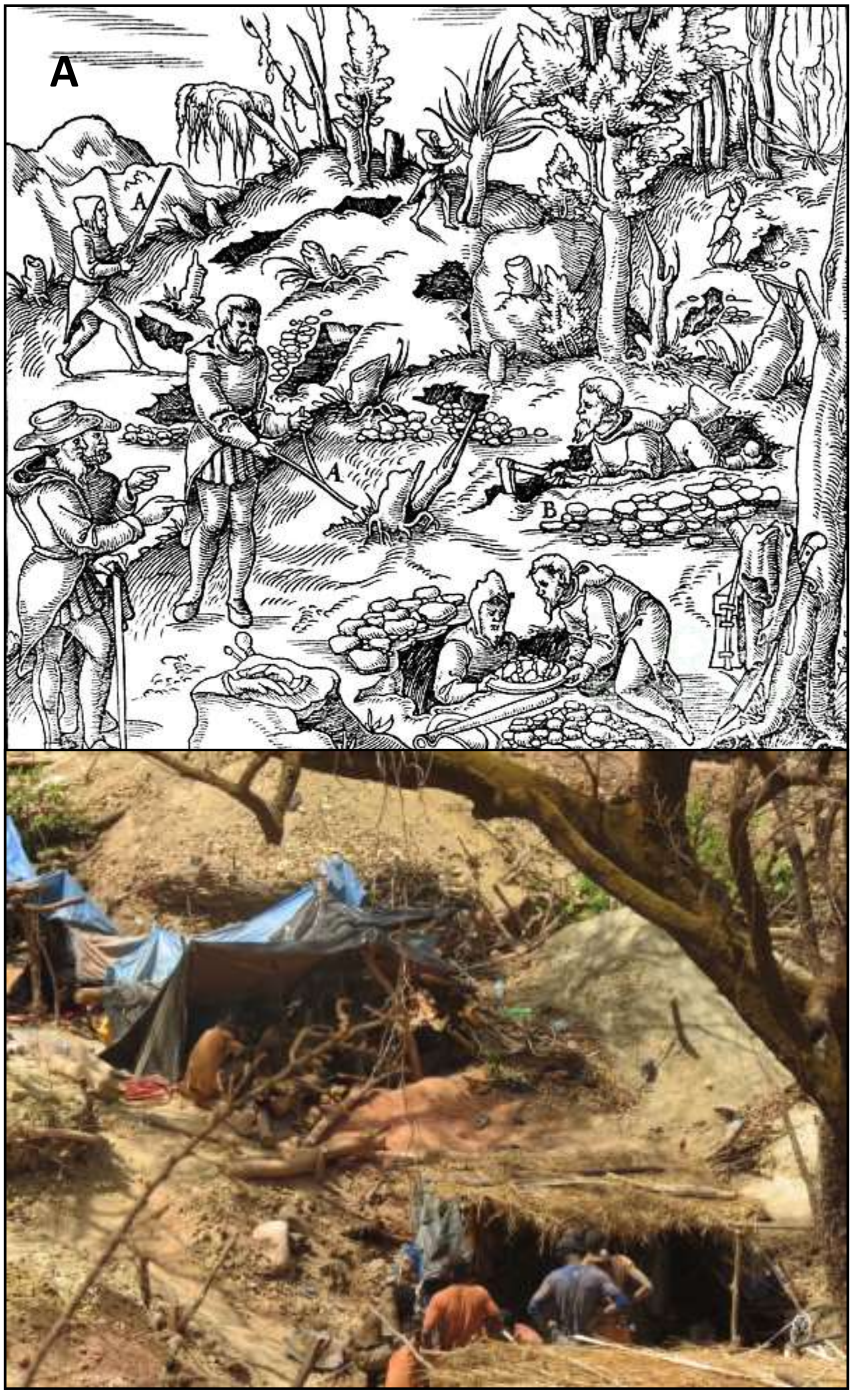

Figure 2.3 Comparative images of the set up for shaft mining in medieval Europe in the 1500s and in southeastern Senegal in 2014. Image A from Agricola, 1950 [1556]; image B photo by K. Boyer Ontl

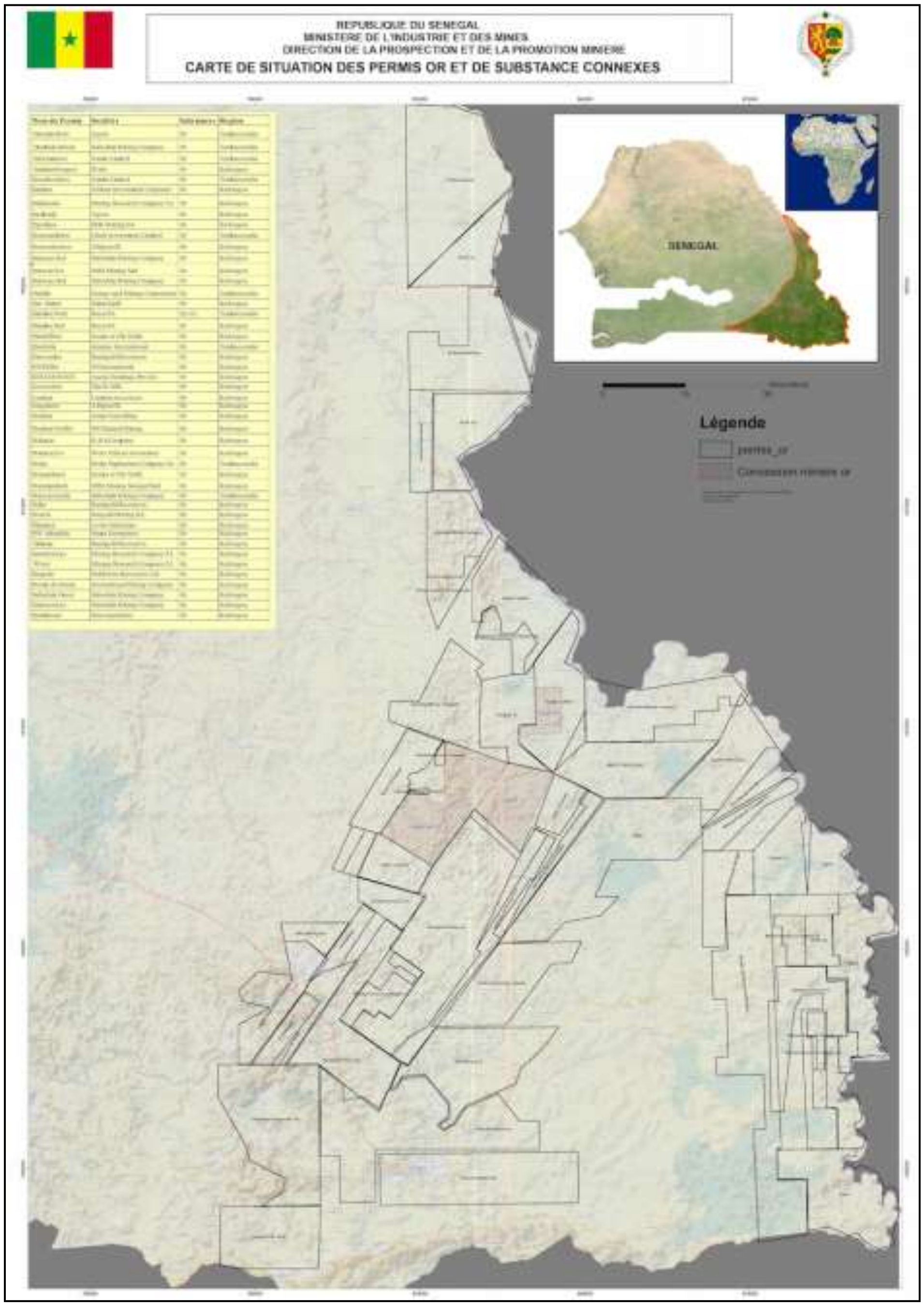

Figure 2.4 Locations of gold mining permits in Senegal. Source: Direction des Mines et de la Géologie du Senegal

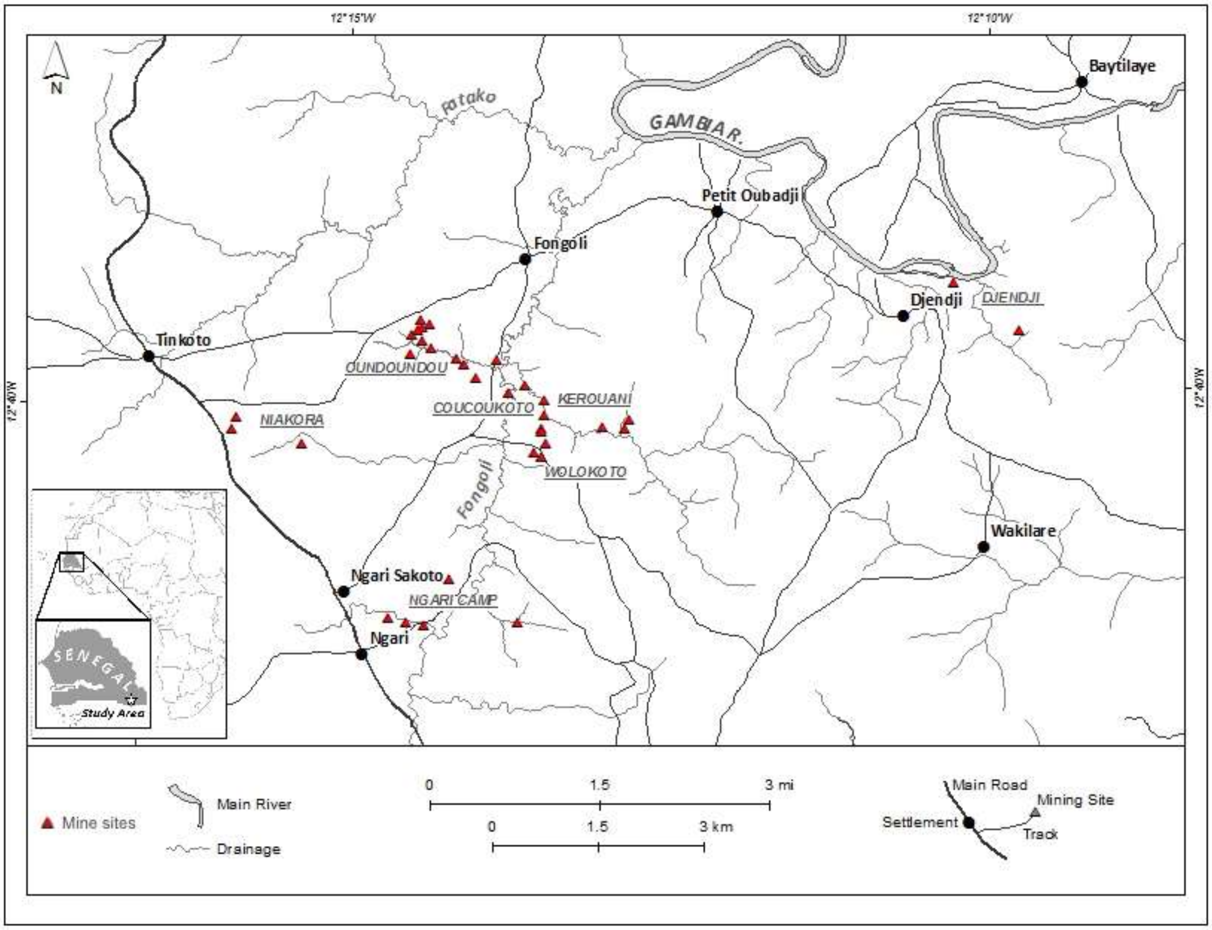

Figure 2.5 Full extent of ASGM mining locations in 2014 within or bordering the Fongoli chimpanzees' home range.

Figure 2.6 Chimpanzee feeding in a baobab tree across from the Oundoundou mine in the dry season in 2009. Mining pits can be seen in the background where the vegetation has been disturbed and bare ground is showing.

Figure 2.7 Trenches dug at the Oundoundou mine in 2013 and 2014 on the plateau above the ravine. Image taken in 2015 by K. Boyer Ontl.

Figure 2.8 Small-scale mining near the Djendji village showing a sluice box and the mine tailing. Image taken in 2015 by K. Boyer Ontl.

Figure 2.9 Corporate small-scale mining activity near the Djendji village, showing industrial size sluice box and machinery. Image taken in 2015 by K. Boyer Ontl.

CHAPTER III

FONGOLI SAVANNA CHIMPANZEE PROJECT: THE STUDY OF A COUPLED HUMAN AND NATURAL SYSTEM

Coupled human and natural systems

In every primate habitat, complex interactions and feedbacks occur between ecological and human systems. As primate conservationists we are aware of this complexity; however, we often find it impedes our conservation goals (e.g., action plans conflicting with local community needs, a well-supported community program not supported by government officials, etc.). Ultimately, insights into these conflicts cannot be achieved from ecological or sociological research alone. The Coupled Human and Natural Systems (CHANS) framework focuses on collaborative approaches to studying these interactive and complex systems (Liu et al., 2007a, Liu et al., 2007b. The idea that human and natural systems influence one another through complex interactions is not new (Folke et al., 1996; Soule, 1985; Kareiva and Marvier, 2012). However, historically our methods of understanding conservation issues and change focused on only one or two components of a much larger and more complex system. Through the assessment of social, political, economic, and ecological factors, a CHANS framework may be used to address complex primate conservation issues where human activities are impacting primates and their habitats (i.e., anthropogenic disturbance). In this chapter I use the CHANS framework to assess the complex coupled system at Fongoli, Senegal.

The use of CHANS incorporates social and biological sciences to assess the linkages between the human and natural systems, the impacts they have on one another, and the scale, ranging from local to global, at which these impacts occur (Liu et al., 2007a). Each system, human and natural, creates feedback loops that impact the other. In the case of wildlife, human activities can impact all aspects of a species' environment, including the size, structure and connectivity of habitats, the availability of resources, and abundance of heterospecifics (Tuomainen and Candolin, 2011). These impacts often change the species' behavior and ultimately impact population viability (Tuomainen and Candolin, 2011). In turn, behavioral changes of wildlife may impact humans and create areas of human-wildlife conflict. For example, habitat depletion and degradation from human activity can force wildlife to search for resources within human-dominated landscapes, causing crop raiding, livestock depredation and even human injury or deaths (Woodroffe et al., 2005; Madden, 2004; Munster and Munster, 2012). This reciprocal effect has been reported for chimpanzees and human communities living in Bossou, Guinea in West Africa. Chimpanzees at Bossou live alongside human communities and have for generations, as the people of Bossou revere the apes as reincarnations of their ancestors (Kortlandt, 1986). The pressure of human agricultural activity, however, has altered the feeding behavior of the chimpanzees to opportunistically feed on agricultural crops (Hockings, 2007). This behavioral shift has forced humans and chimpanzees into more frequent contact and has resulted in direct conflict and attacks, both by humans towards chimpanzees and vice versa (Hockings, 2007; McLennan and Hockings, 2016). In order to reduce human-chimpanzee conflicts, people have altered their cultivars, cropping regimes, and the location of their crops with varying levels of success (Hockings, 2007; Hockings and Humle, 2009).

In addition to human alteration, natural changes and cycles can also bring human and wildlife systems together. In East Africa, for example, natural wildebeest migrations affect the ranging behavior of elephants, driving them out of reserves and bringing them into contact with humans more frequently (Sitati and Ipara, 2011). Climate change impacts have also resulted in behavioral changes in wildlife and bring them into contact with humans more often, as is the case with polar bears in Manitoba, Canada (Regehr et al., 2007).

Human and natural systems have arguably been coupled since the beginning of human history. However, recent globalization and modernization have increased the rate of change within these systems. Changes on the local scale can have a global impact when amassed. The current state of global defaunation is considered a cumulative result of the local scale impacts of human activities on wildlife populations (Dirzo et al., 2014). At the same time, global changes in human behavior and thought can have significant impacts on local wildlife behavior and population viability.

In this chapter, I assess linkages between the human and natural systems at the Fongoli chimpanzee study site in southeastern Senegal. I focus primarily on local feedback interactions between the people and the natural environment; however, these relationships are often influenced by the larger national or global systems, which I will address in turn. This evaluation and in-depth analysis of the field site examines how the Fongoli chimpanzee community has coexisted with human communities in recent decades, illustrates the complexity of the larger system, and sets the stage for understanding the impacts of increasing gold mining activities.

Location

The West African nation of Senegal is subdivided into 14 regions. Three of these regions make up eastern Senegal: Bakel, Tambacounda and Kedougou. The Kedougou region, formerly within the Tambacounda region, was created in 2008 and is further subdivided into three departments (Kedougou, Salemata and Saraya), which are further delineated into four districts: Salemata, Bandafassi, Saraya, and Fongolimbi (Figure 1). The Dakar-Bamako Corridor, a highway connecting the capital cities of Senegal and Mali, bisects the region of Kedougou and passes through the administrative capital city of the same name. This is the only paved highway passing through the region, which remains fairly isolated and remote from the rest of the country.

The Fongoli field site is located in the region of Kedougou, approximately 15km from the administrative capital city of Kedougou (12°400 N, 12°130 W, Fig. 2). The chimpanzee's home range encompassed 110km^2 (see Chapter Five on ranging), and overlapped with seven villages (Ngari, Ngari Seekoto, Tenkoto, Fongoli, Petit Oubadji, Djendji, and Wakalari) and seven active artisanal gold mines in 2014 (see Chapter Two). The Gambia River delimits the chimpanzees' home range along part of the northern and eastern borders, and the N7 national road limits the range along the western border.

The Kedougou region is situated within the Mandingue Plateau, an area home to an estimated 1,500 chimpanzees (as of 2003) and listed as a priority area of exceptional importance for West African chimpanzee conservation (Kormos and Boesch, 2003). The study site also lies in an unprotected area between Senegal's Zone d'Intérêt Cynégétique (ZIC) of Falémé, a wildlife hunting area, and Niokolo-Koba National Park, the country's largest national park. The Kedougou region lies entirely within the Precambrian

Basement of Senegal and is, therefore, home to the country's gold mining. As gold mining and exploration have increased in Senegal, private and corporate mining companies have established themselves in the Kedougou region. Kedougou is also one of the poorest, least developed departments in the country with a low human population density (Republic of Senegal, 2012). However, as mining operations have increased, the human population and related environmental threats are also on the rise (see Chapter Two).

The major human systems in the Kedougou region that influence the Fongoli field site include the local government, which stems from historical and national governance, permanent residents of local villages, and transient human communities. These human systems interact with the local climate, natural resources, and wildlife populations, of which I focus primarily on the resident chimpanzee population.

The human systems

Governance and history

Senegal received its independence from France in 1960, at which time Senegal was considered one of the most advanced Sub-Saharan African countries in terms of average per capita income (Lewis, 1987). Senegal's capital Dakar was the headquarters for the francophone West African colonies and tied the country very closely to France, a relationship that remains strong today (Claassen and Salin, 1991). Under colonial rule as well as in their newly independent government, Senegal maintained a top heavy, highly bureaucratic and centralized government. The country has since decentralized much of the state's power during structural adjustment programs in the 1970s, '80s and '90s, including forestry and natural resource management. Today, Senegal is a semipresidential democratic republic with a unicameral parliament, electing a president to serve a five-year term as well as a prime minister. The country is delineated into 14 regions, which are further subdivided into departments, arrondissements, rural communities, communes and villages. Rural communities and rural community councils were established in the 1990s in the continuing decentralization of power (Faye, 2008). In 1998, the Forestry Code gave the rural councils the right to protect and manage their communal forests and natural resources (Republic du Senegal, 1998). However, despite the 1998 Forestry Code, the national forest service continues to control much of the forest resources (Poteete and Ribot, 2011).

The Fongoli field site is located in the region of Kedougou, department of Kedougou, Bandafassi arrondissement, Tomboronkoto rural community, and Djendji commune. The prefect of the commune lives within the chimpanzees' home range in the village of Djendji. Although the exact history of human habitation within the Fongoli chimpanzee range is unknown, the region of Kedougou has a long history of human habitation dating back to the Paleolithic (Huysecom et al., 2012). Pre-colonial records indicate elaborate human settlements, intensive agriculture, iron smelting, gold mining and ceramic production (Parks, 1887; Huysecom et al., 2012). In an entry on May 16, 1767 from Mungo Park's *Travels to the Interior of Africa*, the author details his arrival at the town of Kirwani, in southeastern Senegal. Although written with a British spelling, the pronunciation is nearly identical to the name of the small river that runs the length of the Fongoli home range today, Kerouani.

> *May* 16.—We departed from Baniserile and travelled through thick woods until noon, when we saw at a distance the town of Julifunda, but did not approach it, as we proposed to rest for the night at a large town called Kirwani, which we reached about four o'clock in the afternoon. This town stands in a valley, and the

> country for more than a mile round it is cleared of wood and well cultivated. The inhabitants appear to be very active and industrious, and seem to have carried the system of agriculture to some degree of perfection, for they collect the dung of their cattle into large heaps during the dry season for the purpose of manuring their land with it at the proper time. I saw nothing like this in any other part of Africa. Near the town are several smelting furnaces, from which the natives obtain very good iron. They afterwards hammer the metal into small bars, about a foot in length and two inches in breadth, one of which bars is sufficient to make two Mandingo corn-hoes. (Parks, 1887)

Today, the human population in the region of Kedougou makes up only 1% of the country's total population; however, the growth rate for the region has increased from 0.9% in the 1980s to 2.7% in 2010, and has likely increased further (Republic of Senegal, 2011). Still, the region remains one of the poorest and least developed in the country (Pison et al.1995; Republic of Senegal, 2012). In 2011, Kedougou had the country's highest child mortality rate of 15.4%, compared to the national average of 7.2% (UNDP report, 2013). Kedougou also has one of the highest incidences of severe poverty in the nation; second only to the region of Kolda.

Permanent human communities

Southeastern Senegal is a multicultural environment comprised predominately of three major cultural groups known as the Tenda, Mandë, and Peule (Stirling, 2012). Each of these three groups can be further subdivided. The main subgroups that are found within the focal study area are, Bedik and Bassari (Bëliyan) of the Tenda culture, Diakhanké and Malinké of the Mandë culture, and the Peule-Fouta of the Peule culture (Stirling, 2012; Republic of Senegal, 2011). The major religion in the region is Islam, practiced by the Mandë and Peule people. Although a minority religion in the country, Christianity is practiced to some extent by the Tenda people. Animist and traditional religious beliefs are fused with Islam and Christianity within the Mandë and Tenda cultures, respectively, whereas the Peule people are strictly Muslim (Stirling, 2012). Within the Fongoli range, all of these major ethnic groups are present; however, the Mandé culture predominate in the village of Fongoli, Djendji, and Ngari Sekoto; Bassari people in Petit Oubadji, and both Peule-Fouta and Bassari in Wakalare. There are no Bedik villages within the Fongoli chimpanzee range, but the Fongoli Savanna Chimpanzee Project employs three Bedik field assistants, and neighboring Bedik villages have agricultural fields within the Fongoli range.

Traditionally, the cultural groups in this area of southeastern Senegal were divergent in their methods of subsistence: Tenda were hunter-gatherers, the Mandé were agriculturalists, and the Peule, pastoralists. While the Tenda are still known to be avid hunters, and the Peule own the majority of the region's livestock, all of the ethnic groups today depend heavily on subsistence agriculture, cultivating millet, sorghum, peanuts, rice and maize (Wula Nafaa, 2006). Crops are used primarily for household consumption, but any surplus remaining may be sold for profit. Land is prepared using the traditional "slash and burn" technique. The communities in the vicinity of Fongoli also rely heavily on forest resource collection. Much of village construction uses forest resources, including soils for brickmaking, grasses for roofs, bamboo for building frames, and tree barks for cord and lashing material. In addition to building materials, people also harvest fruits, medicinal plants, bushmeat, and livestock fodder from forested areas.

Bushmeat hunting is an important economic livelihood in southeastern Senegal. Hunting is used to incorporate protein into a grain-heavy diet and to supplement agricultural revenue (Ba et al., 2006). A recent study on national bushmeat hunting activity indicated that 70% of reported kills came from the Kedougou region (Ba et al., 2006). The actual percentage is likely higher due to the large rural and poor population in Kedougou who are less likely to report their kills, as they are not able to afford hunting licenses and therefore hunt illegally. Although bushmeat hunting is widespread, all of the ethnic groups living in the region have strict taboos against eating chimpanzees (Carter et al., 2003; Clavette 2005). The Tenda are known to eat other primates such as patas (*Erythrocebus patas*), baboons (*Papio hamadryas papio*) and vervet monkeys (*Chlorocebus pygerythrus*). In neighboring countries of Mali and Guinea, however, some of the same ethnic groups (e.g. Malinké and Peule-Fouta) are known to engage in chimpanzee hunting for bushmeat consumption and medicinal purposes despite Islamic taboos against consuming primates (Kormos et al., 2003; Duvall et al., 2003.).

In addition to bushmeat, communities also collect large quantities of wild fruits. One of the major fruit species collected in Fongoli is *Saba senegalensis* (Knutsen, 2003; Waller and Pruetz, 2016). The yellow-orange fruit grows on a vine and is about the size of an orange. Unlike an orange, when the thick outer skin is removed the fruit's flesh is divided into segments surrounding large individual seeds. The tart fruit grows only in southern Senegal but is popular throughout the country. Collection of the fruit is a profitable seasonal livelihood for people living in the region of Kedougou to supplement their agricultural income (Knutsen, 2003; Waller, 2005; Pacheco, 2012). Collection is done by hand, often transported in rice sacks by bicycle to a nearby village and then sold to a transporter. Transporters will haul tons of *Saba* to Dakar, Senegal's capital city, each year (USAID, 2010). *Saba* fruit are also consumed by many species of wildlife and are a major part of the chimpanzee diet (Pruetz, 2006).

Transient human communities

Other major community residents in the Kedougou region are seasonal pastoralists and miners. Pastoralists bring their livestock south from northern Senegal during the dry season in search of water and fodder. Over the past 30 years there has been an emerging trend of southern advancement of Peule-Fouta pastoralists in West Africa, moving from the drier Sahel into the more humid Sudanian and Guinean savannas (see Bassett and Turner, 2007). The trend is apparent in Senegal where pastoralists from northern Senegal have recently begun to migrate into the Kedougou region during the dry season to graze and water their livestock (primarily sheep and goats). Increased irrigation for agriculture along with decreasing rainfall in northern Senegal may be fueling this southern migration (Massa, 2011). Pastoralists provide fodder for their livestock by cutting branches from the crowns of select tree species and traveling through the bush between villages. When stopping at a village, the community members often welcome pastoralists as the goat and sheep herds will fertilize the fields adjacent to the village. Although herds can be beneficial to communities as one level, transhumance activities have been listed as among some of country's most serious threats to biodiversity (USAID, 2008).

In addition to the increasing impacts of pastoralists, a growing threat to biodiversity in southeastern Senegal is artisanal small-scale gold mining (ASGM). ASGM has long been a livelihood in Senegal, dating back before colonial times (Parks, 1887) and perhaps as far back as 2000 years, but the practice has changed dramatically by incorporating machinery, advanced technology, and unsustainable practices (see Chapter Two on the history of ASGM in West Africa).

While much of the local Kedougou population is active in gold mining activities, there has also been a large influx of gold mining immigrants into Senegal from neighboring Mali, Guinea and Burkina Faso, as well as migrants from as far as Ghana and Nigeria (Republic of Senegal, 2015). Rush type gold mining (see Chapter 2) can turn small villages into large mining hubs within months, as in the case of Kharakhena village that went from 110 villagers to tens of thousands of inhabitants in a six-month period in 2013 (S. Keita, Village Chief, pers. comm.). Large mining villages experience changes in other economic activity associated with the increased population and subsequent demand such as markets for food and goods, transport, bars and prostitution. At smaller ASGM sites, including those found within the Fongoli field site, miners travel to and from the mine daily, staying in nearby villages rather than creating a new village or long-term camp at the mine site. As the human population increases in the region of Kedougou due to gold mining immigration (Republic of Senegal, 2011), urban areas are expanding and converting wildlife habitat into areas of human settlement, cultivation, and gold mines (USAID, 2008). Gold mining often takes precedence over natural resource management and is therefore one of the top threats to wildlife and biodiversity in the region.

Fongoli Savanna Chimpanzee Project

The final human system to be address in the Fongoli system is the Fongoli Savanna Chimpanzee Project (FSCP). The FSCP began in 2001 by Dr. Jill Pruetz with the objective of studying the behavioral ecology of West African chimpanzees living in hot, open and dry savannas (Pruetz et al., 2002). The project is comprised of Western and Senegalese staff, scientists and field assistants who monitor the behavior of the resident chimpanzees on a daily basis. Having constructed a compound of huts at the Fongoli village, the FSCP team has had a permanent presence since the project's inception and has been living within the Fongoli field site since 2007.

Following four years of habituation efforts from 2001 through 2005, systematic all-day follows of focal subject male chimpanzees of the Fongoli community were possible (Piel et al., in prep.; Pruetz & Bertolani, 2007). All individuals in the group were identified by January 2006. The data collection protocol for Fongoli includes daily all-day focal-subject follows of adult male chimpanzees and their sub-groups or 'parties'. Daily follows of focal males begin as they emerge from their night nest in the morning until they build and enter their night nest in the evening. Throughout the follow period researchers remain a minimum distance of 10m from the study subjects and regularly remain at distance of 20m. At distances of 10m or less, all researchers and observers are required to wear surgical masks that protect the subjects from zoonotic respiratory disease transmission. Data collected during daily follows include the GPS location of the individual and socio-behavioral data of the focal subject as well as variables related to ecology like habitat types and substrates used. Additionally, researchers collect opportunistic and all occurrence data based on specific research questions, e.g., hunting and meat sharing behavior. Since 2005, data collection for each male subject has regularly included the subject's location, activity, and food source when eating, along with data on nearest neighbor chimpanzees, providing the project with a 10-year database for these items.

Female chimpanzees are not targeted as focal subjects due to slight but real chance that female chimpanzees in Senegal are hunted for their infants who are then sold into the pet trade (Pruetz and Kante, 2010). The FSCP protocol on habituating females has been in place throughout the duration of the project, resulting in females remaining more timid than males when females are encountered alone. Although females are not systematically followed, data is collected opportunistically when they are in parties with adult males.

The natural systems

Climate and seasons

Fongoli is located within the Shield ecoregion (Tappan et al., 2004) in a Sudano-Guinean climate. The region has a short wet season from June through September (average rainfall 786-900 mm per year, Pruetz & Bertolani, 2009; Ba et al., 1997) and a long dry season from October through May, with maximum temperatures frequently reaching over 40 degrees Celsius (Pruetz and Bertolani, 2009). Highest temperatures coincide with the driest period of the year in April, May, and early June whereas lowest temperatures in the upper 20s Celsius occur at night in December and January. Climate and seasons impact water and forest resources annually through seasonal rains, winds and temperatures. One example of this is the hot and dry harmattan winds that blow across the landscape during the months of January and February, drying the air, preventing rain, and increasing fires (Dobson and Fothergill, 1781). The seasonal cycles are reflected in fruit production, forest canopy cover, and the number of water sources available. Climate change impacts are already being felt in Senegal including erratic and extreme weather events, increased flooding events, and extreme periods of drought (WFP, 2014; Galat-Luong et al., 2009).

Forest resources and land cover

The vegetation cover in southeastern Senegal is classified as a mosaic of dense and open Sudanian wooded savanna, Guinean forests, and grasslands (Frederiksen & Lawesson, 1992; Tappan et al., 2004). Named for its complex Precambrian geology, the Shield ecoregion is characterized by low hills, terraces and valleys comprised of volcanic and sedimentary rock from the Paleoproterozoic period (Tappan et al., 2004). Much of the soil is gravely and poor for agriculture. Laterite rock sits just below the soil and in some areas protrudes to the surface, restricting root growth and created large grassy areas known locally as *bowé* (Pulaar) or *fourre* (Malinké).

While much of the landscape is open woodland, gallery forests cross the landscape lining alluvial valleys and are characterized by evergreen, closed canopies. These forests are diverse in their vegetation and include the following tree species *Ficus capensis*, *Ficus gnaphalocarpa*, *Erythrophlaeum guineense*, *Piliostigna thonningii*, *Syzygium guineense*, *Khaya senegalensis*, *Elaeis guineensis*, *Parkia biglobosa*, *Terminalia macroptera*, *Ceiba pentandra* and *Cola cordifolia* (Stancioff et al., 1986). Few grasses grow under the dense canopy, but shrub species such as *Saba senegalensis*, *Mimosa pigra*, *Mitragyna inermis*, *Baissea multiflora*, *Nauclea latifolia* and *Raphia sudanica* are found in abundance. The gallery forests are cooler than open habitat land cover types (Pruetz, 2007) and provide microclimate refugia for wildlife during the long and hot dry season. Although gallery forests make up a small percentage of the total habitat in southeastern Senegal, they are critical habitat for chimpanzees who nest, feed and rest in their shade (Pruetz and Bertolani, 2009; Boyer, 2011). *Saba senegalensis* is also found primarily in the gallery forests and secondarily in woodland land cover types (Waller and Pruetz, 2016).

Water resources

Water availability is likely the most important and limiting resources for humans and wildlife in much of southeastern Senegal (Carter et al., 2003). During the dry season, water sources are scarce (Pruetz and Bertolani, 2009; Pruetz, 2006; Pruetz, 2007). Gallery forests often provide the only locations for permanent water sources used by many species of wildlife and people. During the seven-month long dry season, seasonal rivers and streams dry completely, leaving wildlife to dig into the water table or concentrate around year-round springs (Galat-Luong et al., 2009). In Fongoli, by the month of April, as few as two permanent water sources may remain in the entire chimpanzee home range (Pruetz, unpublished data). Ranging behavior becomes more restricted to these areas, until food resources are depleted (Pruetz and Bertolani, 2009).

As of 2013, all of the villages within the chimpanzees' home range have either a water pump or a well to access drink water. However, prior to 2013, the inhabitants of Fongoli village drew water from the Fongoli River, which runs alongside the village and is shared by wildlife. Still, even with access to ground water within the villages, women and children are known to use natural water sources such as the Fongoli and Kerouani rivers to wash clothes and bathe.

Chimpanzees and other wildlife

Senegal's large mammals have been on the decline over the last century. Giraffe (*Giraffa camelopardalis peralta*; Ciofolo, 1995), cheetah (*Acinonyx jubatus*; Belbachir, 2008), korrigum (*Damaliscus lunatus*; Sayer, 1982), and dama gazelle (*Nanger dama*;

Cano et al., 1993) have all been extirpated from the country. Other species nearing extirpation include elephants (*Loxodonta africana*), wild dogs (*Lycaon pictus*), lions (*Panthera leo*) (Henschel et al., 2014), buffalo (*Bubalus bubalis*), roan antelope (*Hippotragus equinus*), Western Derby eland (*Taurotragus derbianus derbianus*) and chimpanzees; although the rates of declines and current population densities estimates of these species vary West African savanna chimpanzees have been listed as Endangered on the IUCN Red List of Threatened Species^{TM} since 1988, and due to recent declines in populations are now listed as Critically Endangered (Humle et al., 2016). Within West Africa, Senegalese chimpanzees are afforded highest level of priority for conservation (Kormos & Boesch, 2003). Population surveys from 2003 indicated a range of 300-500 chimpanzees remaining in Senegal. A regional survey has been recently completed to provide a more up to date population estimate, which is likely higher than previous estimates due to improved detection methods and research coverage (Ndiaye et al., in prep. and see Chapter One for an estimation of Senegal's chimpanzee population).

The chimpanzees of Senegal live at the northernmost geographic limit of the species' global range, in an environment that is hotter and drier than almost any other chimpanzee habitat (McGrew et al., 1981; Pruetz & Bertolani, 2009). Like forest dwelling apes are primarily diurnal, incorporate fruit into their diet, nest in trees, and prefer closed canopy habitats for some activities. However, adjustments to the hot and dry ecosystem of southeastern Senegal have resulted in unique behaviors not yet seen in other chimpanzee populations, including hunting mammals with tools (Pruetz & Bertolani, 2007), soaking in pools of water (Pruetz & Bertolani, 2009), engaging in nocturnal activity (Pruetz & Bertolani, 2009), using caves (Pruetz, 2007), and predicting the movement of fires (Pruetz & Laduke, 2010).

The average chimpanzee community size at Fongoli from 2006 through 2013 is 31.6 individuals, with a minimum of 29 individuals in 2010 and a maximum of 36 individuals in 2012. On average, adult males comprise 31.9% of the community and adult females 22.5%. In comparison to chimpanzees elsewhere, those at Fongoli have larger and more cohesive parties (both in absolute numbers and relative to their community size), which is likely a mechanism to maintain social connectivity within the larger home range (Pruetz and Bertolani, 2009). The Fongoli chimpanzee home range within the forest-savanna mosaic is comprised of patchy resources and has been estimated as two to six times larger than home ranges of chimpanzees living in forested environments (Pruetz and Bertolani, 2009).

System interactions

The central tenant to the Fongoli system is access to and use of land and water resources (Figure 4). All members of the human and natural systems depend on these resources to survive and flourish. In some instances, human and natural systems impact each other directly; however much of the feedback between the two systems are linked indirectly through the impacts each have to the land and water resources. Direct impacts between human systems and chimpanzees result over conflicts of land and water resources. Pastoralists have been reported to yell at and intimidate the chimpanzees in order to have undisturbed access to water for their livestock (Pruetz, pers. comm.). Agriculturalists from the villages have also been seen and heard scaring chimpanzees out of their fields, even though they are not crop-raiding (Pruetz, unpublished data). These types of direct impacts are relatively rare with respect to the total number of human-chimpanzee encounters (see Chapter 4). However, the indirect impacts of human activity on the chimpanzee and the natural systems are extensive. Here I focus on the impacts to timber and water resources (for more information on human uses and impacts on natural resources see Chapter 4).

Both permanent and temporary residents use and deplete timber and non-timber forest resources. Permanent inhabitants of nearby towns and villages enter into the Fongoli field site area to harvest timber that can be either used for personal consumption or sold to people in urban areas (Ribot, 1998). The close proximity of the urban town of Kedougou coupled with the adjacent national highway makes the Fongoli area a target area for resource and timber harvesting, particularly as forested areas closer to Kedougou become depleted (Deutsche, 2011). Depletion of timber, particularly in the gallery forests and woodlands, reduces preferred nesting trees for chimpanzees (Ndiaye et al., 2013). Hardwoods, such as *P. erinaceus*, *Diospyros mespiliformis*, *Parkia biglobosa*, *Anogeissus leiocarpus*, *Cola cordifolia*, and *Syzygium guineense* are preferred nesting trees used by chimpanzees and are also commonly used by people for woodworking, fuel, and medicinal purposes (Ndiaye et al., 2013; Ba et al., 1997).

Transient pastoral communities also reduce timber resources by cutting branches to allow their livestock access to the green leaves at the tree crown (Massa, 2011). Many of these tree species are also species that are either part of the chimpanzee’s diet or used for nesting (Massa, 2011). The loss of the tree crown reduces the tree’s ability to produce fruit and eliminates possible nesting locations for resident chimpanzee populations. Although cutting the crown does not kill the tree, the cutting technique used by the pastoralists creates a conical shape as the cut branches falling alongside of the tree trunk (Figure 3). As these branches dry, they create large amounts of fuel for following dry season's bushfires, which subsequently can consume the remaining living portions of the tree. Both local and transient communities contribute to the fires during the dry season. Fires are used to clean the landscape, add nutrients to the soil, and as a hunting technique (Mbow et al., 2003). Fires lit in villages or along roads can persist throughout the bush for kilometers, burning slowing for days in the heat of the dry season (Deutche, 2011; Pruetz and LaDuke, 2010). These fires can also reduce of chimpanzee food resources by inhibiting the growth of key food resources such as *Saba* (Pruetz, 2006). In addition to the impacts of pastoralist tree cutting, transient and permanent gold mining communities also impact forest resources by cutting trees to create support structures for the gold mine shafts (Doucouré, 2014). Hardwoods are used to shore up the sides of the shafts and are also used as supports in underground tunnels.

Due to the scarcity of water in the region, water points can be areas of conflict between people and chimpanzees (Carter et al., 2003). Villagers, pastoralists and miners use natural water sources during the dry season to wash clothes, bathe, and collect water when village wells have run dry. The simple presence of people at a water source can deter wildlife from approaching and accessing the water. One of the priority actions for chimpanzee conservation regionally has been to improve people's access to water sources via village wells and pumps in an effort to reduce human-chimpanzee conflict (Carter et al., 2003). Water sources are particularly important for pastoralists and gold miners whose livelihoods are located in the bush and do not have access to village wells or water pumps. Pastoralists who arrive with their flock in the dry season will often take over permanent water sources for days at a time where they will dig wells and carve troughs from trees for their herds to drink (K Boyer Ontl, pers. obs.). In other instances, herders have blocked access to waterholes by weaving acacia limbs around the area thus inhibiting wildlife from drinking (J Pruetz, pers. comm.). With human presence around the water source, this limits the availability for wildlife, including chimpanzees. Ultimately the intensive use of the source can deplete the water table, making it even more difficult for wildlife to drink once the herders have moved on.

The impacts of gold mining on the water system are evident throughout the process. There are two main phases of gold processing: extraction and treatment. The first phase, extraction, uses little water, whereas the treatment phase requires large quantities to wash the crushed ore down sluice boxes (See Chapter 2 for details on gold processing). The treatment process is often completed away from the ASGM site and closer to rivers where water can be pumped out for use. Although the first phase of ASGM (extraction) uses relatively little water compared to the treatment phase, it directly impacts the water sources in the chimpanzees' home range at Fongoli. Most of the ASGM sites are located next to natural water sources. In the case of the largest mine, Oundoundou, the footprint extends down a ravine and into a valley with a seasonal water source. To mine in this area, the water source had to be diverted. Diverting and using water for gold mining activities depletes the water table, making it more difficult for chimpanzees and other wildlife to find and access water sources. At the Kerouani mining site, pits have been dug in the Kerouani streambed and filled with ground water, creating new water sources for wildlife to use. However, the safety of these newly formed water sources comes into question due to the lack of sanitation at mining sites (Doucouré, 2014;

Small, 2012). An example of this is seen at the Oundoundou mine in the Fongoli range, where the mined areas are located on sloping hillsides. As people spend the day at the mine, they move to the edge of the mining areas to urinate and defecate. During the rainy season, human excrement then washes down the hillside into the water source below (see environmental impact of ASGM in Chapter Two).

As the human communities, both transient and permanent, deplete and degrade the forest and water resources, the local chimpanzees and people who use the natural resources are impacted. Loss of nesting trees, fruit trees, and degraded water sources in addition to habitat fragmentation may result in increased travel distances for chimpanzees to find water and between feeding patches, which can be particularly costly in the hottest and driest time of the year. The increased presence of people, along with the dwindling forest resources, increases human-chimpanzee encounters as well and the risk of greater human-ape conflict (see Chapter 4).

Although much of the interactions between the human and chimpanzee communities are negative, the people of Fongoli derive indirect positive benefits from the chimpanzees as well. Chimpanzees are known predators of crop-raiding wildlife species such as baboons and vervet monkeys. People living in the village of Djendji have reported that having chimpanzees near their fields reduces the likelihood of crop-raiding species (J. Pruetz, pers. comm.). Chimpanzees have been shown to be seed dispersers of the *Saba* fruit, an important fruit to people in the area (Pruetz, 2006). Other positive impacts have come via the presences of the Fongoli Savanna Chimpanzee Project. The presence of this critically endangered subspecies initiated the creation of the project that has provided livelihoods and temporary employment to local community members and has also supported village schools and education programs.

Telecoupling processes

Although this analysis has been primarily limited to the Fongoli field site, the CHANS framework acknowledges that no system exists in a vacuum. In general, broad-scale fluctuations at the national or international level create change at the local level and are known as telecoupling processes in the CHANS literature (Liu et al., 2007a; Cater et al., 2014). At Fongoli, broad-scale processes influencing the local gold rush include the most recent global financial crisis and subsequent human migration (Figure 4).

Global economic fluctuations from the 2008-2009 global recession resulted in rising gold prices that have fueled the gold rush in southeastern Senegal (Prause, 2016). Prior to the financial down turn, in 2003 Senegal had committed itself to neoliberal ideologies and policies, liberalizing their mining code and making the country more attractive to foreign exploration companies (Niang, 2012). By 2012, over 50 exploration and exploitation permits had been distributed to national and international mining companies, and tens of thousands of artisanal gold miners had arrived from other West African nations (Prause, 2016). As mining activity has expanded in the artisanal sector, materials and equipment have become more technologically advanced incorporating metal-detectors, electric pumps that remove ground water from the mining pits, ore crushing machines, generators, and jack hammers. Although mining has been occurring in the region of centuries, the influx of technology and gold mining expertise, along with the ease of travel along major highways in the region has increased the scale and pace at which mining activities occur.

Conclusions

The Fongoli field site is a complex system of human and natural systems that can best be understood through the nesting of local systems within their regional and global systems, and through assessing the reciprocal impacts between the systems. Local communities, influenced by regional, national and international structures and processes, impact local wildlife and their habitats. In return, the natural habitats, and wildlife within, impact the livelihoods and activities of the local communities. To fully understand the interactions and relationships between the social and natural, research efforts should bridge disciplines and methodologies of the social and natural sciences.

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Table 3.1 Governance Structures for Senegal and the Fongoli Field Site

	Appointed Official	Elected Official	Fongoli Field Site
State	Prime Minister, Cabinets	President, legislature	Senegal
Region	Governor	Regional Council/Regional Council President	Kedougou
Department	Prefect	N/A	Kedougou
Arrondissement	Subprefect	N/A	Bandafassi
Rural Community	N/A	Rural Council/Rural Council President	Tomboronkoto
Commune	Prefect	Municipal Council/Mayor	Djendji
Villages	Traditional Chief (inherited title or elected)		Fongoli, Petit Oubadji, Djendji, Wakalari, Ngari

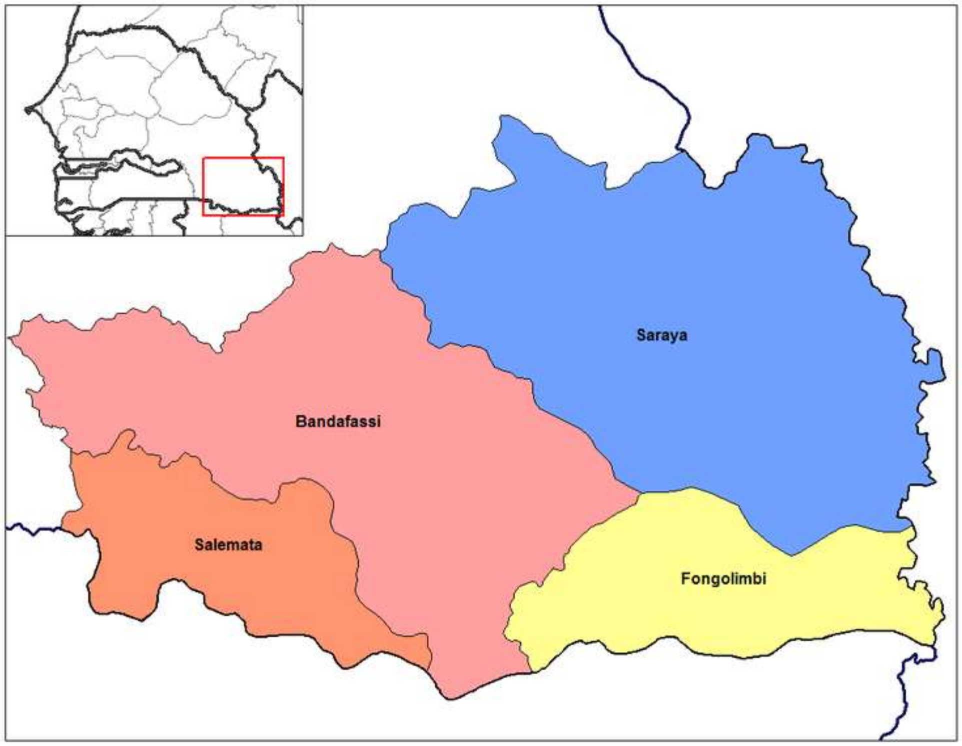

Figure 3.1 Kedougou region subdivided into the four districts. The administrative capital is indicated with a black star.

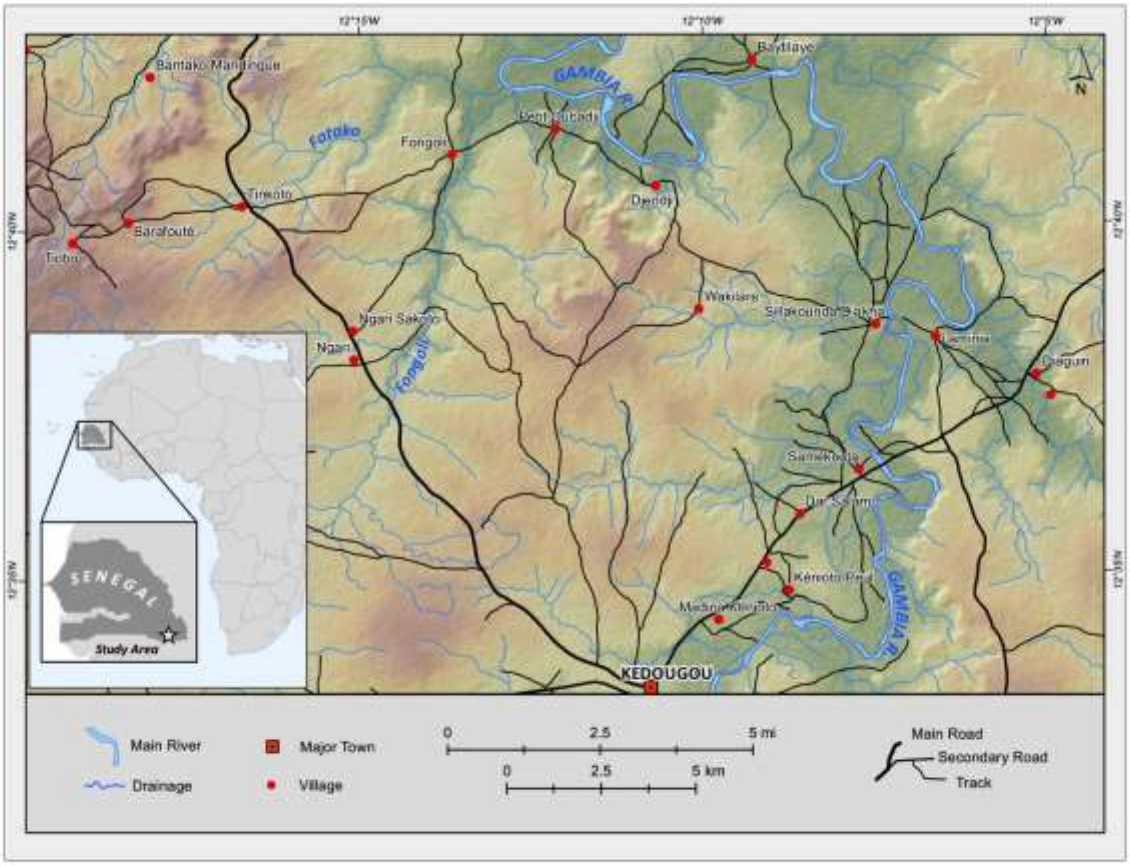

Figure 3.2 The Fongoli field site in Kedougou, Senegal

Figure 3.3 Pastoralists cut branches of trees, bending them downward to the ground, for livestock to access the green leaves. These branches dry over the course of the year and become fuel for bushfires.

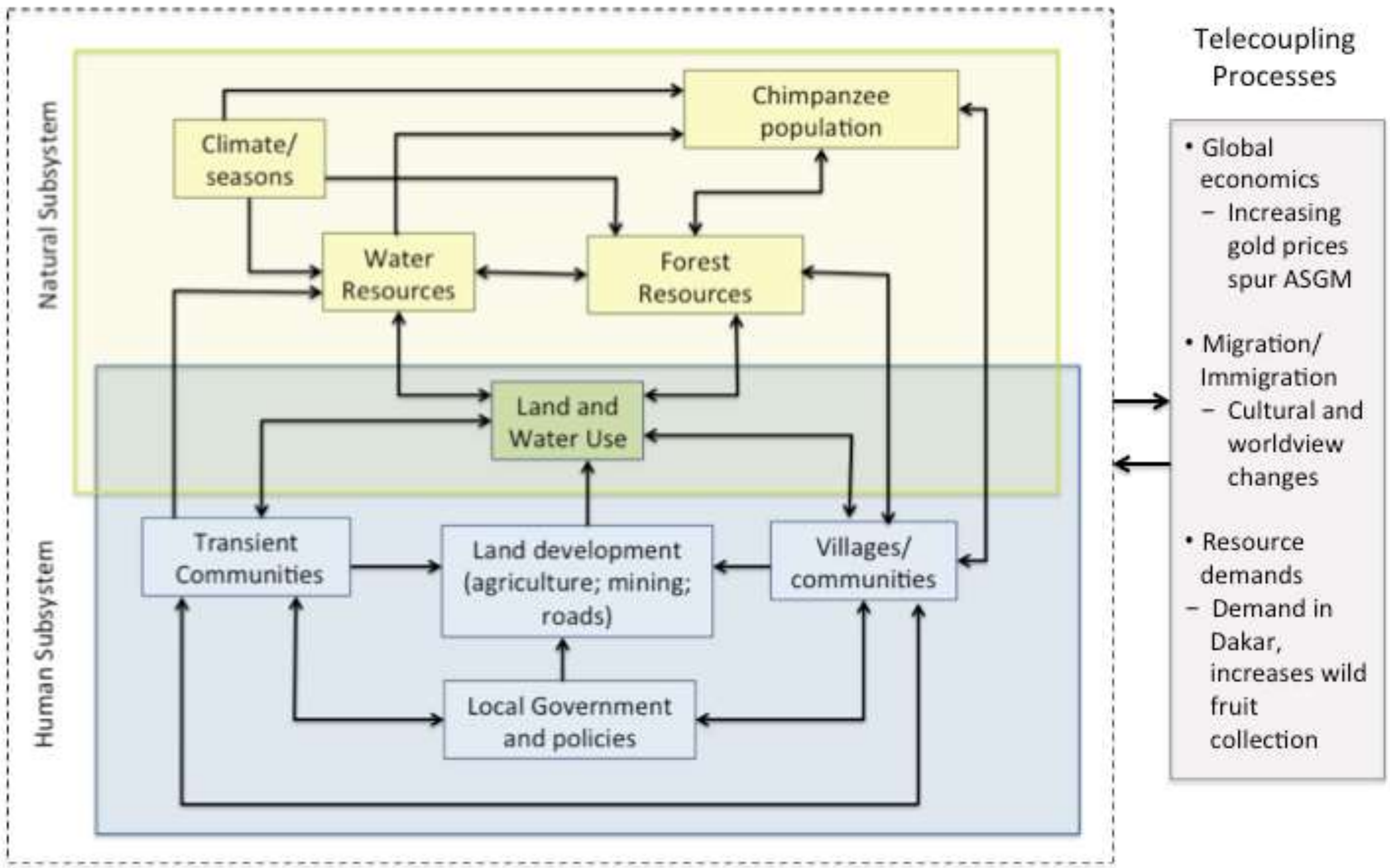

Figure 3.4 Conceptual diagram of the coupled human and natural system of the Fongoli field site. Area delineated with the dotted line illustrate the interactions and feedback between the systems within Fongoli. The grey box to the right lists the telecoupling processes that link the Fongoli system with National and Global activities.

CHAPTER IV

DYNAMICS OF HUMAN-CHIMPANZEE ENCOUNTERS AT FONGOLI, SENEGAL, 2006-2014

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Abstract

As global gold prices increased rapidly in the wake of the 2008 global recession, southeastern Senegal experienced a widespread gold rush with increased artisanal small scale gold mining (ASGM). In this study, we examine how human-chimpanzee encounters have changed at the Fongoli study site in Senegal starting in 2006 (prior to the gold rush) and through 2014 (during active gold mining). Using detailed records from the Fongoli Savanna Chimpanzee Project, we analyzed all observations of visual and auditory encounters of people by chimpanzees over the nine-year study period. We found that human-chimpanzee encounters increased over the study period and people's activities shifted from primarily the collection of non-timber forest products (NTFPs) to ASGM activities. Additionally, people were more likely to initiate interactions with the chimpanzees in later years, although these interactions were rare. The chimpanzees exhibited significantly different reactions depending on the activity and transportation type of the people they encountered, such as fleeing when encountered by people collecting NTFPs resources on foot, vocalizing at ASGM miners in vehicles, and hiding from hunters. Overall, chimpanzees were significantly less likely to flee during encounters and more likely to vocalize during the height of the gold rush in the later years of the study. Aggressive reactions towards encounters also increased, although not significantly. People and chimpanzees at Fongoli have long lived in coexistence, the increase in ASGM and related human-chimpanzee encounters may result in human-chimpanzee conflict and greater threats to these critically endangered apes.

Introduction

Human and non-human primate populations have been living sympatrically for millennia on the African continent, affecting each other behaviorally and culturally (Kormos et al. 2003). The study of the human and non-human primates (hereafter primate) interface is known as ethnoprimatology. Although the discipline is relatively new (Sponsel, 1997; Fuentes, 2006; Fuentes and Hockings, 2010), the relationships are not. It has been estimated that human and chimpanzee lineages have been living in sympatry since the evolutionary split between *Pan* and early hominins (McBrearty and Jablonski, 2005). Chimpanzees shared the landscape with species of the *Homo* genus in East Africa as far back as the Middle Pleistocene, 781,000 to 126,000 years ago, and occupied similar environments (McBrearty and Jablonski, 2005).

Although more recent primate fossils are rare, due in part to the acidity of tropical soil in Africa (Tutin and White, 1999), other evidence suggests chimpanzee occupation in West Africa over the past 4,000 years. For example, much of the West African landscape was covered in savanna-forest mosaics, similar to the habitat where chimpanzees are found in southeastern Senegal and other parts of the Mandingue Plateau today (Tutin and White, 1999; Tappan et al., 2004). Chimpanzees have likely been woodland-savanna dwellers for much of their evolutionary history. This hypothesis was supported by genetic analyses of East African chimpanzees (*Pan troglodytes schweinfurthii*) showing that chimpanzees did not evolve in a forest environment (Goldberg & Ruvolo 1997). Rather, chimpanzee evolution would have taken place in a more open and variable environment consisting of woodland and savanna ecologies (Goldberg & Ruvolo 1997). Although our knowledge of chimpanzees was initially derived from studies of East African chimpanzees, and forest dwelling populations in particular, studies of Senegalese populations show that chimpanzees are able to live and adapt to open, dry and hot habitats (Pruetz and Bertolani, 2009). Other evidence of the long-term presence of West African chimpanzees includes archaeological studies on chimpanzee tool use that suggest chimpanzee occupation in Côte d'Ivoire prior to the establishment of agriculture (Mercader et al, 2007). Mercader and colleagues (2007) found evidence of modified stones in the Taï forest embedded with starch residue dating back to 4300 BP, which they attribute to chimpanzee activity. Taï chimpanzees today are known to process four species of nuts not eaten by humans using percussive tool technology (Boesch and Boesch, 1982).

Across Africa, chimpanzees have been living alongside people practicing swidden agriculture for centuries (Leblan, 2014). In West Africa in the mid-1900s, reports of hearing chimpanzees, rather than seeing them, indicates that the relationship between these apes and humans has not changed drastically in the region (Leblan, 2014). Anthropogenic activity, including clearing land for agriculture, using fire, and changing vegetation through the planting of domesticated plants, likely had indirect impacts on primates in antiquity. In Mali, evidence suggests that humans altered habitat by discarding seeds from preferred wild fruits such as baobabs (*Adansonia digitata*), which, once grown, became important resources for chimpanzee communities (Duvall, 2008).

While some historical human-primate conflicts are well supported, such as the devastating impact that the arrival of humans to Madagascar had on lemur populations 1500 years ago (Godfrey and Irwin, 2007), most historical analysis of human-primate conflict and coexistence are largely speculative (Tutin and White, 1999). Some archaeological studies have provided evidence of early relationships, including the discovery in Cameroon of chimpanzee and gorilla bones in association with human artifacts (de Maret, 1996). Although difficult to assess motive, it is possible that competition over plant resources led to conflict, with humans killing chimpanzees to protect resources. The apes may also have been killed for consumption, medicinal purposes, or for skins and ornamentation (Mittermeier, 1987). In Lope, Gabon archaeological and primatological research indicate that people living here for the past 3000 years were likely living off of forest resources with diets similar to chimpanzees (Tutin and White, 1999). The similar diets of humans and these apes may have led to resource competition, likely with spatial and temporal niche partitioning. The ability to coexist relies on the partitioning of realized niches and resources (Hutchinson, 1958). Partitioning of niches can occur through spatial separation, where two competing species are able to exploit different resources within the same landscape, or through temporal separation, where competitors use the same resources at different times of the day, month or year (Morin, 2011).

Humans and primates – conflict and commensalism

Human wildlife conflict (HWC) is defined as an interaction between people and wildlife where at least one of the two experiences a negative impact

(Woodroffe et al., 2005). As human populations increase, human habitation and disturbance are pushed into previously undisturbed areas of wildlife habitat, ultimately increasing competition for resources such as food, water, timber, and non-timber forest resources. The depletion of wild resources results in a two-fold problem for wildlife: 1) People enter into wildlife habitat to access resources, disturbing and displacing wildlife and reducing their resources, and 2) as resources are depleted, wildlife enter human dominated landscapes with greater frequency to access crops and other human resources, exacerbating the HWC and often resulting in retaliation by people (McLennan and Hockings, 2016). In both cases, the initial resource conflict can quickly become dangerous with humans protecting their resources and wildlife reacting defensively.

Human encroachment into primate habitat and use of natural resources are increasing rapidly (Estrada et al. 2017). The expansion of settlements and development projects into previously undeveloped habitat are impacting primate habitat. Anthropogenic pressures vary by location, population density, technology, and human activities (Holdren and Ehrlich, 1974; Oates,1996; Dietz and Rosa, 1997; Estrada et al. 2017), and primate responses to human pressures also vary. In West and Central Africa, roads and human settlements have impacted how chimpanzees and gorillas range and use their habitat (Hockings and Humle, 2009; Stokes et al., 2010; Carvalho et al, 2013; Hicks et al;, 2012). In South America, Ecuadorian pygmy marmosets (*Cebuella pygmaea*) show changes in habitat use related to increases in ecotourism and human activities (de la Torre et al., 2000). In much of Asia, plantation expansion has impacted several species of primates by reducing available and viable habitat, including orangutans (*Pongo abelii* and *Pongo pygmaeus*), gibbons (*Nomascus leucogenys*, *Nomascus hainanus,* and *Hoolock hoolock*), the Bengal slow loris (*Nycticebus bengalensis*) and Phayre's langur (*Trachypithecus phayrei*) (Estrada et al., 2017).

The complex relationship between humans and primates creates a continuum from primates as problematic pests to primates as paragons (Hill and Weber, 2010). Today, crop raiding by primates is perhaps the most widespread instigator of human-primate conflict, occurring in all primate inhabited regions of the world (Hill 2005; *Chlorocebus pygerythrus* in Uganda, Saj et al., 2001; *Macaca tonkeana* in Indonesia, Riley, 2007; *Macaca fascicularis* and *Presbytis thomasi* in Sumatra, Marchal and Hill, 2009; *Chlorocebus aethiops* in St. Kitts, Dore, 2017; *Pan troglodytes verus* in Guinea, Hockings et al., 2009). In some West African nations, chimpanzees raid crop fields, resulting in reciprocal violence by humans against these apes (i.e. Guinea Bissau, Guinea Conakry, Sierra Leone, Senegal). At other localities, some even bordering the above-mentioned sites, primates are tolerated and protected (*Pan troglodytes verus* in Guinea-Bissau, Hockings and Sousa, 2011), considered sacred (*Macaca fascicularis* in Bali, Wheatley, 1999), or revered (*Semnopithecus entellus* in India, Hrdy and Hrdy, 1976).

Human-chimpanzee interface in Fongoli, Senegal

In Senegal, where chimpanzees are not frequently hunted and people are tolerant of the apes, the chimpanzees appear to be somewhat tolerant of people, having been observed nesting, feeding, resting, and traveling near areas of human activity (Lindshield et al., 2017; Boyer, 2011). Still, Senegalese chimpanzees do avoid direct confrontation with people (e.g., abandoning feeding or resting sites when disturbed by people), but they do not generally react to people in the same aggressive fashion as they do a consistent and significant predator such as leopards (Pruetz & Boyer Ontl, in prep; Lindshield et al., 2017). The coexistence between people and chimpanzees at Fongoli may be due to the long history of people living in chimpanzee habitat and the cultural taboos against hunting chimpanzees.

Most rural villages in southeastern Senegal, including those within the home range of the Fongoli chimpanzees, are comprised of family compounds that use timber and non-timber resources, competing for use and collection of resource important to chimpanzees (USAID, 2010). A traditional compound contains mud-brick huts, grass roofs, wooden benches, woven bamboo mats (for sitting and used as fencing), wooden fence posts, and wooden shade structures with woven grass awnings (*ombar*) (Figure 1.). Within the compound people use wood and charcoal to make fires and children can be seen eating wild fruits such as *Saba senegalensis*, *Cordyla pinnata*, *Lannea* spp. or baobab. Women process the nuts from the Shea tree (*Vitellaria paradoxa*) to make shea nut butter, a cream used for moisturizing the hair and body. In addition to timber and non-timber forest products, people also herd livestock, mine for gold and use water outside of their village.

<u>Collection of non-timber forest products:</u>

Non-timber forest products (NTFPs) are defined as resources collected or harvested from natural areas that do not necessitate the logging of timber. Such resources can include plants and plant parts (including fruits, nuts, leaves, flowers), fibers, grasses, barks, resin, nectar, as well as fish and game. Some NTFPs are consumed as food or drink, while others are used for medicinal or utilitarian purposes, the latter including livestock fodder, fuel, and construction materials. NTFPs are extremely important to chimpanzees, as well as Senegalese people, society, and culture (Sene, 2001). Human collection of NTFPs is primarily for regional sale with only a small amount reserved for consumption in the home (Republic of Senegal, 2015a). In southeastern Senegal the economic benefit from NTFPs is most important for low-income households and can provide 50% of household income (Ba et al., 2006). The following sections provide information on some of the most common NTFPs collected in the Kedougou region that are also used or consumed by chimpanzees in Senegal.

Bamboo (*Oxytenanthera abyssinica*) –West Africa has one naturally occurring bamboo species (Bystraikova et al., 2004) and, in Senegal, it is one of the chimpanzees' most frequently consumed plant species throughout the year (Table 1.). This species is a woody bamboo and is harvested for poles to make furniture, roofing framing, and to collect of fruit from tall trees (Doucouré, 2014; Wula Nafaa, 2003). Bamboo poles can also be cut into long thin strands that are woven together to create mats (approximately 1.30 x 3.40 m) known locally as *crintin* (Doucouré, 2014). *Crintin* mats are used as panels for fencing, and can also be used to create shelters for shade. Bamboo poles themselves are sometimes woven together to create the walls of structures, including fences and a rural one-room school that was dismantled in the wet season (K Boyer Ontl, per. obs.). The Bassari people living in the village of Petit Oubadji make these panels in the Fongoli area and sell them to people living both in and around the field site and Kedougou. Although the government regulates the collection of bamboo through a quota system, much of the bamboo harvest is done illicitly. Bamboo is a fast growing plant and can quickly recover from harvesting, however, there is still the risk of overexploitation as has occurred in East Africa (Bystraikova et al., 2004).

Food products - Many of the NTFPs collected in southeastern Senegal are used for sustenance or medicinal uses, including the most important chimpanzee food resources (Table 1). *Saba senegalensis* is one of the most collected and important wild food products in the region. It is also the source of human-chimpanzee competition as it is one of the top most frequently consumed fruit by chimpanzees (Waller and Pruetz, 2016). *Saba* is a medium-sized, yellow, spherical fruit with a thin outer skin, approximately 8 cm in diameter. The fleshy fruit pulp is sectioned around individual seeds. The fruit is a preferred food item for many people in Senegal, even those living outside of the fruit's natural range (Waller & Pruetz 2016). Because of this, large quantities of the *Saba* fruit are collected during the end of the rainy season and transported as far as Dakar for sale (Knutsen reference). People will eat the fruit itself or prepare the fruit pulp with sugar as a drink. Other wild food and drink products that are collected include palm wine tapped from *Borassus aethiopum* or *Elaeis guineensis*, baobab fruit, and other seasonal fruits. Through the VALEURS project (*Valorisation des Espèces pour une Utilisation Durable des Ressources Sauvages au Senegal*), an IUCN coordinated initiative focusing on sustainable use and harvest of NTFPs, researchers interviewed over a thousand NTFP collectors and found reports of increasing resource scarcity in southeastern Senegal (Ba et al, 2006). Some of the species in noticeable decline were *Saba,* baobab*, Parkia biglobosa*, and *Tamarindus indica* (Ba et al, 2006).

Grasses - Multiple grass species are used to thatch the roofs of Senegalese huts, with *Vetiveria nigritana* preferred due to its resilience against termites and extended lifespan as a roofing material (Goudiaby et al., 2003; Figure 1). Grasses are collected by hand, bundled, and sold to people in the immediate village as well as to people in larger towns where roofing grass is harder to come by. Grass is used to cover huts and shade structures.

Honey - Most honey is cultivated in Senegal in woven grass beehives that are placed in the bush and then later harvested, but some honey collectors still collect honey from wild hives. Kedougou is one of the Senegal's most productive beekeeping regions, although bees (*Apis mellifera adansonii*) here can be particularly aggressive (Hussein, 2001). Most harvesting is done during the end of the dry season in May and June. Traditional honey harvesting of wild sourced honey is usually a destructive practice that destroys the beehive and can also result in the lighting of bushfires (Ba et al., 2006). Entire trees can be cut down to access the hive, although harvesters may also merely enlarge an access hole to a hive, which does not usually result in tree death.

Shea or Karité tree (*Vitellaria paradoxa)* – The use of shea tree products has a long history in West Africa, documented by pre-colonial Arabic and European traders (Chaflin, 2004). Karité is the local and francophone name for shea butter processed from the nut of this tree. Fruit is first collected from wild shea trees and the flesh is removed from the inner nut (it has a sweet and pleasant flavor and is sometimes eaten). The defleshed nut is processed through a series of boiling and drying before removing the hard outer shell of the nut from the inner seed. The seed is pounded and ground using a mortar and pestle before being soaked in hot water. Once it has cooled and the butter has risen to the top, it is strained, boiled, and re-strained to continue purifying the butter. The processing of shea butter is traditionally done exclusively by women (Chaflin, 2004). Chimpanzees consume the fruit of the shea tree during the wet season.

Collection of timber products

Timber is collected primarily for firewood. Youm et al. (2000) estimated that 93% of energy consumed by rural household came from burning biomass, the majority of which comes from fuelwood and charcoal. Fuelwood is collected by hand from downed trees and branches then bundled for transport. Some is used within the household, but much of it is sold to people living in the larger town of Kedougou. Timber is also used for woodworking and plank making, which are used primarily for furniture. Some of the most important tree species used by chimpanzees for nesting are also used by people for wood-working and for fuelwood (Ndiaye et al. 2013). An association between the hardness of the wood and preference by both chimpanzees and wood-workers to use the species may explain this finding. Rosewood (*Pterocarpus erinaceus*) is used to make bed frames and armoires by craftsmen in town. Timber is also collected for village use to make huts, attach *crintin*, and for livestock enclosures. Some families use timber fencing to enclose corrals or their family compounds. Since the gold rush of 2008, hardwood trees have been selectively harvested by traditional gold miners to shore up pits and provide stability to mining tunnels (Persaud et al., 2017; Doucouré, 2014). At the Fongoli field site, most of the large *P. erinaceus* trees had been harvested by 2016, by teams working for Kedougou businessmen who sell 2-meter long planks for doors and other construction (J. Pruetz, pers, comm.). Approximately 5-6 planks are taken per individual tree, leaving the rest of the wood to rot and/or burn in annual bushfires.

Agriculture and livestock herding

Subsistence and small-scale agriculture has long been the primary economic activity of rural communities in Senegal. In 2013 in the Kedougou region, 69% of households practice agriculture as a major livelihood (Republic of Senegal, 2015). The dominant crops for the region are peanuts, rice, local corn, beans, millet, sorghum and fonio, a cereal native to West Africa. Fields are located on the outskirts of the village when possible; however, some people will travel longer distances to access land to cultivate. In these cases, family will often live alongside their fields during the cultivation and harvesting seasons and then return to their villages for the rest of the year. In recent years the Senegalese government has reported a progressive abandonment of agriculture in favor of gold mining, citing a 16.5% decrease in land sown to cereal crops from 2008 to 2013 (Republic of Senegal, 2015b).

Livestock herding is done both by villagers and by transient pastoralists. Transient pastoralists do the majority of livestock herding that takes place outside of the village. The most recent data on livestock comes from 2011 when the region was estimated to have 52,254 head of cattle, 16,334 sheep, 15,334 goats, 150 pigs, 28 equines and 897 donkeys (Republic of Senegal, 2015b). Livestock species are limited in southeastern Senegal by the presence of tsetse flies (*Glossina* spp.) that transmit trypanosomiasis, and therefore exclude susceptible species such as horses and zebu cattle from living in the region. Kedougou is also one of the few departments in the country that practices pig farming due to the department's relatively high percentage of non-Islamic faiths. Poultry farming is a growing industry in the region.

Herding livestock also contributes to the collection of leaves as livestock fodder (USAID, 2008). At the Fongoli site, most cattle roam freely to graze and seek out water for much of the year. Small goatherds are kept by many of the families living in villages. During the dry season transient pastoralists with large goat and sheep herds migrate from northern Senegal into the south to access vegetation for their herds (Massa, 2011).

<u>Gold mining</u>

Gold mining has for centuries been a companion activity for local agriculturalists in this region (Keita, 2002). During the dry season after the harvest, cultivators will spend time mining and panning for gold. Most people travel by foot to the mine sites, but as mining activity has increased since 2008, more people are traveling by motorcycle, trucks and bush taxis. The global financial crisis of 2008 resulted in a steady rise in the price of gold from $650/oz. in 2007 to $1800/oz. in September 2011, remaining over $1500/oz. through April 2013. Although the price has wavered, the cost of gold has not dropped below $1000/oz. since 2009. The economic opportunity that arose with these prices has resulted in an increase in gold mining throughout the Kedougou region. By 2012, gold mining was the main attractant to international migrants entering the Kedougou region.

Between 2010 and 2012, Kedougou had a 366% increase in international immigration (Republic of Senegal, 2011; Republic of Senegal, 2015a). Although slower than in 2012, international immigration into the region continued in 2013 with a positive net growth of 1,486 people (an increase of 202% from 2010 levels - Republic of Senegal, 2015b). The growing mining attracted people from Guinea, Mali, Burkina Faso, Nigeria, and Ghana, as well as people from across Senegal (Republic of Senegal, 2015b). Reports of up to 14 nationalities have been recorded within one gold mining location (Republic of Senegal, 2015b). At Fongoli, a new dirt road was created in 2012 to access the mining area near the Kerouani stream, although this road has not since been maintained and was infrequently used in 2016.

Water collection and use

Although water pumps and wells have been installed in each of the villages within the Fongoli chimpanzee home range, people still use natural water sources. Prior to water pump installation women would travel to streams to collect drinking water. In the dry season shallow wells were dug in streambeds to access the ground water. These wells were also used by wildlife (Pruetz, unpublished data) and rivers and streams are used for laundering clothes and dishes.

Scope of study

This study examines changes in human-chimpanzee encounters over a 9-year period at the Fongoli study site in Senegal following the identification of all individuals in the chimpanzee community in 2006, up through the rise of global gold prices, to 2014. Due to increasing gold mining activity in southeastern Senegal in general and in the Fongoli chimpanzees' home range specifically, we expected to see an increase in human-chimpanzee encounters over the course of the study period. As local community members become engaged in mining activities over the course of the study period, we also expected to see a shift in people's activities from collection of NTFPs, collection of timber products and agricultural activities to gold mining activities. Chimpanzee reactions were expected to reflect the arrival of many unfamiliar people, shifting from little reaction when encountering people from local villages early in the study (2006-2009) to fleeing/displacement when encountering gold miners in later years.

Study site

The Fongoli field site (12° 39'N, 12° 13'W) is located in southeastern Senegal within the region of Kedougou (Figure 2). Kedougou is in the shield region of the country (Tappan et al., 2004), where gallery forests line valleys and waterways, cutting through woodlands, laterite outcrops and savanna grasslands to create a mosaic of vegetative land cover. Although scarce, in some areas comprising less than 1% of the landscape (Pruetz et al., 2002), gallery forests are important microclimates for chimpanzees and other wildlife in the heat of the dry season (Pruetz and Bertolani, 2009). The Fongoli chimpanzees also prefer to nest in gallery forest and woodland habitat (Pruetz et al., 2002; Pruetz and Bertolani, 2009). Kedougou's climate is characterized by two distinct seasons, a dry season from November to May and a rainy season from early June to the end of October, with rainfall averaging 900-100 mm annually (Ba et al, 1997). The dry season can be further subdivided into the early dry season, November through February, and the late dry season, March through May (see Chapter 6). Southeastern Senegal has been considered the hottest and driest climate for chimpanzees (McGrew et al., 1981; Hunt and McGrew, 2002). The chimpanzees' home range km^2 between 2005 and 2014 included a total area of 110.4 km^2, of which the apes used an annual average of 64.6 (ranging annually from 56 km^2 to 77 km^2 - see Results section in Chapter 5). Seven villages, ranging in size from a few households at Fongoli to the village of Djendji with approximately 140 people, border the chimpanzees' home range (Waller and Pruetz, 2016). Estimating the local human population at approximately 200 permanent residents, the human population density within the total chimpanzee home range would be 1.8 people per km^2; whereas the chimpanzee density is 0.29 chimpanzees per km^2. The ethnic groups comprising the local community include Malinké, Diakhanké, Peule, and Bassari. The communities are primarily subsistence agriculturalists, although they engage in other livelihoods, including hunting, gathering, pastoralism, and gold mining.

Over the course of our study period the chimpanzee community averaged 31.7 individuals, with a maximum group size of 36 in 2012 and a minimum of 29 in 2010 (Pruetz et al., 2016). Although most chimpanzee communities have more adult females than males, the Fongoli community is male-skewed, with an average of 10 adult males to 7 adult females (2006-2014). Study was initiated on the Fongoli community in 2001, and chimpanzees were habituated for systematic all-day follows of adult males by early 2005 (Pruetz, 2006).

Methods

9:42am: Man collecting Saba at Kerouani [stream] here, less than 50 m from Fanta [chimpanzee] and company. [His] bike is parked here. They (the chimpanzees) sit quietly below the vines along the Kerouani and watch. – JP, June 30, 2007

The data collection protocol for the Fongoli field site included attempted daily all-day focal-subject follows of adult male chimpanzee subjects and their sub-groups or ‘parties’ (Boesch, 1996). During a focal follow, researchers and field assistants collected data at five-minute intervals on the subject’s location and behavior. While following a subject, observers also recorded all occurrences of visual encounters with people. A visual encounter with people was defined as chimpanzees making visual detecting humans. Auditory encounters with people were defined as hearing human activity, voices, or gunshots. During an encounter the person or people were not necessarily aware of the chimpanzees’ presence. When available, information on the person’s activity or behavior, as well as the chimpanzees’ reactions, was recorded. A person’s activity was determined by direct observation, or based on equipment people carried (e.g., a gun), clothing worn, or conversations had with the individual or individuals. For example, collection of NTFPs is usually performed by hand with tools including knives, machetes, and bamboo poles. If an individual was seen with large bags and a bamboo pole during the months of March through June, this individual was presumed to be a *Saba* collector. If a person was observed wearing clothing saturated with red soil and walking near a known gold mine, they would be listed as a gold miner. Often a person's activity was not distinguishable by their appearance; when this was the case no activity was entered. Other data collected opportunistically in association with human-chimpanzee encounters included the gender of the person/people, their transportation, interaction with the chimpanzees, and the chimpanzees' reactions (Table 2). In addition to human-chimpanzee visual encounters, observers also recorded all occurrences of gunshots heard (auditory encounters) and all interactions (both auditory and visual) that humans initiated with the chimpanzee subjects. Gunshots, chimpanzee reactions, and interactions between people and apes were reliably collected for all occurrences; however, auditory encounters of other human activities (i.e. NTFP collection) were not consistently collected. We, therefore, limited our analyses of auditory encounters to gunshots, chimpanzee reactions to, and chimpanzee interactions with humans.

Variables associated with the encounter were extracted *post hoc* from the full description of the encounter. Human activities were grouped into the following categories: carrying food, working in agricultural fields, gold mining, herding livestock, hunting, collecting NTFPs, collecting timber products, using water, and activities associated with a village. Chimpanzee reactions to human encounters were classified into eight categories based on the behaviors described by the observer (Table 3). We conducted all statistical analyses in the program R version 3.3.1 (R Core Team, 2016) and set the level of significance at $a = 0.05$.

Results

We analyzed 1782 observation days between 2006 and 2014 during which 669 human-chimpanzee visual encounters and 835 auditory encounters were recorded (Table 4). Of the auditory encounters, 292 were gunshots. Using a logistic regression model with a binary response variable (1 = visual encounter, 0 = no encounter), we found an overall increase in human-chimpanzee encounters over the nine-year study period. For each unit increase (one year), there was a 1.17 times higher likelihood of chimpanzees encountering a person per day (Wald z-statistic of 7.778, $p < 0.001$, 95% CI [1.12, 1.21], Figure 3, Table 5). The relationship, however, was not linear. Using a piecewise regression from the 'segmented' package in R, a breakpoint was estimated in year 2009 as encounters decreased to their lowest frequency (0.17 encounters/observation day). Following 2009 encounters increased, reaching the highest frequency of encounters in 2014 at 0.61 encounters observed per observation day. We ran two more regressions based on this break point: 1) all observations from 2006 through 2009 and 2) all observations after 2009. From 2006 through 2009, the chimpanzees were less likely to encounter a person per day with each additional year by a factor of 0.79 (Wald's z-statistic = -2.956, $p = 0.003$, 95% CI [0.68, 0.93]). After 2009, the chimpanzees were 1.27 times more likely to encounter a person per day with each additional year (Wald's z-statistic = 5.548, $p < 0.001$, 95% CI [1.17, 1.38]).

Human activities

Over the course of the study, the most encountered activities performed by people during the encounters shifted from the collection of NTFPs to gold mining activities (Figure 4). We used logistic regression models with binary response variables (1 = yes, 0 = no, for each of the nine activity types) to assess the changes in the activities people were performing during encounters. Encounters with people collecting NTFPs and engaged in gold mining were the only two activities that showed significant change over time (Table 5). The results from the NTFPs collection model indicated that chimpanzees were less likely to encounter people collecting NTFPs over the course of the study period by a factor of 0.87 with a 95% CI [0.80, 0.94]. The coefficient on the NTFPs variable had a Wald z-statistic equal to -3.307 with $p < 0.001$. The likelihood of encountering a person engaged in gold mining increased over the study period by a factor of 1.38 (Wald z-statistic = 5.441, $p < 0.001$, 95% CI [1.23, 1.56]). While the frequency of encounters with hunters did not change significantly over the nine years, it should be noted that the frequency of gunshots heard decreased significantly from 2006 onward (odds ratio = 0.85, 95% CI [0.80, 0.89], Wald z-statistic = -6.099, $p<0.001$, see Figure 5).

NTFPs collected from the bush during this study included grass, honey, karité, leaves for livestock, soil, yam vines, bamboo, bark and plant fibers, *Saba*, palm wine, and birds. *Saba* was by far the most frequently collected resource during encounters, making up 68% of NTFPs collection, followed by bamboo (17%), honey (4%), grass (2%), karité (2%), birds (2%), and all others (1% each)

(Figure 6). Encounters with people collecting resources changed from 2006 to 2014 regarding *Saba* and bamboo (Figure 7). Encounters with *Saba* collectors was highest in 2006 and 2007 with 0.06 and 0.08 encounters per day, respectively, and then declined significantly in 2008 to 0.01 encounters per day. Encounters with *Saba* collectors remained depressed throughout the remainder of the study period, reaching a maximum of 0.03 encounters per day in 2009 and in 2012. Encounters with people collecting bamboo were highest in 2006, with 0.05 observations per day (n=9 observations). Encounters with bamboo collectors dropped to zero in 2007 and 2008, then resumed from 2009 through 2014 but remained below 0.01 encounters per day.

People engaged in gold mining activities during encounters were first observed in 2008 (Figure 8). From 2008 through 2011 there was a small increase in gold mining activities during encounters, from 0.02 to 0.03 encounters per day; however, this increases rapidly and significantly to 0.09 in 2012 and further increases to 0.12 encounters per day in 2013. The rate decreased to 0.06 in 2014 but remained elevated with respect to 2006–2007 baseline levels before the economic downturn and subsequent gold rush. The rate of gold mining activities followed the same trend as the rise in gold prices.

Chimpanzee reactions

8:30am: I saw that a female (chimpanzee) was very scared. Her hair was standing on end and she was baring her teeth (in a fear grin). She didn't have her infant on her back. She wanted to run but couldn't; her infant was up in the tree. I heard the sound of the infant in the branches as he let himself fall to the ground. His mother came and grabbed him. As soon as she had left I saw four dogs coming towards me. I threw a stone in their direction and at the same time heard a person whistle for them. I remained completely silent as I started to move in

their direction, but I did not see the person. [At the base of the stream at Grand Baobab.]
-MS, January 18, 2010

Chimpanzee reactions to humans were recorded in 385 visual encounters and 117 reactions to auditory encounters. A multinomial logistic regression model from the 'VGAM' package in R was used to predict changes in the frequency of each chimpanzee reactions over the course of the study period, using year as a predictor, chimpanzee reaction as the response variable, and "no reaction" as the reference group. We found significant changes over the nine-year period in how frequently the chimpanzees would flee and vocalize in response to a human encounter (Table 6). The odds ratio for flee reactions indicated that for each year increase, the chimpanzees were 0.75 times less likely to be observed fleeing from a human encounter (95% CI [0.64, 0.89], Wald z-statistic = -3.265, $p = 0.001$). Although the overall trend showed a decrease in flee reactions, the relationship was not linear. A breakpoint analysis indicated a break at 2012 when flee reactions began to increase; this increase, however, was not significant. Vocalizations by the chimpanzees in response to an encounter were 1.24 times more likely to be observed for each year increase (95% CI [1.04, 1.48], Wald z-statistic = 2.45, $p = 0.01$) (Figure 9).A break point analysis indicated that vocalizations began to increase in 2009. Between 2006 and 2009, the likelihood of chimpanzees to vocalize in response to a human encounter decreased by a factor of 0.36 for each year (95% CI [0.12, 0.81], Wald z-statistic = -2.27, $p = 0.03$). After 2009, this likelihood increased annually by a factor of 1.36 (95% CI [1.16, 1.60], Wald z-statistic = 3.798, $p < 0.001$).

Aggressive reactions to human encounters showed an increasing trend over the study period with $p = 0.086$ (Table 6). Although this is not significant at the $p < 0.05$ level, it is relevant to note that aggressive reactions were greatest in 2012, 2013, and 2014. Outside of these years, only one aggressive reaction to a human encounter was observed in 2009.

Chi-square analyses showed chimpanzee reactions differed with respect to human activity [X^2 (42, $N = 502$) = 67.983, $p < .01$] and transportation types [X^2 (28, $N = 502$) = 131.03, $p < .001$]. Chimpanzees were more likely to (1) be disturbed by herders, (2) flee from people collecting NTFPs, (3) hide from hunters, (4) show vigilance to people working in fields, and (5) vocalize at gold miners (Table 7). In addition, they were significantly less likely to be vigilant at gold miners and to vocalize at hunters. Regarding transportation, the most notable finding is the chimpanzees' propensity to vocalize at vehicles, which includes both cars and trucks (Table 8). Vehicles were less likely to cause them to be vigilant, disturbed or flee. Bicycles were met with both vigilance and low-level reactions, and motorcycles saw no reaction. People walking caused chimpanzees to flee or become otherwise disturbed, and were less likely to elicit vocalizations or no reaction at all. The 'other' category included donkey carts and airplanes, which elicited vocalizations from the chimpanzees, although these were infrequently used types of transportation. Figure 10 shows the frequency of each transportation type used according to each activity group. We saw an overall increase in most of the transportation types related to the overall increase in encounters during the study period (Figure 11). The increase in people walking during encounters in 2014 may be related to the decrease in motorcycles and vehicles used in the same year. Encounters with people using motorcycles were rare early in the study period but sharply increased in 2011 and remained elevated in 2012 and 2013. Encounters with people using vehicles were also generally unused early on, but use increased six-fold between 2011 and 2012. Vehicle encounters dropped in 2013 and 2014 but remain elevated compared to pre-2012 years. Encounters with people using bicycles decreased from 2006 to 2011 then increased from 2011 to 2012. Donkey carts were only observed on two occasions in 2014 and no activity was recorded in either occurrence.

Human-initiated interactions

8:54am: A man who is passing by on a bicycle charged with a bundle of wood yells to the chimpanzees in the distance "I-yo, Ndiaramadé!" [a polite greeting in Peule], two times. I think he must be afraid because it was too curt. – MS, January 11, 2012

During human-chimpanzee encounters in this study, people were not necessarily aware that they were in the presence of chimpanzees. On most occasions whether the people were aware of the chimpanzees or not, they showed no acknowledgment and did not engage the apes. However, during a few of the encounters some people initiated an interaction with the subjects (n=35 of 667 encounters, or 5.2%). During these interactions people were observed imitating the chimpanzees' vocalizations (40%), yelling at them (26%), talking to them (17%), throwing stones at the apes (9%), chasing them (6%), and approaching them (3%, see Figure 12).

Interactions were separated into visual and non-visual interactions. Visual interactions occurred during 3% of all encounters recorded and accounted for 20 of 667 encounters. The most frequent form of interaction was yelling (n=8), followed by talking, (n=4), and imitating chimpanzee vocalizations (n=3). The remaining visual interactions included two incidences of people throwing stones toward the chimpanzees, two cases of people chasing after them, and one occasion where children attempted to approach apes. On 15 additional auditory encounters people were heard imitating (n=11), talking to (n=2) or yelling at (n=1) the chimpanzees. On one occasion a person, who was out of sight, threw a stone towards the chimpanzee group. Interactions were rare each year; however, year 2012 saw a disproportionate increase in the rate of interactions with respect to the rate of human-chimpanzee encounters (Figure 13). Interactions in 2013 and 2014 dropped off again.

Gender

Most of the people encountered by chimpanzees were men. Although there was an increasing trend of women being encountered by 2014, this was not significant. Women were mostly encountered using water and working in the fields (Figure 14). All hunters (n=18) were male, and all people carrying food were women (n=2). Gender of the person encountered had no significant impact on chimpanzee reactions.

Time of day

Most encounters were between 800-1000 hours, and 1800-2000 hours (Figure 15). Activities differ by time of day, with the collection of NTFPs making up the majority of activities observed during midday (Figure 16). *Saba* collection may drive this pattern as it is done throughout the day, with a peak at 1400 hours. Hunters were encountered and gunshots were heard in the early morning and late evening, as expected. Gold miners were most often encountered in the morning between 800-1100 hours, and timber resources were collected in the mornings and late afternoons.

Discussion

In this study, we examine how human-chimpanzee encounters have changed at the Fongoli study site in southeastern Senegal over a nine-year period starting in 2006 (prior to the gold rush) and through 2014 (during active gold mining). We found that encounters decreased initially from 2006 to 2009 and then increased overall from 2010 through 2014. One factor likely contributing to this shift was the change in people's livelihoods. Over the nine-year study period, as gold prices increased and gold mining became a more lucrative activity, we found that chimpanzees were less likely to encounter people collecting NTFPs and more likely to encounter people engaging in gold mining related activities, which supported our hypotheses. Despite reports that agricultural activity is declining throughout the region (Republic of Senegal, 2015a), encounters with people engaging in agricultural activities remained consistent throughout the study period. The growth in gold mining activities matches closely the rise in gold prices (Figure 8) as well as the increasing number of artisanal gold mining sites within the Fongoli study site (see Chapter 2). The stability of the agricultural sector may reflect the traditional method of mining and cultivating in different seasons. Historically, artisanal gold mining supported communities during the dry season after the harvest and, today, the gold miners of Fongoli appear to be following a similar pattern. Conversations with miners at Fongoli's artisanal mines in 2016 supported this (F. Camara, pers. comm.).

The decrease in NTFPs collection may be related to the increase in gold mining activity as people shift their livelihoods to the more profitable resource, although this is difficult to assess without further study. The decrease may also be related to increasing NTFPs scarcity across the nation. A study conducted in 2006, with data preceding the timeframe of our current study, found that people in southeastern Senegal attributed the depletion of NTFPs to road improvements that provide greater access to natural resources, as well as the influence of bushfires and droughts that inhibit wild plant growth (Ba et al., 2006). It is unlikely that any of these factors would have reversed their trajectory from 2006 to 2014 and, more likely, that depletion of NTFPs would have been exacerbated.

Chimpanzee reactions

We hypothesized that chimpanzees would become more fearful and likely to flee from unfamiliar people, particularly with the increase in international immigration. Instead, we saw the greatest frequency of chimpanzees fleeing in the earlier years of the study, which is likely due to the early stages of the habituation process. Fleeing behavior declined overall throughout the study period, but in 2013 and 2014 fleeing behavior began to increase. Although this increase was not significant, it is noteworthy. If the reduction in fleeing behavior were related completely to the level of habituation, we would not expect to see an increase toward the end of the study. Instead, this increase may be attributed to people's return to collecting NTFPs, which also increased in 2013 and 2014. Chimpanzees were more likely to flee from people collecting NTFPs than any other activity group, which may be linked to the manner of in which people collect NTFPs. *Saba* grows in woody thickets along riverine areas and in woodlands (Orwa et al., 2009), which are preferred locations for chimpanzees to retire from the heat of the day. *Saba* collection occurs throughout the day with the highest frequencies of collection during the hottest times of the day (Figure 16) when chimpanzees are most likely to be resting (Pruetz and Bertolani, 2009). Additionally, chimpanzees may also flee from *Saba* collectors while they are feeding on the fruits themselves, as humans and chimpanzees engage in contest competition and are both drawn to the same *Saba* patches.

In the later years of the study period when artisanal gold mining sites were established (2010 – 2014), we saw an increase in chimpanzee vocalizations. Vocalizations were mainly linked with vehicles, which were used only by people working in association with the gold mines. Vehicles and motorcycles were not seen to cause chimpanzees to move or become displaced from their location, most likely because of the predictable nature of motorized vehicles to remain on well-established pathways. Most of the vocalizations recorded in association with vehicles were "wraaa" barks, a distress vocalization to signify danger (Goodall, 1989). Why chimpanzees are distressed or fearful of vehicles is difficult to say apart from the vehicle size and associated noise; however, this behavior has also been observed at the Chimpanzee Conservation Center in Guinea where captive chimpanzees would “wraaa” bark at moving trucks and, on at least one occasion, attacked a stationary vehicle on the road (Boyer Ontl, pers. obs.).

Human-initiated interactions

Although rare in this study, human-initiated interactions are of great interest as they often signal a direct human-primate conflict and provide information about the perceptions of chimpanzees by Senegalese people. Imitation of chimpanzee pant hoots makes up the majority of the interactions. While this interaction may be a form of alerting chimpanzees to people’s presence, it is often performed by children and in a playful manner. People in Senegal do not hunt chimpanzees because of religious taboos, and different ethnic groups maintain chimpanzee origin stories within their folktales that indicate that chimpanzees were once humans (Clavette, 2005). As the human population of southeastern Senegal grows, including an increase in people from other areas that may not have such taboos, and natural resources become scarcer, current perception of chimpanzees in Senegal is an area in need of greater study.

Yelling at chimpanzees during encounters made up a quarter of the interactions and was a mechanism to scare off the apes. Talking to the chimpanzees, even without the apparent intention to scare them off, was described during observations as a tactic to alert them to the person’s presence when he or she was feeling uneasy. Along with throwing stones and chasing, 58% of the interactions were likely initiated to drive away a perceived threat. Chimpanzees are known to be an aggressive species. In Uganda, chimpanzees have been described as “friendly but dangerous” (Webber, 2006), and they have been recorded to attack humans in Guinea and, in rare cases, in Senegal, after being chased extensively (J. Carter, pers. comm.).

Interactions between chimpanzees and humans may be attributed to a function of proximity and context, which was not examined in this study. For example, some of the interactions that included yelling were associated with chimpanzees either in or near an agricultural field. Although chimpanzees are not known to raid cultivated crops at Fongoli, on one occasion a community member stated that he did not want the chimpanzees eating the wild fruits growing on tamarind trees in his field because they belonged to him.

Gender

Traditionally, women were the primary *Saba* collectors (Knutsen, 2003) but as the industry has become more financially lucrative men have been increasingly collecting the fruit (Waller and Pruetz, 2016). We see this reflected in our study, with 72% of the *Saba* collectors reported as male and 11% as female, with 17% of observations not including a gender. Additionally, a previous study in southeastern Senegal from 2006 found that 77% of *Saba* harvesters were male (Ba et al., 2006).

Conclusion

As gold mining activities increase in southeastern Senegal, human-chimpanzee encounters and the use of motorized vehicles have risen at the Fongoli field site causing the resident chimpanzee community to show signs of distress. Although our study was limited to one field site, the results can be extrapolated to other mining communities in Senegal and West Africa. The greatest concern related to increased human-chimpanzee encounters is the expected increase in threats to chimpanzee populations, such as hunting chimpanzees for bushmeat and the pet trade (Hicks et al., 2010; Kabasawa, 2009), disease transmission, habitat degradation, and increased human-ape conflict (Hockings & Humle, 2009). With increased human activity, disruption in the chimpanzee habitat and the greater risk of human-chimpanzee proximity, we find a greater risk of aggression between the species (McLennan and Hockings, 2016). This is reflected in our results of increased negative interactions as human encounters increased. Although aggressive reactions to human encounters were rare at Fongoli, they showed an increasing trend over the study period. Across West Africa, attacks by chimpanzees are a real threat to people as they come closer in contact with one another (McLennan and Hockings, 2016). Local communities across the Kedougou region retell accounts of chimpanzees attacking people (K. Boyer Ontl, pers. obs.). Although rare, these incidences can cause long-term hostility towards the species (McLennan and Hockings, 2016).

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Table 4.1 The top 20 plant species eaten by the Fongoli chimpanzees during each season (early dry = Nov. – Feb.; late dry = Mar. – May; wet = Jun. – Oct.) listed with the proportion of use out of total observations and their uses by people.

Season	Scientific name	Malinke	Prop. of obs.	Code	Human Uses
Early Dry	*Adansonia digitata*	Sita	1.2533	BAO	Food/rope/Medicine
	Pterocarpus erinaceus	Keno	0.2956	KENO	Woodworking/Fuel/Medicine
	Spondias mombin	Minkon	0.2434	MK	Food/Medicine
	Oxytenanthera abyssinica	Bo	0.1989	BAM	Building materials/Rope
	Vigna spp.	Sossocinas	0.1497	SOS	-
	Cissus populnea	Boumbango/Mosokyo	0.1401	BBN	Medicine
	Diospyros mespiliformes	Kukuo	0.1207	CCO	Food/Medicine
	Ficus spp.	-	0.1135	FICUS	Food/Medicine
	Elaeis guineensis	Tengo	0.1033	TMR	Food
	Afzelia africana	Lenkie	0.0682	LK	Medicine
	Ficus umbellata	Suro/Tro	0.0608	SURO	Food/Medicine
	Ficus ingens	Sekho	0.0550	SKH	Food/Medicine
	Bombax costatum	Bunkungo	0.0459	BC	Medicine/Food additive
	Strychnos spinosa	Kara	0.0412	KAR	Food/Medicine/Fuel
	Acacia dudgeoni or senegal	Tandasaro	0.0398	TBR	Medicine
	Grewia lasiodiscus	Sambe	0.0351	SMB	Food/rope/Medicine
	Gardenia erubescens	Tankango	0.0343	TNK	Food/Medicine
	Piliostigma thonningii	Fara	0.0309	FRA	Food/Medicine/Fuel
	Oncoba spinosa	Kondongo	0.0254	CDN	Food/Medicine/Fuel
	Ceiba pentandra	Bantango	0.0243	BANT	Food/Medicine/Other
Late Dry	*Saba senegalensis*	Kaba	0.6735	SABA	Food/rope/Medicine
	Piliostigma thonningii	Fara	0.5007	FRA	Food/Medicine/Fuel
	Pterocarpus erinaceus	Keno	0.2448	KENO	Woodworking/Fuel/Medicine
	Daniellia olivieri	Santango	0.1877	STN	Food/Medicine/Gum
	Ficus sur	Sotonunko	0.1571	STNK	Food/Medicine

Table 4.1 Continued

Season	Scientific name	Malinke	Prop. of obs.	Code	Human Uses
	Oxytenanthera abyssinica	Bo	0.1541	BAM	Building materials/Rope
	Cola cordifolia	Taba	0.1500	TABA	Stimulant/Rope
	Parkia biglobosa	Nete	0.1317	NT	Food/Medicine/Toothbrush
	Gardenia erubescens	Tankango	0.1149	TNK	Food/Medicine
	Ficus spp.	-	0.1026	FICUS	Food/Medicine
	Ficus umbellata	Suro/Tro	0.0608	SURO	Food/Medicine
	Strychnos spinosa	Kara	0.0440	KAR	Food/Medicine/Fuel
	Ficus ingens	Sekho	0.0354	SKH	Food/Medicine
	Lannea velutina	Bembenanya	0.0340	BNN	Food/Medicine/Woodworking
	Hannoa undulata	Kieko	0.0317	KEKO	Food/Medicine
	Bombax costatum	Bunkungo	0.0299	BC	Medicine/Food additive
	Oncoba spinosa	Kondonngo	0.0272	CDN	Food/Medicine/Fuel
	Adansonia digitata	Sita	0.0164	BAO	Food/rope/Medicine
	Lannea kerstingii	Bembe (Bambara)	0.0116	LANNEA	Food/Medicine/Rope/Fuel
	Baissea multiflora	Banombo	0.0108	BNB	Medicine/Rope
Wet	*Saba senegalensis*	Kaba	0.3219	SABA	Food/rope/Medicine
	Spondias mombin	Minkon	0.2116	MK	Food/Medicine
	Pterocarpus erinaceus	Keno	0.1930	KENO	Woodworking/Fuel/Medicine
	Oxytenanthera abyssinica	Bo	0.1681	BAM	Building materials/Rope
	Baissea multiflora	Banombo	0.1408	BNB	Medicine/Rope
	Adansonia digitata	Sita	0.1278	BAO	Food/rope/Medicine
	Ficus spp.	-	0.1200	FICUS	Food/Medicine
	Ficus umbellata	Suro/Tro	0.1051	SURO	Food/Medicine
	Allophylus africanus	Irindingo/Halahato?	0.0638	YR	Wood
	Hexalobus monopetalus	Gundje	0.0624	GDI	Food/Medicine/Rope/Fuel/wood working
	Cordyla pinnata	Dougouta	0.0441	DGT	Food/Medicine

Table 4.1 Continued

Season	Scientific name	Malinke	Prop. of obs.	Code	Human Uses
	Landolphia heudelotti	Fole	0.0276	FL	Food/Medicine/Latex
	Cola cordifolia	Taba	0.0251	TABA	Stimulant
	Lannea kerstingii	bembe (Bambara)	0.0200	LANNEA	Food/Medicine/Rope/Fuel
	Zehneria spp.	-	0.0157	YAM	-
	Nauclea latifolia (Sarcocephalus latifolius)	Battio	0.0143	BTY	Food/Medicine/Fuel
	Cissus populnea	Boumbango/Mosokyo	0.0141	BBN	Medicine
	Afzelia africana	Lenkie	0.0141	LK	Medicine
	Zahna golungensis(?)	Petit minkon	0.0138	PMK	-
	Bombax costatum	Bunkungo	0.0124	BC	Medicine/Food additive

Table 4.2 Data collected during observations and used for analyses of human-chimpanzee encounters.

Variable	Description
Date	Month, day, year that observation was made
Time	Time observation was made
Location	Latitudinal and longitudinal coordinates of observation
Number of people	Number of people observed during the encounter
Transportation	Mode of transportation of people in the encounter (vehicle, motorcycle, bicycle, walking, donkey cart)
Activity	Activity that people are actively or passively engaged in during the encounter (agriculture, gold mining, NTFR collection, timber use, water use, village activities, livestock herding, carrying food, hunting, unknown)
Chimpanzee Reaction	Behaviors exhibited by chimpanzees in response to human encounter (vocalization, flee, aggressive, move, vigilant, hide, no response)
Full description	Full detailed description of the human-chimpanzee encounter transcribed from the data books used to extract the above variables.

Table 4.3 Chimpanzee reactions defined

Reaction	Description
aggressive	agonistic behavior, including displaying, chasing, throwing stones; often includes vocalization (aggress*)
disturbed	behaviors that indicate being startled or anxious, including displacement away from their current location, climb down or up tree, or nervous behavior
flee*	subjects run away, either silently or with vocalizations
hide*	subjects conceal their location and remain out of sight
low-level reaction	subjects acknowledge people but do not behave as if disturbed; they then resume their previous behavior. Includes inquisitive "hoo" vocalizations*, being startled but not leaving, and brief vigilance
no reaction	subjects do not appear to notice or respond to the people; behavior continues uninterrupted
vigilant	Alert, silent, listening to and watching people for extended period
vocalize	subjects vocalize, often recorded as pant-hoot chorus or "wraaa" vocalizations*, although many times recorded by observer simply as "vocalize"

*following Nishida et al. 1999

Table 4.4 Total days of observation, number of human-chimpanzee encounters, and the average daily human-chimpanzee encounter rate used in analyses for each year of the study for visual and auditory encounters.

Year	Observation Days	Total no. of encounters	Daily Vis. Encounter Rate	Total no. of auditory encounters	Daily Aud. Encounter Rate
2006	116	42	0.36	87	0.75
2007	157	36	0.23	55	0.35
2008	206	58	0.28	101	0.49
2009	247	42	0.17	56	0.23
2010	187	56	0.30	98	0.52
2011	210	52	0.25	117	0.56
2012	245	136	0.56	163	0.67
2013	211	124	0.59	107	0.51
2014	203	123	0.61	50	0.25
Totals/ Average	1783	669	0.37	834	0.48

Table 4.5 Summary of logistic regression models predicting the likelihood that chimpanzees would visual encounter people and of encountering people engaged in each of the nine activities listed.

	Estimate (SE)	Wald z-statistic	*p*	Odds Ratio (CI 95%)
Visual Encounters	0.155 (0.020)	7.778	< 0.001	1.17 (1.12 - 1.21)
Activities				
Collecting NTFPs	0.138* (0.042)	-3.307	< 0.001	0.87 (0.80 - 0.94)
Gold mining	-0.322* (0.060)	5.441	< 0.001	1.38 (1.23 - 1.56)
Working in field	0.002 (0.060)	0.04	0.968	1 (0.89 - 1.12)
Herder	0.017 (0.060)	0.284	0.777	1 (0.88 - 1.22)
Timber collection	0.036 (0.082)	0.435	0.664	1 (0.90 - 1.15)
Hunter	-0.031 (0.092)	-0.338	0.735	0.97 (0.81 - 1.17)
Water use	0	0	1	NA
Village activities	0	0	1	NA
Carrying food	1.094 (0.847)	1.292	0.196	NA

SE = Standard error, CI = confidence interval* = significant at $p < 0.05$

Table 4.6 Summary of multinomial regression predicting the likelihood of each reaction type over the nine-year study period.

Reaction	Estimate (SE)	Wald z-statistic	*p*	Odds Ratio (CI 95%)
Year: aggressive	0.338 (0.197)	1.719	0.086	1.40 (0.95 – 2.06)
Year: disturbed	0.017 (0.097)	0.18	0.858	1.02 (0.84 - 1.23)
Year: flee	-0.281* (0.086)	-3.265	0.001	0.76 (0.64 - 0.89)
Year: hide	0.050 (0.171)	0.295	0.768	1.05 (0.75 - 1.47)
Year: low-level	-0.018 (0.163)	-0.111	0.912	0.98 (0.71 - 1.35)
Year: vigilant	-0.014 (0.085)	-0.16	0.873	0.99 (0.83 - 1.17)
Year: vocalize	0.217* (0.088)	2.45	0.014	1.24 (1.04 - 1.48

SE = Standard error, CI = confidence interval, * = significant at $p < 0.05$

Table 4.7 Chi square analysis output for chimpanzee reaction to activity type. Adjusted residuals that exceed +/- 2 are in bold.

		Field	Gold Miner	Herder	Hunter	NTFPs	Timber	Other	Marginals
Aggressive	Obs.	0	1	2	1	0	1	1	6
	Exp	0.97	1.63	1.00	0.37	1.40	0.43	0.20	
	Column %	0%	2%	6%	8%	0%	7%	14%	
	Res	-0.99	-0.49	1.00	1.03	-1.18	0.87	1.79	
	Std. Res	-1.09	-0.59	1.11	1.08	-1.37	0.92	1.85	
Disturbed	Obs.	5	6	10	2	6	3	0	32
	Exp	5.18	8.69	5.33	1.98	7.47	2.29	1.07	
	Column %	15%	11%	29%	15%	12%	20%	0%	
	Res	-0.08	-0.91	2.02	0.01	-0.54	0.47	-1.03	
	Std. Res	-0.09	-1.16	**2.40**	0.02	-0.67	0.53	-1.14	
Flee	Obs.	4	6	7	3	14	3	1	38
	Exp	6.15	10.31	6.33	2.35	8.87	2.71	1.27	
	Column %	12%	11%	20%	23%	29%	20%	14%	
	Res	-0.87	-1.34	0.26	0.42	1.72	0.17	-0.24	
	Std. Res	-1.05	-1.74	0.32	0.48	**2.18**	0.20	-0.27	
Hide	Obs.	1	1	1	2	0	1	0	6
	Exp	0.97	1.63	1.00	0.37	1.40	0.43	0.20	
	Column %	3%	2%	3%	15%	0%	7%	0%	
	Res	0.03	-0.49	0.00	2.67	-1.18	0.87	-0.45	
	Std. Res	0.03	-0.59	0.00	**2.80**	-1.37	0.92	-0.46	
Low-level reaction	Obs.	1	0	1	0	0	1	0	3
	Exp	0.49	0.81	0.50	0.19	0.70	0.21	0.10	
	Column %	3%	0%	3%	0%	0%	7%	0%	
	Res	0.81	-1.06	0.78	-0.45	-0.96	1.77	-0.32	
	Std. Res	0.74	-0.90	0.71	-0.43	-0.84	1.70	-0.32	

Table 4.7 Continued

		Field	Gold Miner	Herder	Hunter	NTFPs	Timber	Other	Marginals
No reaction	Obs.	2	6	2	0	5	2	1	18
	Exp	2.914	4.886	3.000	1.114	4.200	1.286	0.600	
	Column %	6%	11%	6%	0%	10%	13%	14%	
	Res	-0.612	0.618	-0.661	-1.140	0.466	0.684	0.549	
	Std. Res	-0.536	0.504	-0.577	-1.056	0.390	0.630	0.516	
Vigilant	Obs.	14	9	10	2	14	3	3	55
	Exp	8.90	14.93	9.17	3.40	12.83	3.93	1.83	
	Column %	41%	16%	29%	15%	29%	20%	43%	
	Res	1.71	-1.53	0.28	-0.76	0.33	-0.47	0.86	
	Std. Res	**2.17**	**-2.09**	0.35	-0.91	0.43	-0.57	1.02	
Vocalize	Obs.	7	28	2	3	10	1	1	52
	Exp	8.42	14.11	8.67	3.22	12.13	3.71	1.73	
	Column %	21%	49%	6%	23%	20%	7%	14%	
	Res	-0.49	3.70	-2.26	-0.12	-0.61	-1.41	-0.56	
	Std. Res	-0.62	**4.99**	**-2.86**	-0.15	-0.81	-1.68	-0.65	
Marginals		34	57	35	13	49	15	7	210

Table 4.8 Chi square analysis output for chimpanzee reaction to transportation type. Adjusted residuals that exceed +/- 2 are in bold.

		Bike	Motorcycle	Vehicle	Walking	Other	Marginals
Aggressive	Obs.	1	0	2	4	0	7
	Exp	1.35	0.82	1.32	3.40	0.11	
	Column %	2%	0%	3%	3%	0%	
	Res	-0.30	-0.90	0.59	0.33	-0.33	
	Std. Res	-0.34	-0.97	0.66	0.46	-0.34	
Disturbed	Obs.	5	3	1	25	1	35
	Exp	6.74	4.09	6.62	17.00	0.55	
	Column %	8%	8%	2%	16%	20%	
	Res	-0.67	-0.54	-2.19	1.94	0.60	
	Std. Res	-0.79	-0.61	**-2.57**	**2.87**	0.64	
Flee	Obs.	8	4	0	46	0	58
	Exp	11.16	6.77	10.98	28.18	0.91	
	Column %	13%	11%	0%	30%	0%	
	Res	-0.95	-1.06	-3.31	3.36	-0.96	
	Std. Res	-1.16	-1.25	**-4.07**	**5.18**	-1.07	
Hide	Obs.	1	1	0	6	0	8
	Exp	1.54	0.93	1.51	3.89	0.13	
	Column %	2%	3%	0%	4%	0%	
	Res	-0.43	0.07	-1.23	1.07	-0.36	
	Std. Res	-0.49	0.07	-1.38	1.51	-0.36	
Low-level reaction	Obs.	4	1	1	2	0	8
	Exp	1.54	0.93	1.51	3.89	0.13	
	Column %	7%	3%	2%	1%	0%	
	Res	1.98	0.07	-0.42	-0.96	-0.36	
	Std. Res	**2.24**	0.07	-0.47	-1.35	-0.36	
No reaction	Obs.	9	10	3	10	0	32
	Exp	6.16	3.74	6.06	15.55	0.50	
	Column %	15%	27%	5%	6%	0%	
	Res	1.15	3.24	-1.24	-1.41	-0.71	
	Std. Res	1.34	**3.64**	-1.45	**-2.07**	-0.76	
Vigilant	Obs.	20	6	6	38	0	70
	Exp	13.47	8.17	13.25	34.01	1.10	
	Column %	33%	16%	10%	25%	0%	
	Res	1.78	-0.76	-1.99	0.68	-1.05	
	Std. Res	**2.24**	-0.92	**-2.51**	1.08	-1.20	

Table 4.8 Continued

		Bike	Motorcycle	Vehicle	Walking	Other	Marginals
Vocalize	Obs.	13	12	47	23	4	99
	Exp	19.05	11.56	18.74	48.09	1.56	
	Column %	21%	32%	78%	15%	80%	
	Res	-1.39	0.13	6.53	-3.62	1.95	
	Std. Res	-1.86	0.17	**8.74**	**-6.09**	**2.37**	
Marginals		61	37	60	154	5	317

Figure 4.1 Traditional mud hut in southeastern Senegal village. Timber and non-timber forest products are essential to the way of life.

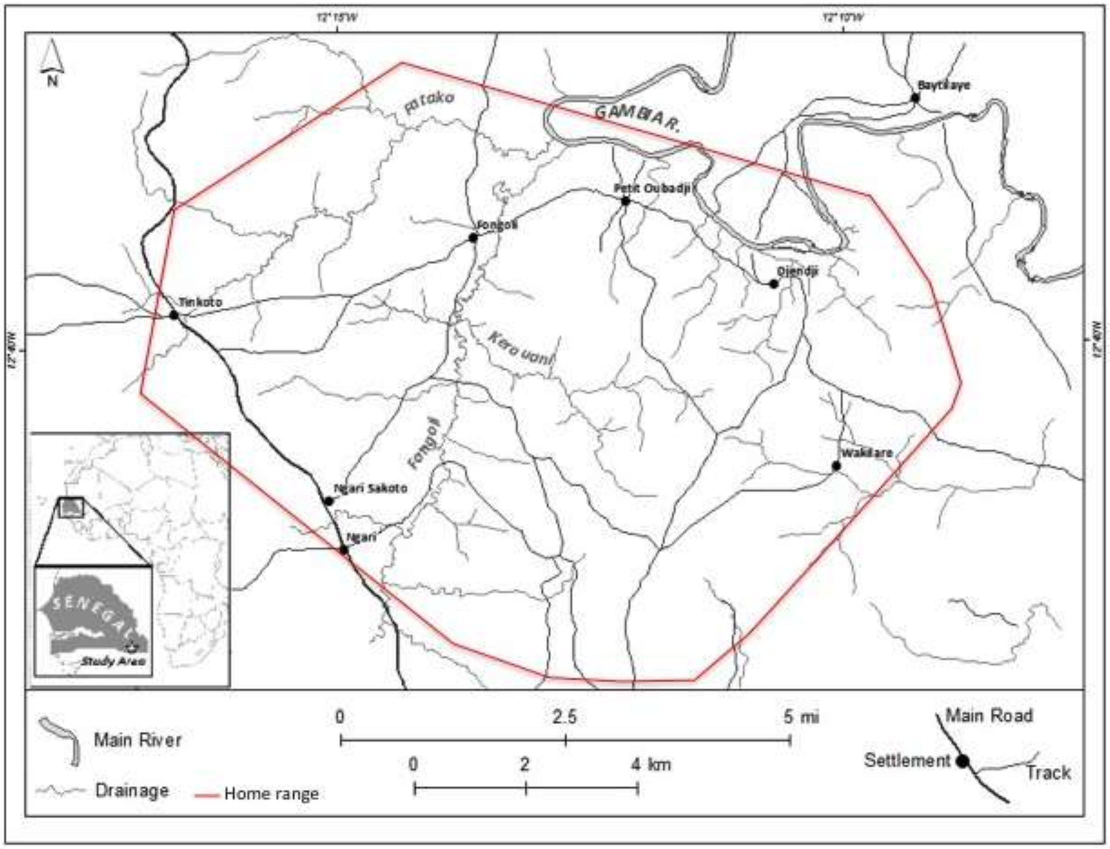

Figure 4.2 Fongoli field site

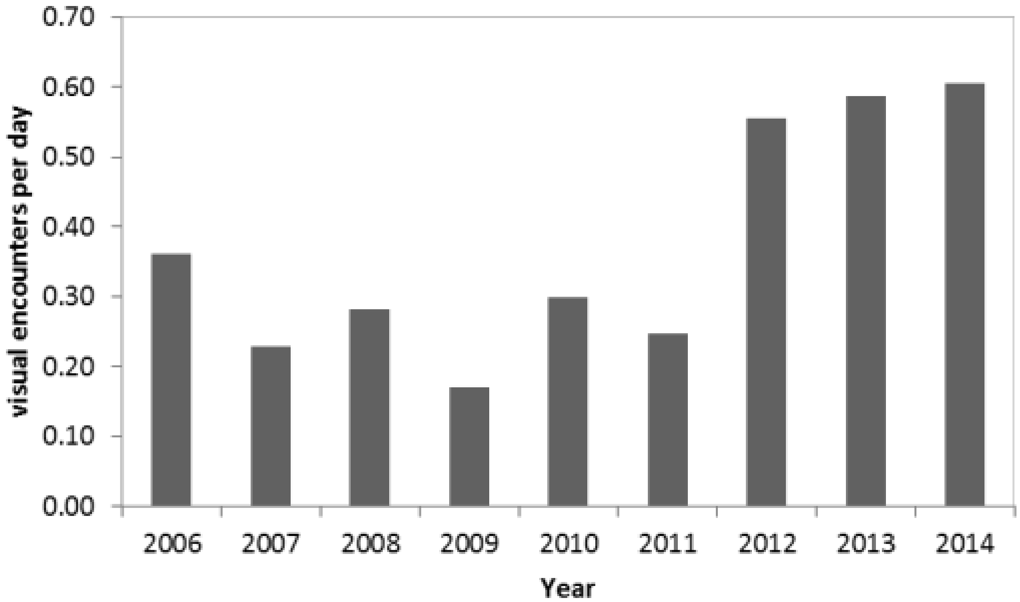

Figure 4.3 Human-chimpanzee encounter rates per observation day for study period 2006-2014.

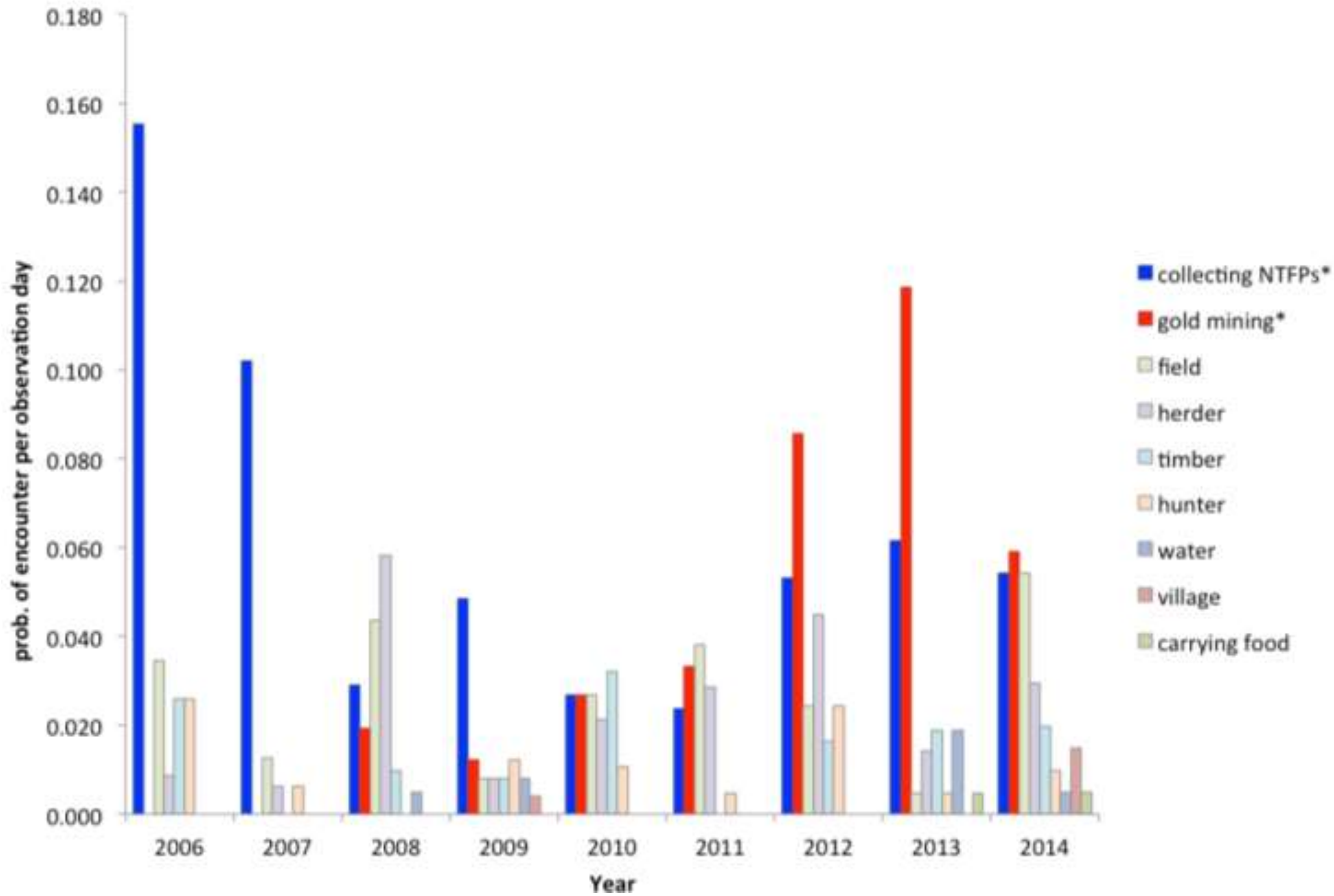

Figure 4.4 Daily probability of encountering people engaged in nine separate activities in the bush over the study period. Activities that changed significantly over time are indicated with an asterisk.

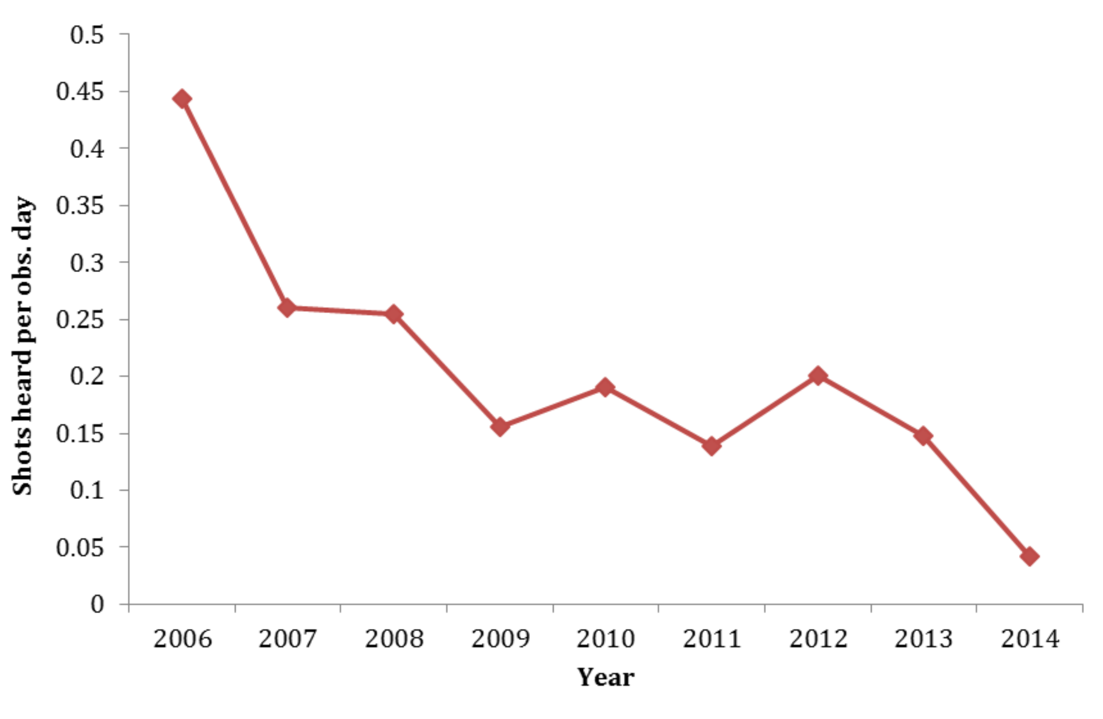

Figure 4.5 Gunshots heard per observation day 2006-2014

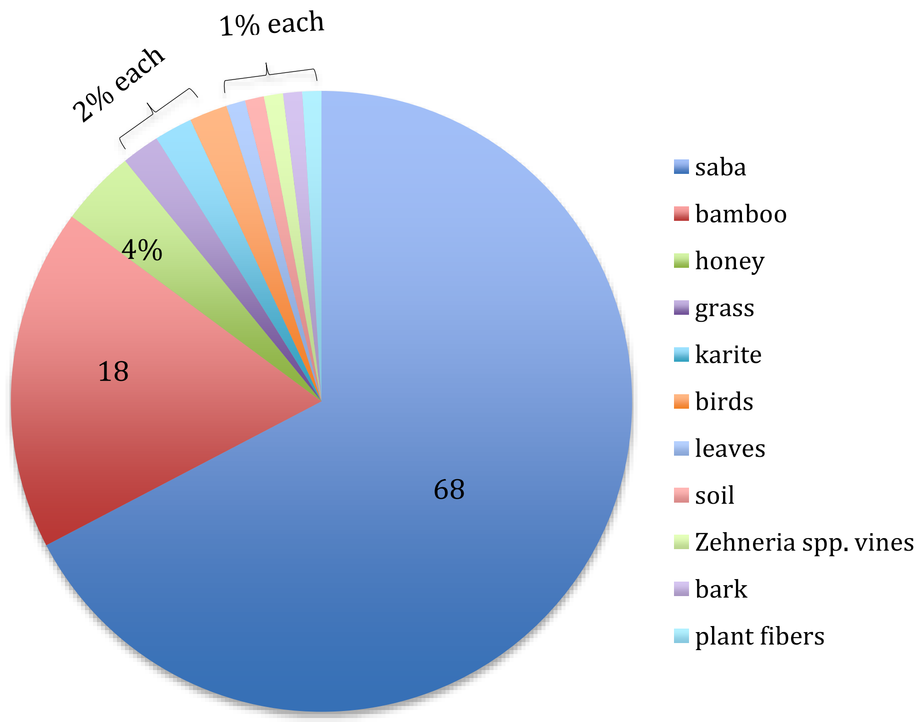

Figure 4.6 Breakdown of non-timber forest products collected during encounters throughout the study period

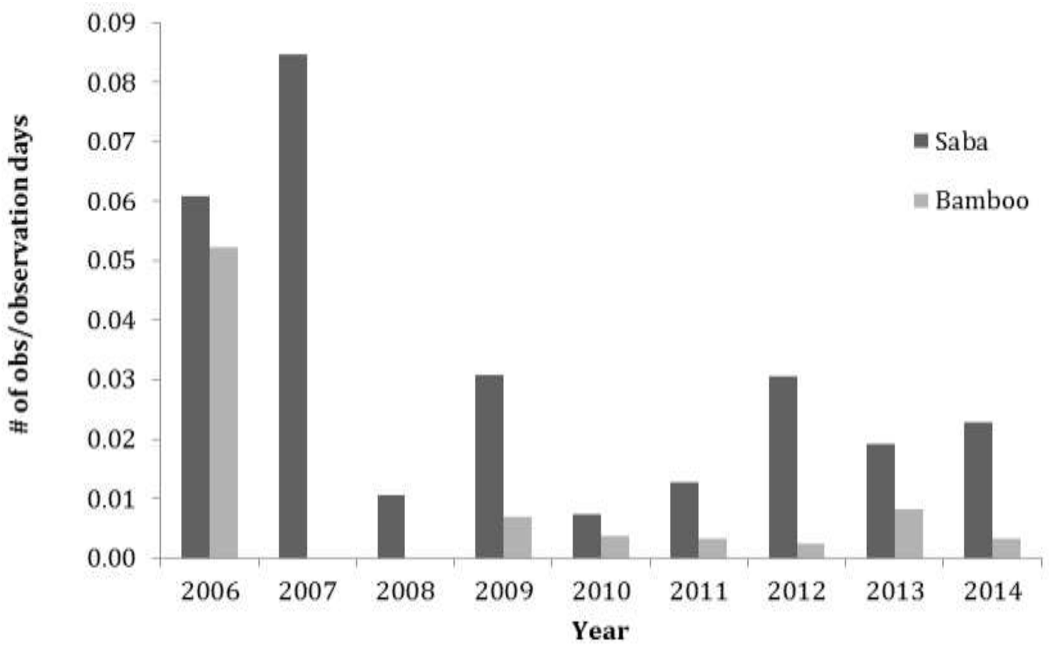

Figure 4.7 Significant changes in NTFPs collection rates over the study period

Figure 4.8 Rates of gold mining activity observed during human-chimpanzee encounters and price of gold per ounce from 2006 through 2014 (Goldprice.org)

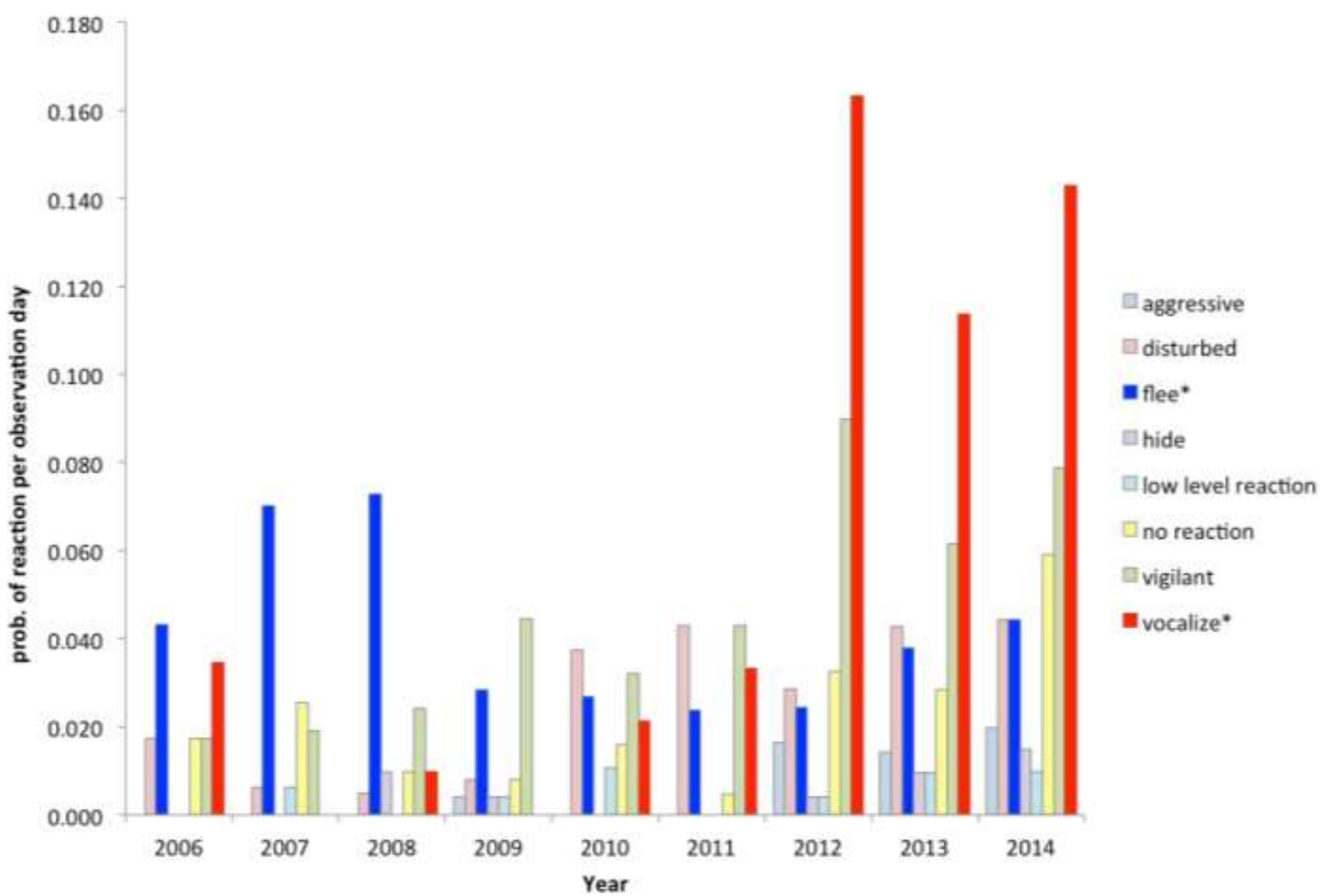

Figure 4.9 Daily probability of chimpanzee reactions when encountering people over the study period. Reactions that changed significantly over time are indicated with an asterisk.

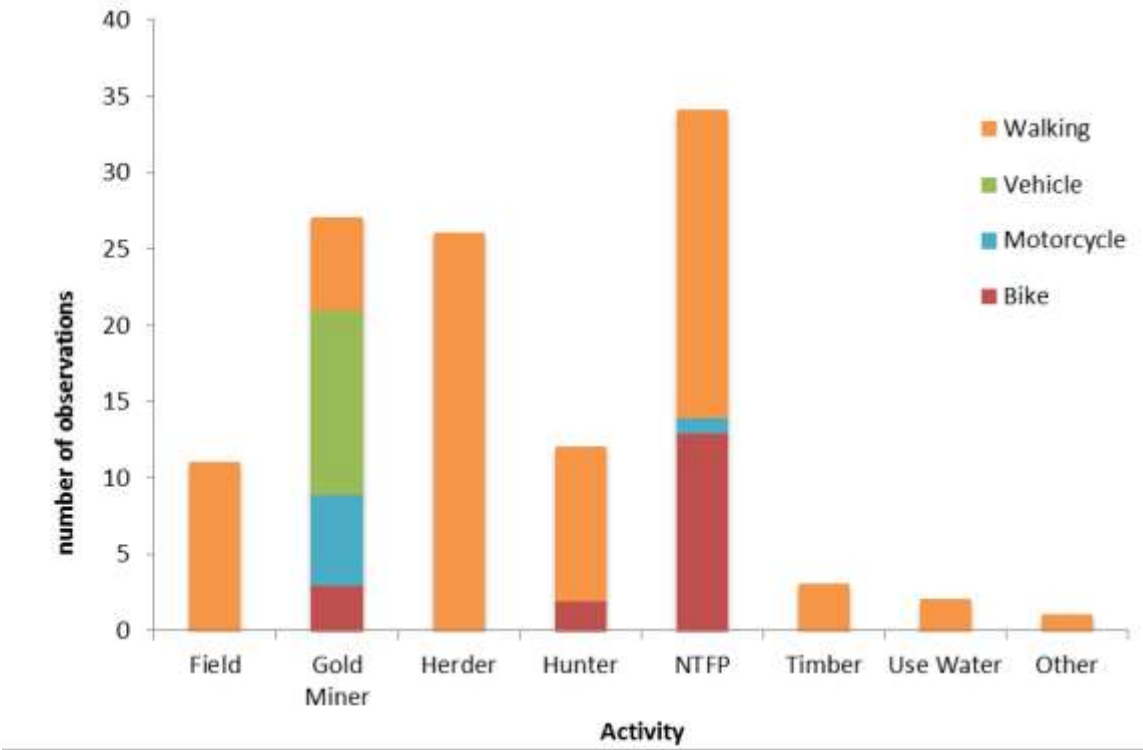

Figure 4.10 Transportation used for each activity type

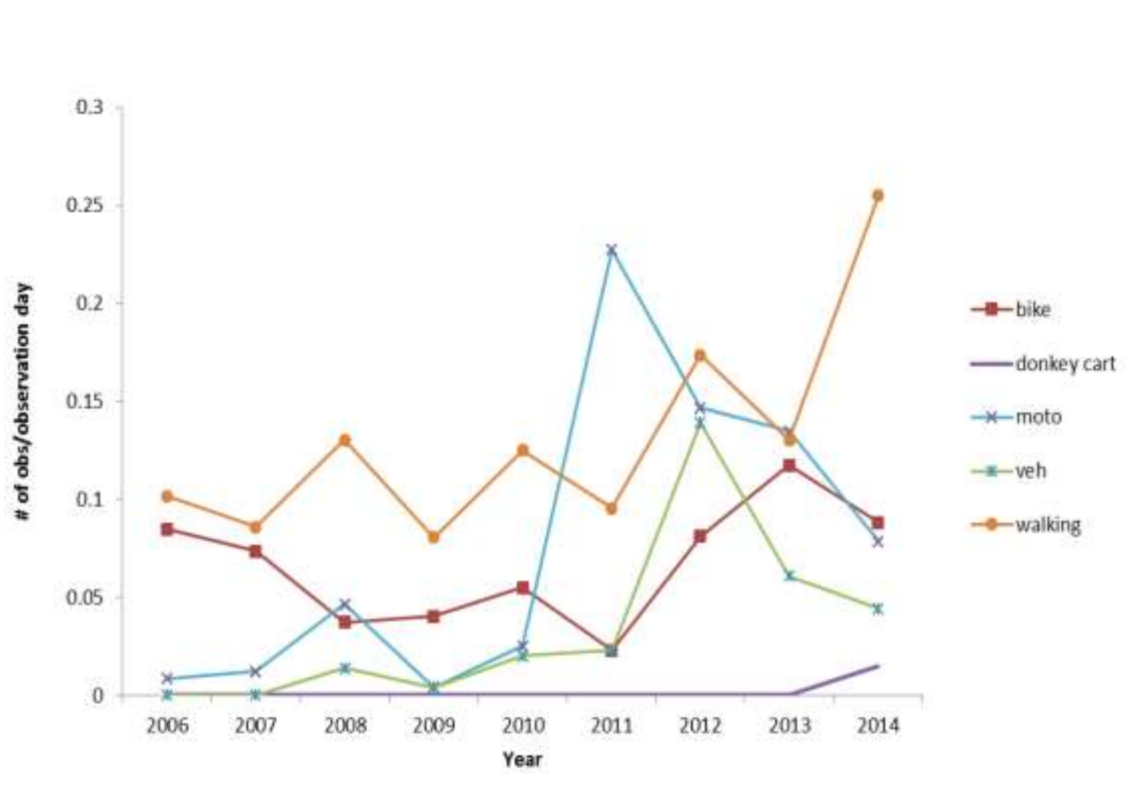

Figure 4.11 Transportation used during daily encounters from 2006-2014

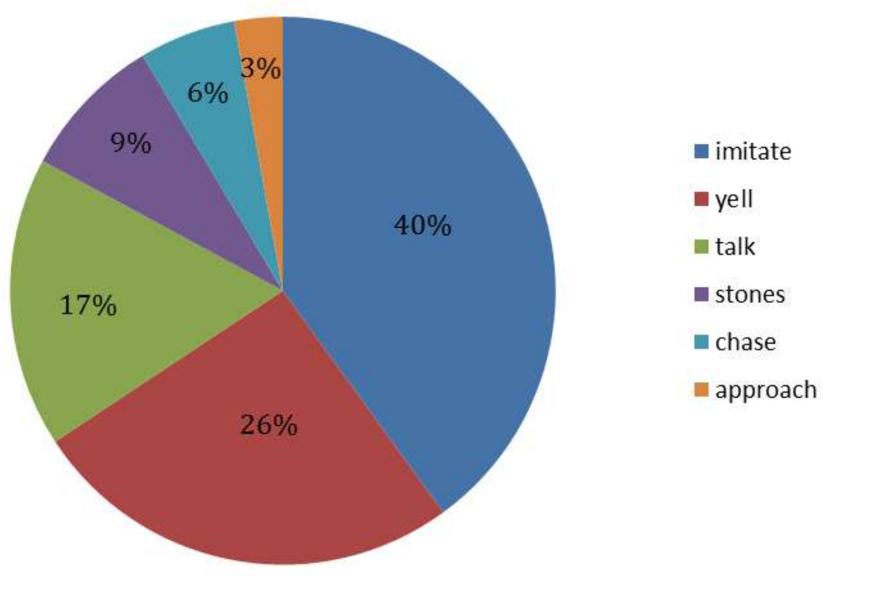

Figure 4.12 Breakdown of human-initiated interactions with chimpanzees

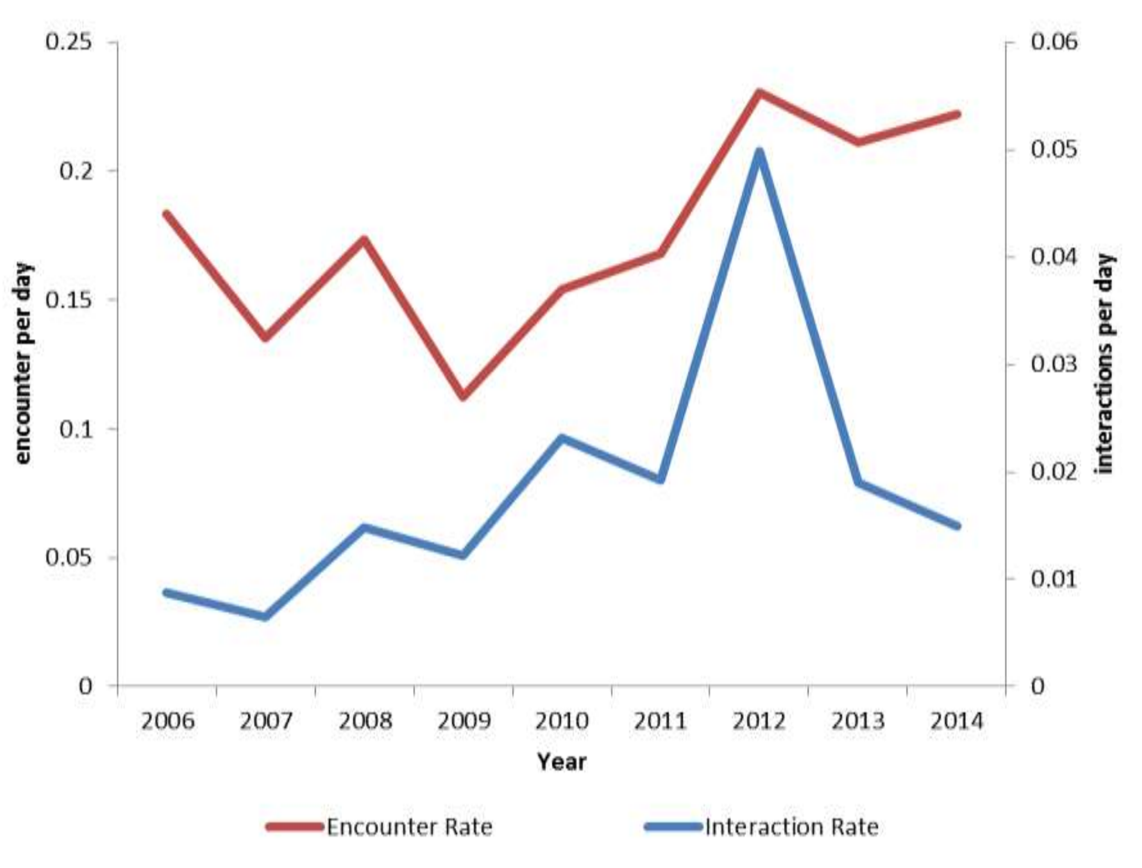

Figure 4.13 Rates of human-initiated interactions and overall human-chimpanzee encounter rates for 2006-2014

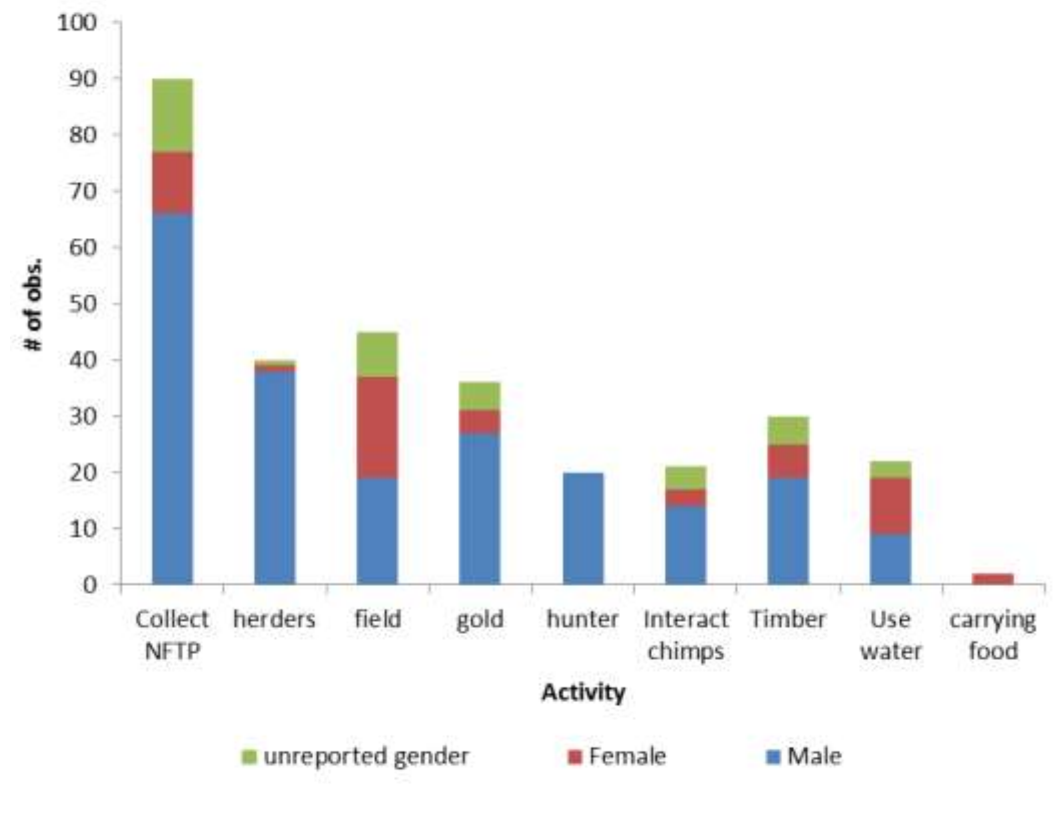

Figure 4.14 Number of men and women engaged in the various activities observed during human-chimpanzee encounters throughout the study period.

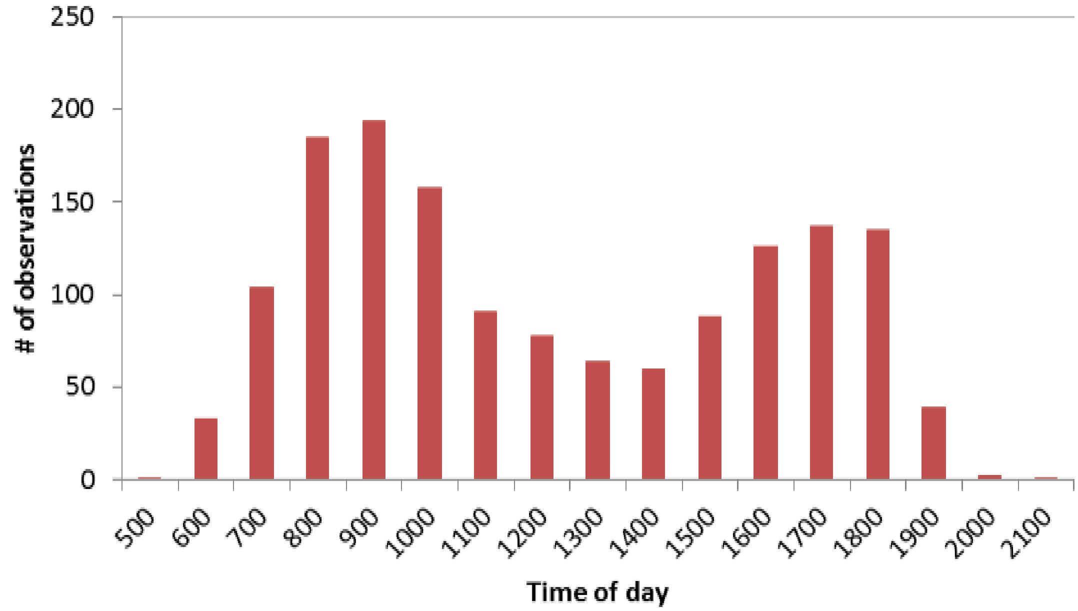

Figure 4.15 Distribution of human-chimpanzee encounters by hour of day

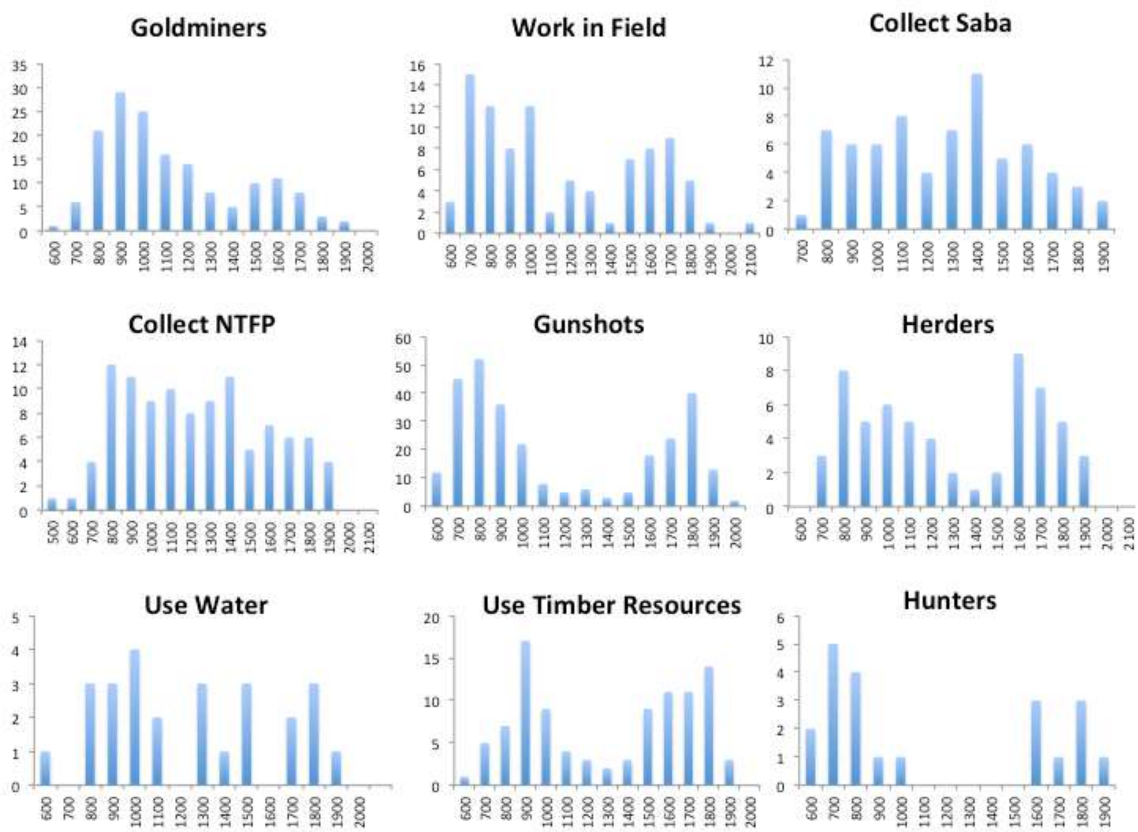

Figure 4.16 Distribution of number of observations for each activity by hour of day.

CHAPTER V

IMPACTS OF ARTISANAL SMALL-SCALE GOLD MINING ON THE LONG-TERM RANGING BEHAVIOR OF THE FONGOLI CHIMPANZEES

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Abstract

Ecological and environmental factors, particularly related to habitat, influence primate ranging behavior. For West African chimpanzees (*Pan troglodytes verus*), the fastest growing factor affecting their ranging behavior is anthropogenic disturbance. Here we investigate the impacts of artisanal small-scale gold mining (ASGM) on the ranging behavior of the Fongoli chimpanzee community in southeastern Senegal, where gold mining has become more prevalent since the mid-2000s, resulting in the formation of seven mining sites within the chimpanzees' home range. Using 10 years of chimpanzee ranging data from the Fongoli Savanna Chimpanzee Project from 2005 through 2014, we calculated changes in the community's home range and 50% core range using the minimum convex polygon (MCP) and the kernel density estimator (KDE) methods. We also analyzed chimpanzee ranging in and around the seven mining sites as they appeared on the landscape. Over the study period, the Fongoli chimpanzees shifted their ranging patterns toward the largest mining site when mining activity was low, then away from the site as mining expanded and increased in intensity. A significant decrease in the 100% MCP range over the years indicated that fewer ranging events were taking place at the western periphery of the community's range near the largest ASGM site. Overall, we found that chimpanzees not only tolerate but also may be attracted to areas with low levels of mining. Higher levels of mining activity, however, can disrupt chimpanzee travel routes and influenced shifts in their home range. Behavioral changes in response to anthropogenic disturbances, such as ASGM, may result in demographic changes over time and should be regarded as an important warning of the potential negative impacts of extractive industries.

Introduction

The greatest threat to primates today is loss of habitat from anthropogenic activities (Estrada et al., 2017). Human-dominated landscapes can have long-term effects on vegetation and forest structure, which affects food availability, habitat suitability, and, ultimately, can alter behavior (Bryson-Morrison et al., 2017; Goossens et al., 2016; de la Torre et al., 2000). The most severe impacts stem from agriculture and ranching, extractive industries (i.e. logging and mining), and hunting (Estrada et al., 2017). Artisanal small-scale gold mining (ASGM) is a traditional extractive industry that alters the long-term productivity of critical primate habitat through the clearing of vegetation and disruption of soil structure (Arcus Foundation, 2014). Here we investigate the impacts of ASGM on the ranging behavior of West African chimpanzees (*Pan troglodytes verus*) in a savanna habitat in southeastern Senegal.

Burt (1943: 351) was first to define the concept of a home range as the area "traversed by an individual in its normal activities of food gathering, mating, and caring for young." This definition, focusing on localized behavior and excluding migratory routes and occasional forays into generally unused areas, is still used today. Recent studies have illustrated the complexity of range determination, connecting mammalian ranging behavior to group size, body size, group composition, resource availability, and intergroup relationships. For many primates, resource availability is thought to be a primary driver of home range size. Ecological constraint theory states that to meet the nutritional needs of new community members, range size will increase as group size increases (Altmann, 1974; Isbell, 1991; Clutton-Brock and Harvey 1977; Ganas and Robbins, 2005). Dunbar (1988) suggested that, among primates, pressure from neighboring groups may also be key in determining the area of group ranges, along with food availability and group size. Chimpanzees are generally considered frugivores, and the availability of fruit can be reflected in chimpanzee ranging behavior, with fruit scarcity leading to larger home ranges and vice versa (Doran, 1997; Nakamura et al., 2012). Other studies have found contrasting results in that food availability does not impact ranging (Boesch and Boesch-Achermann, 2000; Amsler, 2009), however. These contradictory results may be explained by overall fruit availability and productivity of the habitat. Chimpanzees living in marginal environments, where food resources are patchy and seasonal, are likely to be more severely affected by fruit scarcity than chimpanzees living in areas where the food supply is more consistently available (Amsler, 2009). At the Fongoli field site, the chimpanzees use their large home range cyclically, moving into areas of food or water abundance as availability changes with the seasons (Pruetz and Bertolani, 2009). This is in line with previous studies showing that primates living in habitats of lower resource availability need to travel farther to obtain the necessary nutrients (Nakamura et al., 2012 – *Pan troglodytes schweinfurthii*; Ganas & Robbins – *Gorilla beringei beringei*, 2005; Wieczkowski, 2005 – *Cercocebus galeritus*).

Ranging in forests and savannas

For chimpanzees, ranging behaviors differ based on habitat type, with forest and savanna dwelling chimpanzees in East Africa showing similar ranging patterns to those in similar habitats in West Africa (Table 1). Studies of habituated forest dwelling chimpanzees in East Africa include those from Gombe and Mahale, Tanzania and Kibale, Kalinzu, and Budongo, Uganda. These four sites can be compared to studies of forest dwelling chimpanzees in West Africa in the Tai Forest, Cote D'Ivoire and at Bossou, Guinea. Across forested communities we see similarities in home ranges size, daily path length, and the size of core ranges. Home range size for forest communities in the east and west are relatively small, ranging from 5 km^2 to 37 km^2, whereas home range estimates of savanna chimpanzees differ by an order of magnitude (Nakamura et al., 2012, Table 1). Daily path lengths at Kibale (Pontzer and Wrangham, 2003) and Tai (Doran, 1997) were similar at 1.9-2.4 km per day and 1.9–3.0 km per day, respectively. Daily path lengths at Gombe were slightly higher at 3.9 km per day (Wrangham Ph.D. dissertation, cited in Mitani, 1979). The average daily path length for savanna chimpanzees at Fongoli during the early rainy season was 3.3 km per day (Wessling, 2011).

To date, Fongoli is the only long-term field site that has habituated savanna chimpanzees, making it difficult to establish direct comparisons and trends between eastern and western Africa. The savanna chimpanzees from the Semliki-Toro Project in Uganda have not been fully habituated to researcher presence but have been compared to unhabituated chimpanzees at the Mt. Assirik field site in Senegal (Hunt and McGrew, 2002). The home range size at Semliki was estimated at a minimum of 72.1 km^2 using the minimum convex polygon (MCP) method based on observed locations of identified individuals (Samson and Hunt, 2012). Using a similar method at Mt. Assirik in Senegal, Baldwin et al. (1982) estimated the Assirik chimpanzee's home range at 37.4 km^2, which the authors described as conservative. In the same publication, the authors provide a more liberal estimation of 72.1 km^2 using contiguous nest sightings. A major factor, which should not be overlooked when making the comparison between these two sites, is the number of estimated individuals at each site and the resulting population density. The

Semliki community is estimated at approximately 104 individuals (Samson and Hunt, 2012), whereas Mt. Assirik was estimated to be home to a maximum of 37 individuals (Baldwin et al., 1982). Although these are only estimations, the projected population densities suggest a drastic difference in how these two chimpanzee populations range within their relative savanna habitats. The home range estimate and population density of the Fongoli field site are similar to those seen at Assirik. The home range area for Fongoli has thus far been estimated at $63km^2$ using estimates of nesting patterns and individual core ranges (Pruetz, 2006). A more recent estimate has been given as $>85km^2$ from unpublished data (cited in Pruetz and Lindshield, 2011). Here we present a 10-year estimate of the Fongoli home range size using MCP and kernel density estimation methods.

Other studies of unhabituated savanna chimpanzees at Kasakati and Ugalla, Tanzania from East Africa have provided estimates of home range sizes of $122\text{-}124km^2$ and $400\text{-}500km^2$, respectively (Izawa, 1970; Ogawa et al., 2007). Although unhabituated studies can provide detailed and useful data on chimpanzees, it is difficult to accurately determine home range calculations. At Ugalla, and for other estimates of the Mt. Assirik home range ($278\text{-}333\ km^2$), size was calculated using nest densities, which inflates the home range estimation (Ogawa et al., 2007; Baldwin et al., 1982). Without genetic testing of hair samples from the nests, it is not possible to know if all recorded nests were from the same community or from neighboring communities, making it impossible to delineate a community boundary.

Overall, we see differences between the home range size of forest and savanna chimpanzees. However, it should be noted that most chimpanzee studies occur inside protected areas, which may have important implications. Most long-term study sites occur in protected parks or reserves, including Kibale, Budongo, Semliki, Mahale, Gombe, and Tai, whereas the Bossou and Fongoli field sites are located in unprotected and anthropogenically disturbed areas (McKinney, 2015). The implication is that studying chimpanzees outside of protected areas allows one to understand the impact of intensive anthropogenic activity on chimpanzee ranging behavior. In Senegal, where few chimpanzees live in protected areas, anthropogenic landscapes make up the majority of chimpanzee habitat.

Anthropogenic activity

Anthropogenic activity is likely the fastest growing factor to affect primate ranging behavior. The greatest threat to primate species is the expansion of agriculture activities, followed by extractive logging and hunting (Estrada et al., 2017). Mineral mining comprises the fourth largest threat to primates worldwide and impacts species on all primate-inhabited continents (Estrada et al., 2017; Arcus Foundation, 2014). The massive growth in Africa’s mining sector makes this a threat of particular concern for endangered African great apes (Edwards et al, 2014).

Mining activity alters the landscape, negatively impacting wildlife directly and indirectly. Direct impact of mining leads to forest degradation and fragmentation, as well as the complete loss of forested areas (Alvarez-Berríos and Aide, 2014; Akiwumi and Butler, 2008; Kusimi, 2008). Indirect impacts are associated with the building of infrastructure (e.g., roads and railways), pollution, growth of secondary enterprises, increased population migration, cultural changes, and the spread of infectious diseases (Cowlishaw et al., 2005; Edwards et al., 2014; Arcus Foundation, 2014; Hockings and

Humle, 2009; Laurance et al., 2009; Patz et al., 2004). Research suggests that these impacts can lead to primate population declines (Estrada et al., 2017); however, little is known about how wildlife responds behaviorally to extractive industries. Most studies assessing behavioral responses to extractive industries report changes in habitat use and ranging related to the infrastructure of natural gas and logging activities. For pronghorn antelope (*Antilocapra americana*) in Wyoming, USA, gas field development led to decreases in highest quality habitat patches, increases in poor habitat patches, and avoidance of highly disturbed areas (Beckman et al., 2012). For grizzly bears (*Ursus arctos*) in the Rocky Mountains of Canada and the U.S.A, road infrastructure associated with oil and gas exploration and logging industries displaced the bears from important habitat (McLellan and Shackleton, 1988). Other studies have shown that roads and linear clears in tropical forests increased road-related mortality and created barriers to faunal movement (Laurance et al., 2009). In the Congo Basin, increased road development associated with logging played a role in forest elephant (*Loxodonta africanus cyclotis*) population decline, where the probability of elephant presence increased as distance to roads increased (Blake et al., 2007). In Gabon, one study on the behavioral impacts of noise disturbance related to extraction, specifically seismic oil exploration, found that low-impact seismic operations caused temporary habitat loss for chimpanzees and gorillas (Rabanal et al., 2010).

Studies reporting the impacts of gold mining on wildlife behavior have been limited to large-scale gold mines and ungulates (bighorn sheep [*Ovis canadensis*] - Oehler et al., 2005; caribou [*Rangifer tarandus*] - Weir et al., 2007). Oehler et al. (2005) found that female bighorn sheep living adjacent to an open-pit gold mine had lower quality diets and foraged less during the summer months than sheep living away from the mine. A 2007 study on the impacts of open-pit copper mining on bighorn sheep in Arizona found few behavioral differences inside and outside of the mine (Jansen et al., 2007). Weir et al. (2007) found that the creation and operation of an open-pit gold mine reduced caribou abundance near the mine throughout all seasons of the year. The behavioral impacts of artisanal small-scale gold mining on wildlife, however, have not yet been assessed. Additionally, few studies have addressed the behavioral responses of primates to mining activities, although many report the presence and prevalence of mining within primate habitats (Suriname - Norconk et al., 2003; Democratic Republic of Congo – Plumptre et al., 2015; Peru - Shanee and Shanee, 2014; multiple countries - Arcus Foundation, 2014).

Many of Senegal's metal deposits, including gold, iron, copper and several other economically important metals, are located in the southeastern part of the country, congruent with chimpanzee habitat. Gold mining has become more prevalent in southeastern Senegal since the mid-2000s, increasing concurrently with international gold prices ($400 USD/oz. in 2005 to over $1900 USD/oz. in 2011; World Gold Council, 2016). Current gold prices remained elevated at $1214 USD/oz. (goldprice.org - 9 July 2017) and have been increasing in 2017 (World Gold Council, 2017). Both large-scale corporate mining and artisanal small-scale gold mining (ASGM) have increased recently in Senegal. ASGM is broadly defined as labor-intensive gold mining of marginal deposits, usually using both rudimentary and mechanized tools, with poor health and safety measures, and having a negative impact on the environment (Mining Minerals and Sustainable Development Project [MMSD], 2002). The unregulated and widespread nature of ASGM in unprotected natural areas makes this the focus of our research. In 2009, 10-20,000 people were estimated to be practicing ASGM in Senegal (Pasmi, 2009); however, by 2016 numerous major ASGM sites were identified that had more than 5,000 miners at each site (Persaud et al., 2017). An estimated 20-30,000 ASGM miners could be found at one site alone, although accurate estimations of populations are difficult as people enter and exit the site daily (Prause, 2016)

In assessing the impacts of ASGM on chimpanzee ranging behavior, our study has two main spatial foci; 1) changes in the home range and 2) ranging behavior near each of the seven ASGM affected areas. At the temporal scale, we were interested in how increases in ASGM activity changed the community's range annually and seasonally. We hypothesized that chimpanzees would avoid areas of previous use when mining commenced in those areas. Seasonally, we predicted this decrease in use would be most evident towards the end of the dry season when human presence at the mines is greatest (Persaud et al., 2017). Of the seven mining areas identified, we hypothesized that the greatest shift in ranging activity would be away from the largest mining site, Oundoundou.

For each of the seven mines, we asked 1) whether chimpanzees were spending more or less time in daily visits and/or length of visits in proximity to the area, 2) whether chimpanzees spatially avoided the mined area, and 3) whether the chimpanzees temporally avoided people at the mine (on a 24-hour and/or weekly scale). We predicted that chimpanzee visits to the mining area would decrease as mining activity increased, both in proximity to the mines and length of stay. In addition, we predicted that the chimpanzees would use temporal anti-predator avoidance behaviors to avoid human interaction at the mines (Lima, 1998). Specifically, we predicted they would be more likely to visit the mining areas on Mondays and Fridays when activity ceases due to cultural beliefs and traditions (S. Keita, pers. comm.), as well as early in the mornings or late in the evenings after the miners had returned to their villages. We also explored annual changes in ranging related to demographic variables including number of adult males, number of adult females, and community size, as these variables have been shown to influence ranging at other chimpanzee sites (Taï National Park, Côte d'Ivoire - Lehmann and Boesch, 2003; Mahale Mountains National Park, Tanzania - Nakamura et al., 2012; Kibale National Park, Uganda - Chapman and Wrangham, 1993).

Methods

Study site

The Fongoli Savanna Chimpanzee Project (FSCP) field site (12°39' N, 12°13'W) is located in the Kedougou region of southeastern Senegal. The FSCP has been focused on the ecology and behavior of the chimpanzees since 2001, successfully achieving habituation of all adult male subjects in early 2005, with all individuals identified by January 2006. The vegetation is classified as Sudano-Guinean (White, 1983) and is made up of a mosaic of woodlands, grasslands, and gallery forests (see Chapter Six). The environment is considered the hottest, driest, and most open habitat for chimpanzees across their global range (Hunt and McGrew, 2002). The year has two pronounced seasons: a seven-month dry season lasting from mid-October through mid to late May and rainy season comprising the remaining five months. Annual rainfall for Kedougou is 950 mm (NOAA, 2017).

Fongoli is north of the regional town center of Kedougou. Eight villages, two of which are located along frequent travel routes, flank the chimpanzees' home range. The communities are made up of Tenda, Mandé and Peule Fouta ethnic groups who engage in subsistence agriculture, timber collection, non-timber forest product collection and ASGM activities within the chimpanzees' home range (see Chapter 3). Artisanal mining has long been a traditional livelihood in southeastern Senegal, and has increased on the landscape since 2008. Between 2008 and 2014, ASGM sites have grown from one (Oundoundou) to seven sites (Oundoundou, Kerouani, Ngari, Coucoukoto, Wolokoto, Niakora, Djendji), varying in size, intensity, and length of activity (see section on ASGM sites in Fongoli Chapter 2).

Study subjects

The chimpanzee community averaged 31.8 individuals from 2005 to 2014. The ratio of adult males to adult females is skewed 1.4 to 1. Adult males averaged 10.4 individuals and females averaged 7.2 individuals annually over the study period. During the 10-year period, four alpha males characterized the community (Pruetz et al. 2017). Foudouko was identified as alpha at the beginning of systematic study of the community's males, from early 2005 through September of 2007. Yopogon followed Foudouko as the group's second alpha (September 2007 through November 2008) and Lupin was the third alpha recorded (November 2008 until March 2012). David, the fourth alpha took over in March 2012 and had been alpha for more than five years as of 2017.

Data collection and analyses

We analyzed the ranging behavior of the Fongoli chimpanzees from 2005 through 2014. Data collection entailed daily focal follows of adult male chimpanzee subjects.

Females are not subject to focal follows due to the vulnerability of their offspring as targets of the illegal pet trade (Pruetz and Kante, 2010); however, opportunistic data collection did occur when females were in parties with adult males and was included in our dataset. During data collection, researchers and field assistants follow the focal subject and associated party as they exited their night nest in the early morning (approximately 0600 hours) until they created a new nest at the end of the day (approximately 1900 hours). Data included in our analyses were collected at five-minute intervals and included date, time, GPS coordinates, focal subject, and activity. When feeding was observed during the interval, the food species and type were also recorded. In addition, observers also included all-occurrence notes on select behaviors (e.g. hunting) and anthropogenic activities including gold mining activities and human encounters. For this study we analyzed 1160 days of observation and over 10,300 contact hours for the 10-year study period (Table 2).

Observers recorded data in all-weather notebooks, which were translated from French when necessary, and transferred into Excel spreadsheets. We converted all spatial data into Universal Transverse Mercator (UTM) format. Spatial data were imported into ArcMap 10.4.1 (Environmental Systems Research Institute, Redlands, CA) and assigned to the UTM WGS-84 reference system for Zone 28N. We excluded any observation that were missing or had incomplete components of the relevant variables. Distance to mining areas was calculated in ArcMap using the ‘Near’ function.

Due to incomplete data collection during early years of the project, when chimpanzees were less habituated (June 2005- December 2007; Table 2), these years were combined into a “pre-mining” dataset to represent all seasons. Once combined, the pre-mining dataset included observations during all months except April. The pre-mining dataset accounted for 13% of all possible observation days from 2005 to 2007. For all other years (2008 through 2014), our dataset averaged 41% of all possible observation days.

Seasonal differences in water and fruit availability are hypothesized to impact ranging. Therefore, we analyzed ranging behavior according to three seasons: early dry season, late dry season and wet season (Figure 1). Two distinct seasons are evident with respect to rainfall (dry = no rainfall; wet = rainfall).To account for temperature changes, water and fruit availability, we subdivided the seasons as follows: The early dry season was defined as November 1 (based on the average date of the last rainfall = October 28, SD = 9.43 days) through the end of February. The early dry season has relatively cooler temperatures (Figure 1), and baobab (*Adansonia digitata*) fruit is in season (Pruetz, 2006). Higher temperatures, few water resources, and consumption of an important fruit, *Saba senegalensis,* characterize the late dry season (Pruetz, 2006; see Chapter 6 for seasonal fruit consumption). The late dry season was defined as March 1 through May 31. This was based on the average date of first rainfall greater than 5 mm (May 18, SD = 8.12 days). The wet season follows the late dry season, beginning on June 1 and continues through October. Consistent rainfall and relatively moderate temperatures characterize the wet season.

Home ranges were calculated using both the minimum convex polygon (MCP) method and the kernel density estimator (KDE) method. MCPs calculate the area of use by connecting the outermost animal locations with a convex polygon and assumes an equal probability of use throughout the polygon. The MCP method, therefore, includes areas not used by the community, either due to human disturbance or lack of ecological relevance or in accessibility (i.e., settlements and rivers, see Chapter 6 for avoided land cover types). The MCP method varies with respect to sample size, with home range estimation increasing with the number of locations used in the calculation. Despite the biases of MCP estimation (Börger et al., 2006), we have included MCP estimations primarily due to its widespread and historical use in the literature (Nakamura, 2012), allowing for comparison to other studies. However, MCPs can have meaningful biological value in conservation area management (Nilsen et al., 2008) and illustrate the extent of ranging. We also used the KDE method to create a more accurate representation of chimpanzees' range. KDEs use probability kernels, or three-dimensional hills, to establish the likelihood of animal presence around each of the locations of the study group (Kernohan et al., 2001). The smoothing parameter is determined by the height of the kernel, or bandwidth, and can be defined by a default (h_{ref}), least squares cross-validation (h_{lscv}) or by using a plug-in ($h_{plug\text{-}in}$). Due to the large number of locations in our study, the dataset did not converge using an h_{lscv} bandwidth (Hemson et al. 2005) and, based on the relatively large area of use, $h_{plug\text{-}in}$ was not applicable (Walter et al., 2011). We therefore used the h_{ref} bandwidth for our KDE home range area calculations; this method resulted in reasonable estimates based on visual interpretation.

We calculated the chimpanzees' home range using 100% MCP and 95% KDE for all locations in the dataset using R version 3.3.1 (R Core Team, 2016) and the adehabitatHR package (Calenge, 2015). The adehabitatHR package does not calculate 100% KDE so we used the maximum percentage available which was 95%. Core ranges, defined as the areas with the highest probability of use within the home range, were calculated using 50% MCP and 50% KDE. The centroids of each home and core range polygon were calculated using the Feature to Point tool in ArcMap.

Mining areas (Figure 2) were defined using three methods: data book entries during chimpanzee observations, available LANDSAT 7 satellite imagery from 2007-2014, and local knowledge from the FSCP staff. Mined areas are characterized by cleared vegetation and disrupted soil, which creates visible scars on the landscape. These areas were delineated, when possible, using satellite imagery. For mines under canopy cover, areas were estimated use GPS data from data book entries and information provided by the FSCP staff. Affected mining areas were defined as the area within five meters of the delineated mine boundary.

Results

Home range area

Changes in ASGM activity from pre-mining (2005-2007) to 2014 (N=8) at the Fongoli site significantly affected the overall size of the Fongoli chimpanzee home range on several levels based on MCP estimates but for fewer KDE estimates (Table 3; Figure 3). Using a one-way analysis of variance (ANOVA), we found a significant decrease in 100% MCP range over the years at a $p<0.05$ [$F(1, 6) = 6.265$, $p = 0.0463$]. This significant decrease held when taking into account the number of observation days, $F(1, 6) = 7.9$, $p = 0.0307$] but was not seen in KDE estimates of home range, in total or adjusted values. Total MCP core range significantly increased over the 10 years [$F(1, 6) = 13.59$, $p = 0.0102$]; however, this trend was not significant when adjusting for number of observation days (Figure 4). KDE estimates also showed no significant change over time in core range area. There was a significant correlation between a larger home range and a larger core range when using the KDE areas adjusted for number of observation days [$F(1, 6) = 31.98$, $p = 0.00131$], but not for MCP area estimates. As the 100% MCP home range decreased over time, the core range size remained the same, resulting in a larger core to home range ratio. The MCP core to home range ratio ranged from 0.08 in 2009 to 0.24 in 2014. The KDE core to home range ratio ranged from 0.12 in 2009 to 0.19 in 2008.

Relative to the pre-mining time frame (years 2005-2007), the overall home range (both in MCP and KDE estimates) shifted westward in 2008-2011 then eastward from 2012-2014, reaching its eastern most expansion in 2014 (Figure 5). The centers of activity for each year, measured by the centroid of the 100% MCP home range polygon, had a mean distance of 1.0 km between them (±0.31 SD; Figure 6). The largest distances between two consecutive years occurred between 2008 and 2009 (1.4 km shift from west to east) and between 2011 and 2012 (1.3 km shift from east to west). The largest distance between two non-consecutive years was between 2009 (the most eastward centroid) and 2014 (the most westward centroid), which equaled 2.7 km. We found similar shifts when using centroids from the 95% KDE home range polygon.

We examined multiple factors hypothesized to be related to the size of the chimpanzees' home range. We found no correlation between the number of adult males, adult females, or total community size to changes in the overall size of the home range. There were significant positive correlations between number of adult males and core range size for the MCP and $MCP_{adjusted}$ estimates [$F(1, 6) = 8.481$, $p = 0.0269$, and $F(1, 6) = 6.997$, $p = 0.0383$], but there was no significant effect on core range size using the KDE method.

Seasonal changes

An ANOVA on home-range areas for each season using 100% MCP yielded significant differences [$F(2, 20) = 11.59$, $p = 0.0005$, $N = 32$] (Figure 7). A post-hoc Tukey HSD test showed significant differences in home-range area between early dry and late dry season and between early dry and wet seasons, at $\alpha < 0.05$. Largest home-range size occurred in the early dry season (mean = 52.5 km^2), followed by wet (mean = 37.2 km^2) and then late dry (mean = 28.8 km^2), although there was no significant difference between wet and late dry season range sizes. For all analyses of seasonal home-range comparisons, we removed the home-range estimate for the early dry season range in 2013 due to missing data.

Impacts of ASGM affected areas on home range

Oundoundou - Chimpanzee use of the Oundoundou mine differed with the changing level and extent of mining at the site (Figure 8). This mine was the first to appear in the Fongoli chimpanzees' home range and over the course of six years it expanded to become the largest mined area in their range. We had no observations of chimpanzees in this area prior to the onset of mining at Oundoundou in 2008, however, this may be an artifact of the limited number observations included in the pre-mining dataset. When mining began, the chimpanzees visiting the area on two days in 2008, nine days in 2009 and four days in 2010 (Table 4 and Figure 9). The mining area expanded in 2011 to include previously undisturbed land. Chimpanzees had only used this expanded area on two occasions prior to the mining expansion. However, after the mine expanded, the chimpanzees were at the site on four days in 2011 and one day in 2012. The mine expanded again in 2013, along the Oundoundou valley. This valley had seen regular chimpanzee use before this expansion from 2008 through 2011, appearing to serve as a chimpanzee travel corridor to the mining area and baobab patches beyond the mine. Once the mine expanded into the valley, the chimpanzees ended their use of this area, passing briefly through the valley on only one occasion in 2013 (Figure 10).

In analyzing the impact of the Oundoundou mine on chimpanzee ranging, we calculated the centroid of the core home range area in ArcMap and the distance to the affected area using the 'Near' function. Using a one-way ANOVA, we found no overall significant change in distance from the mine over the course of the study period; however, we did see a trend related to the footprint of the mining area (Figure 11 and 12). The core range shifts westward toward the Oundoundou mine from the pre-mining period through 2012. In 2013 and 2014, the center of the core range moved eastward away from the mine.

Day of the week and the associated presence/absence of miners had a significant impact on chimpanzee use of the Oundoundou mining area as the mine expanded in 2011 (Figure 13). In the earliest and smallest growth phase of the mine, between 2008 and 2010, the apes visited the area nearly equally on all days (mining days vs. miners' days off). In 2011 and 2012, the chimpanzees visited the mining area both when miners were present (5/7 weekdays) or absent (2/7 weekdays) but were more likely to visit the area when the miners were absent [$X^2(1,130) = 6.03$, $p=0.014$].

To examine daily temporal patterns of use at the Oundoundou mine, we increase the sample size of visits to chimpanzee locations within 150 m from the mine (a distance where Oundoundou's mining activity can still be detected aurally but does not overlap with other mining areas). Over the study period we saw a shift from chimpanzee activity near the mine during the daytime in early and expanded mining periods to primarily evening use in late mining (Figure 14).

Kerouani - The onset of mining in the Kerouani area, similar to the Oundoundou mining area, correlates with increased chimpanzee use of the mined area (Table 5). Mining began in the Kerouani stream valley in 2011, continued at the same location in 2012, and then expanded to the east in 2013 and 2014. At the 2011 and 2012 mining site, we found very little chimpanzee use of the site prior to mining (one 10-minute visit in 2009, see Figure 15). Once mining began, apes visited the area on three occasions totaling over seven hours. The area of expansion in 2013 and 2014 had been used regularly by the chimpanzees prior to mining (43 daily visits from 2008 through 2012, averaging 10.8 hours per year). The apes increased their visitation rate once the mining began, visiting the area on 20 separate days in two years and averaging 21.9 hours per year at the site.

Fongoli chimpanzees visited the Kerouani mining site throughout the year, except in the month of October. After mining began in 2011, they visited the area most frequently during the late dry season and early in the wet season. Before mining began, visits to the site were most common in the early morning hours; however, after mining began, visits took place throughout the day, peaking in late afternoon (Figure 16). Visits to the mine occurred most frequently on Wednesdays and there was no difference in visitation relative to miners' workdays or days off (Figure 17).

Coucoukoto - Over the study period, the chimpanzees visited the Coucoukoto mine on eight occasions, all within the dry season from February through May (Table 6). The highest rates of visitation, for both daily visits and hourly visits when adjusted for observation effort, were recorded in 2009 (Figure 18). Mining activity began at the

Coucoukoto site in 2012. The chimpanzees visited the mined area on only one occasion in 2012 for a period of six hours. No visits were recorded in 2013 and 2014. When the chimpanzees were within 150 m of the mine, they spent the most of their time there during the middle of the day, which coincided with a midday resting period [$F(1, 2382) = 13.761$, $p = 0.0002$]. The group was closest to the mine on Fridays. There was no significant interaction between year and hour of the day on the chimpanzees' distance to the Coucoukoto mine.

Wolokoto – Mining activity began in 2011 at the Wolokoto site. We did not see a relationship between visits to the mine and increasing mining activity for the Wolokoto site. The Wolokoto mining area was visited on five days during the study period (Table 7): one day in February 2009, three in March 2010, and one in March 2013. The five visits to the mine showed no relationship to traditional mining workdays. The distance of chimpanzee locations within 500 m of the mining area did not change significantly over the study period. There was also no evidence that chimpanzees avoided this mining area temporally, either on a 24hr scale or weekly, at any distance to the mine.

Djendji - Chimpanzees visited the Djendji mining areas on three occasions, once before mining and two after mining had begun. The initial visit to the location prior to mining occurred in November 2010, and mining at this location began in 2013. Chimpanzees traveled once through the area that was to be later mined. In June of 2014, the chimpanzees passed by and inspected the mined area. This encounter occurred on a Monday morning when no people were working at the mine (Table 8).

The second occurrence of chimpanzee nearing an ASGM site near Djendji was on a Tuesday in April of 2014. A company using machinery and security runs this mine. The apes passed by the area and vocalized at two men near the mine, large parked trucks and the security guards. Before walking to the Gambia River the chimpanzee drank water near the mining site.

Ngari Camp - The Ngari camp mine is located on the periphery of the chimpanzees' home range. Chimpanzees never entered into the Ngari mining area; however, they did, on one occasion, range close enough to the mine that they could see and hear mining activity (approximately 25 m). On this occasion, in March 2013, the group approached the mining area at 1530h. The group was calm and did not vocalize when a truck leaving the mining camp area passed by them. The chimpanzees remained in the area for the remainder of the evening, raiding a beehive for honey from a nearby baobab tree and nesting approximately 100 m from the mine camp. The following morning the group left the area before 800h. Over the course of the study period there was no significant difference in distance to this mining area.

Niakora - As with the Ngari camp, this mining site is located at the edge of the chimpanzees' home range. Chimpanzees were within 10m of the Niakora mining area on one occasion, in December 2011 at 1740h in the evening. They spent 20 minutes traveling past the mined area and vocalized at a truck that drove by. The chimpanzees nested about 300 m from the mine and left the area the following morning. By 800h they were over 500 m from the mine. This is the only observation during the study period of the chimpanzees within 500 m of the Niakora mine.

Discussion

As ASGM activities increased at the Fongoli field site, chimpanzees increased visitation of areas with low levels of mining, appearing to tolerate low-level disturbances from mining. Higher levels of mining activity, however, disrupted chimpanzee travel routes and correlated with shifts in their home range away from the largest mine. Over the 10-year study period, from 2005 through 2014, we found that the Fongoli chimpanzees shifted their ranging patterns toward the largest mining site, Oundoundou, when mining activity was low (2008 through 2010), then shifted away from the site as mining expanded and increased in intensity (2011 through 2014).

Overall, the chimpanzees' range became less dispersed and concentrated closer to areas of more frequent use toward the center of the range. Using the 100% MCP estimation method, we found a significant decrease in home range size over the study period. The MCP estimation method uses the outermost chimpanzee locations to create an all-inclusive polygon, including some areas that were never used by the chimpanzees. The decrease in 100% MCP area over the study period was a result of reduced used the western periphery of their range in the later years of the study period. When using the KDE method, which relies on measuring the probability of encountering a chimpanzee at each location and excludes areas of that are not used, we did not see a significant change in the size of the home or core ranges. Rather, the range shifted from west to east, utilizing different geographic spaces at different intensities during the study. The home range shift was determined by the differences in the centroid of the home range for each year across the study period. The difference between the westernmost centroid in 2009 (low level mining) to the easternmost centroid in 2014 (late level mining) was equal to 2.7 km or 18% of the east-west length of the home range. The largest difference between two consecutive years (2008 to 2009) was equal to 10% of the home range length, shifting the center of the home range eastward toward the Oundoundou mine during its early phase of mining. The second largest shift in the home range occurred between 2011 and 2012 (9% of the home range length) as the center of the range moved 1.3 km to the east, away from the Oundoundou mine and correlating with the largest expansion phase of the mine.

To assess other possible contributing variables to changes in home range activity, we included analyses on community demographics with respect to home range. Previous research has indicated that home range size may be related to the number of males or females in the community (male correlation -Lehmann and Boesch, 2003; female correlation – Nakamura et al., 2012). We did not find that either the number of males nor females contributed to changes in total home range. Lehmann and Boesch (2003) suggest that the number of males in the community is directly related to intrinsic male fighting power and therefore an important factor in determining the size of a home range when home range defense from neighboring groups is necessary. However, the Fongoli home range averages 64.6 km^2 annually, and the community is very cohesive, averaging 15 individuals in a party. Such a large home range with a cohesive community does not create a defendable territory (Lowen and Dunbar, 1994), therefore nullifying the importance of male fighting power in relation to home range size and supporting the lack of correlation between increased males and home range size found at Fongoli.

Impacts of artisanal small-scale gold mining

The Fongoli chimpanzees have been shown to be tolerant, but wary, of human activity and disturbances (Lindshield et al., 2017). Our results supported this and indicated that lower levels of artisanal mining activities were not only tolerated but also attracted the Fongoli chimpanzee community; however, extensive mining resulted in mine avoidance. The greatest impact of mining on ranging behavior was seen at the Oundoundou mine. Although use of the mining area was infrequent overall, initial attraction to, and later avoidance of, the Oundoundou mine was evident when comparing use of the mined area to use of the area prior to mining. The chimpanzees used the mining area in the early and expanded phases of mining at Oundoundou more often than they did prior to mining, and they did not use the area in 2013 and 2014 after the full expansion of mining in the late phase, despite higher rates of use of the area from 2008 through 2012.

Possible explanations for the fluctuating use of Oundoundou over the study period and through the phases of mining include: 1. the level of hunting activity over the study period (see Chapter 4), 2. the ranging behavior of a neighboring chimpanzee group, and 3. changes in leadership within the Fongoli chimpanzee community. Looking into each of these possibilities, we did not find any evidence to support their influence on the changes in the chimpanzees ranging near or at the Oundoundou mine. First, the likelihood that hunting impacted the Fongoli chimpanzees' ranging activity in Oundoundou is low. Had hunting activity been a deterrent during pre-mining years, we would have expected that the chimpanzees would have avoided the Oundoundou area in the early morning and late evening when hunting activity was most prevalent. Instead, we found that the apes used the Oundoundou area (approximately 150 m from the mining site) only during these times of day (Figure 14). Additionally, hunting activity did not increase later in the study period when chimpanzee use of Oundoundou mine decreased. Secondly, preliminary data of a neighboring chimpanzee community (Sandoval-Green and Pruetz, in prep) suggest no effect on the ranging behavior of the Fongoli chimpanzee community. Rather, the nesting locations of the neighboring community showed no encroachment into the Fongoli home range but indicated movement away from their range over the course of our study period.

The third possible explanation relates to leadership among the Fongoli chimpanzee community and alpha males' impacts on ranging. Changes in alpha males over the study period correlate roughly with the shifts in ranging behavior. Foudouko and Yopogon were the alpha males in 2005-2007 and 2007-2008, respectively. During their leadership there is no evidence that the group used the Oundoundou mining area. Once Lupin became alpha in 2008 the group shifted into the Oundoundou area and continued to use it until 2012. David then became alpha, which coincided with the group's shift further east toward the village of Djendji. However, correlation here does not imply causation. At the Gombe field site, while some individuals were more likely to influence the ranging patterns of the community than others, these individuals were not always the alpha male (Goodall, 1986). Non-alpha individuals have also been observed influencing ranging at Fongoli as well (Pruetz, unpublished data). Further study is needed to assess if Fongoli's alpha males have any impact on daily travel paths, feeding site selection, and travel initiation.

The increased use of the Fongoli chimpanzees' range to the east was likely due to the cumulative disturbance caused by extensive mining at Oundoundou and from the smaller mines along Kerouani waterways. While the Kerouani, Wolokoto, and Coucoukoto mining areas did not include extensive and contiguous mining activity and their individual contributions to the mining population was much less than that of Oundoundou (F. Camara, pers. comm.), collectively they contributed to the human presence in the Fongoli-Kerouani confluence. It is possible that the shifting home range eastward, away from the mining activity, was indicative of the overall impact of the mining activity in the general Fongoli-Kerouani confluence area.

A particular area of interest affected by the expansion of the Oundoundou mine, and perhaps the most compelling evidence of the mining impact, was the chimpanzees' travel corridor to Oundoundou through the valley and along the tributary of the Fongoli stream. In 2008 through 2010, the chimpanzees used this valley to travel to areas located alongside the Oundoundou mine in the early and late dry season. The mined area had a relatively small footprint and population at this time. During this early mining period, the chimpanzees traveled to the mine despite associated human activity. As the mine expanded along the tributary valley in 2011, the Fongoli chimpanzees' travel route to Oundoundou and to feeding patches beyond the mine was replaced with mining trenches and machinery. To reach the areas previously used, the community began taking a northerly route towards the village of Fongoli before turning south again toward Oundoundou. Although our dataset is missing data from the early dry season for 2013, only one observation of the chimpanzees passing five meters from the eastern side of the mine area was recorded during the late dry season. In 2014, the chimpanzees bypassed the mining area completely and used a northerly route to access the previously used areas north and west of Oundoundou. The expansion of the Oundoundou mine into the chimpanzee travel corridor illustrates the deleterious impacts of extraction industries. Although mining has a small footprint on the landscape, the unfortunate placement of mining pits and infrastructure can have a significant impact on the wildlife using the landscape.

Although resilient to some changes within their environment, chimpanzees can only tolerate and withstand a certain level of disturbance within their home range before it shifts their behavior. Here, we have established that ASGM activity can have an impact on ranging behavior by blocking travel routes and changing habitat use. Ultimately, shifts in behavior and ranging may impact population dynamics by lowering reproduction and survival rates. This is a particular concern for West African chimpanzees as their population is in dramatic decline (Kühl et al., 2017), and as the region continues to experience increased resource extraction and human population growth. Detection of behavioral changes, before demographic impacts are realized, should be used as an early warning sign of the potential negative impacts of ASGM.

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Table 5.1 Comparison of home range estimates using minimum convex polygon (MCP) or kernel density estimator (KDE) methods of 12 chimpanzee communities arranged by habitat and region.

Habitat	Region	Site	Home Range MCP (KDE) in km^2	Source
Forest	East Africa	Kibale - Kanyawara	14.9 - 37.8	Chapman and Wrangham, 1993; Wilson et al. 2010
		Kibale - Ngogo	28.8 - 35.2	Mitani et al. 2010
		Budongo, Sonso	6.8 - 9.7 (6.9)	Newton-Fisher, 2003; Fawcett 2000
		Gombe - Kasakela	5.4-12	Williams et al. 2002
		Mahale - K	6.2	Hasegawa, 1987
		Mahale - M	19.4 - 27.4	Hasegawa, 1987; Nakamura et al. 2012
	West Africa	Tai - North	13.9 - 26.9 (3.1)	Boesch and Boesch-Achermann 2000, Lehmann and Boesch 2003, Herbinger et al. 2001
		Tai - Middle	12.1 (7.5)	Herbinger et al. 2001
		Tai - South	26.5 (9.5)	Herbinger et al. 2001
Savanna	East Africa	Semliki-Toro*	72.1	Samson and Hunt, 2012
		Kasakati*	122-124 (from sightings and tracks)	Izawa, 1970
		Ugalla*	400-500 (from nest density)	Ogawa et al., 2007
	West Africa	Mt. Assirik*	278-333 (from nest density)	Baldwin et al., 1982
		Mt. Assirik*	37.4-72.1	Baldwin et al., 1982
		Fongoli - Average	64.6 (35.34)	This study
		Fongoli - Cumulative	110 (38.72)	This study

* = unhabituated communities

Table 5.2 Monthly and annual totals of days of data used in analyses.

	Pre-Mining Dataset											
	2005	2006	2007	Total	2008	2009	2010	2011	2012	2013	2014	TOTAL
Jan	0	3	1	4	11	2	10	17	9	0	5	58
Feb	0	15	0	15	5	13	20	4	18	2	2	79
Mar	0	13	0	13	10	18	18	13	14	20	16	120
Apr	0	0	0	0	0	19	4	12	14	23	19	91
May	0	11	0	11	17	16	21	7	0	13	5	90
Jun	1	8	22	24	17	23	1	10	15	16	16	122
Jul	5	4	12	16	20	14	3	14	20	16	9	112
Aug	5	4	7	9	9	3	19	6	16	22	18	102
Sep	0	0	4	4	15	4	12	16	14	12	15	92
Oct	0	0	12	12	8	13	26	14	20	15	14	122
Nov	0	0	7	7	17	13	21	15	10	0	17	100
Dec	0	4	5	8	11	16	5	16	5	0	9	70
TOTAL	11	62	70	123	140	154	160	144	155	139	145	1160

Table 5.3 Home range (100% MCP and 95% KDE) and core range (50% MCP and 50% KDE) estimates for each year of the study period in km2. Each of the MCP and KDE estimates are also shown adjusted for the number of days of observation for each year (km2/day).

	100% MCP*	50% MCP*	95% KDE	50% KDE	100% MCP_{adj}*	50% MCP_{adj}	95% KDE_{adj}	50% KDE_{adj}	Days _obs
pre-mining	72.89	7.90	26.72	4.11	0.59	0.06	0.22	0.03	123
2008	65.81	8.07	37.15	6.41	0.47	0.06	0.27	0.05	140
2009	76.99	5.84	37.99	5.00	0.50	0.04	0.25	0.03	154
2010	64.74	7.50	32.31	4.58	0.40	0.05	0.20	0.03	160
2011	56.18	8.76	40.82	6.75	0.39	0.06	0.28	0.05	144
2012	61.59	9.96	33.17	4.48	0.40	0.06	0.21	0.03	155
2013	57.15	11.49	33.98	5.97	0.41	0.08	0.24	0.04	139
2014	61.48	14.06	40.59	7.19	0.42	0.10	0.28	0.05	145
All Years	110.39	9.97	38.72	4.15					1160
Mean	64.60	9.20	35.34	5.56					145
St. Dev	7.26	4.75	2.59	1.16					

* indicates estimates that either increased or decreased significantly from pre-mining through 2014

Table 5.4 Summary statistics of chimpanzee use of the Oundoundou mining area prior to mining and during mining for each level of mining expansion. Seasons when the chimpanzees visited the mine area as early dry (edry), late dry (ldry) or wet season.

Mining Level	Use	Year	# Days	Hours	Season	Prop. of Obs. days	Prop. of Obs. hours
Early Mining Area	Prior	2005-7	0	0	-	0	0
	During	2008	2	4.25	edry	0.014	0.004
		2009	9	19.42	edry; ldry; wet	0.058	0.013
		2010	4	6.83	edry; ldry	0.025	0.004
Mine Expansion	Prior	2005-7	0	0	-	0	0
		2008	0	0	-	0	0
		2009	2	1.58	edry; ldry	0.013	0.001
	During	2011	4	7.50	edry	0.028	0.005
		2012	1	3.33	edry	0.006	0.002
Late Mining Expansion	Prior	2005-7	0	0	-	0	0
		2008	1	1.92	edry	0.007	0.002
		2009	11	9.00	edry; ldry	0.071	0.006
		2010	2	1.92	edry; ldry	0.013	0.001
		2011	3	3.00	edry	0.021	0.002
		2012	0	0	-	0	0
	During	2013	1	0.08	ldry	0.007	7.0E-05
		2014	0	0	-	0	0

Table 5.5 Summary statistics for chimpanzee use of the Kerouani mining area prior to and during mining at the two levels of mining expansion. Seasons when the chimpanzees visited the mine area as early dry (edry), late dry (ldry) or wet season.

Mining Level	Use	Year	# Days	Hours	Season	Prop. of obs. days	Prop. of obs. hours
Mine Expansion	Prior	2005-7	0	0	-	0	0
		2008	0	0	-	0	0
		2009	1	0.17	ldry	0.006	0.000
		2010	0	0.00	-	0	0
	During	2011	3	7.08	ldry	0.021	0.005
		2012	0	0	-	0	0
Late Mining	Prior	2005-7	7	10.92	All	0.057	0.015
		2008	7	1.67	All	0.050	0.002
		2009	14	18.42	All	0.091	0.012
		2010	6	8.92	All	0.038	0.006
		2011	2	4.00	edry; ldry	0.014	0.003
		2012	7	11.00	All	0.045	0.007
	During	2013	13	25.92	ldry; wet	0.094	0.022
		2014	7	17.92	All	0.048	0.014

Table 5.6 Summary statistics for chimpanzees ranging at the Coucoukoto mining area over the course of the study period. Seasons when the chimpanzees visited the mine area as early dry (edry), late dry (ldry) or wet season.

	Year	# Days	Hours	Season	Prop. of obs. days	Prop.of obs. hours
Prior to Mining	2005-2007	1	0.083	ldry	0.008	0
	2008	0	0		0	0
	2009	3	7	edry; ldry	0.019	0.005
	2010	2	1	edry; ldry	0.013	0.001
	2011	1	0.083	ldry	0.007	0
During Mining	2012	1	6.42	ldry	0.006	0.004
	2013	0	0		0	0
	2014	0	0		0	0

Table 5.7 Summary statistics for chimpanzees ranging inside or less than 5 m from the edge of the Wolokoto mine over the course of the study period. Seasons when the chimpanzees visited the mine area as early dry (edry), late dry (ldry) or wet season.

	Year	# Days	Hours	During months	Prop. of obs. days	Prop.of obs. hours
Prior to Mining	2009	1	0.167	edry	0.006	0.000
	2010	4	1.333	edry; ldry	0.025	0.001
	2011	0	0.000		0.000	0.000
	2012	0	0.000		0.000	0.000
During Mining	2013	1	0.333	edry	0.007	0.000
	2014	0	0.000		0.000	0.000

Table 5.8 Data book entry from June 30, 2014 detailing the chimpanzees' visit to the Djendji mining site.

6/30/2014 Monday, Observer: JP	
915	Mike (adult male) traveling. Pass/approaching *djurra* [ASGM mining area]. Jumkin (adult male) and others look in the mining pit. Siberut (adult male) continues west.
920	Mike is out of sight, but vigilant, at the *djurra*. Multiple chimpanzees approach and examine the [dirt] mounds and shelter at the *djurra*, including Tumbo (adult female), Lupin (adult male), Jumkin, Cy (juvenile), Dawson (adolescent male) and Mike.
925	Mike is traveling in the *djurra*.
By 930 the chimpanzees have traveled 150 m away from the mined area.	

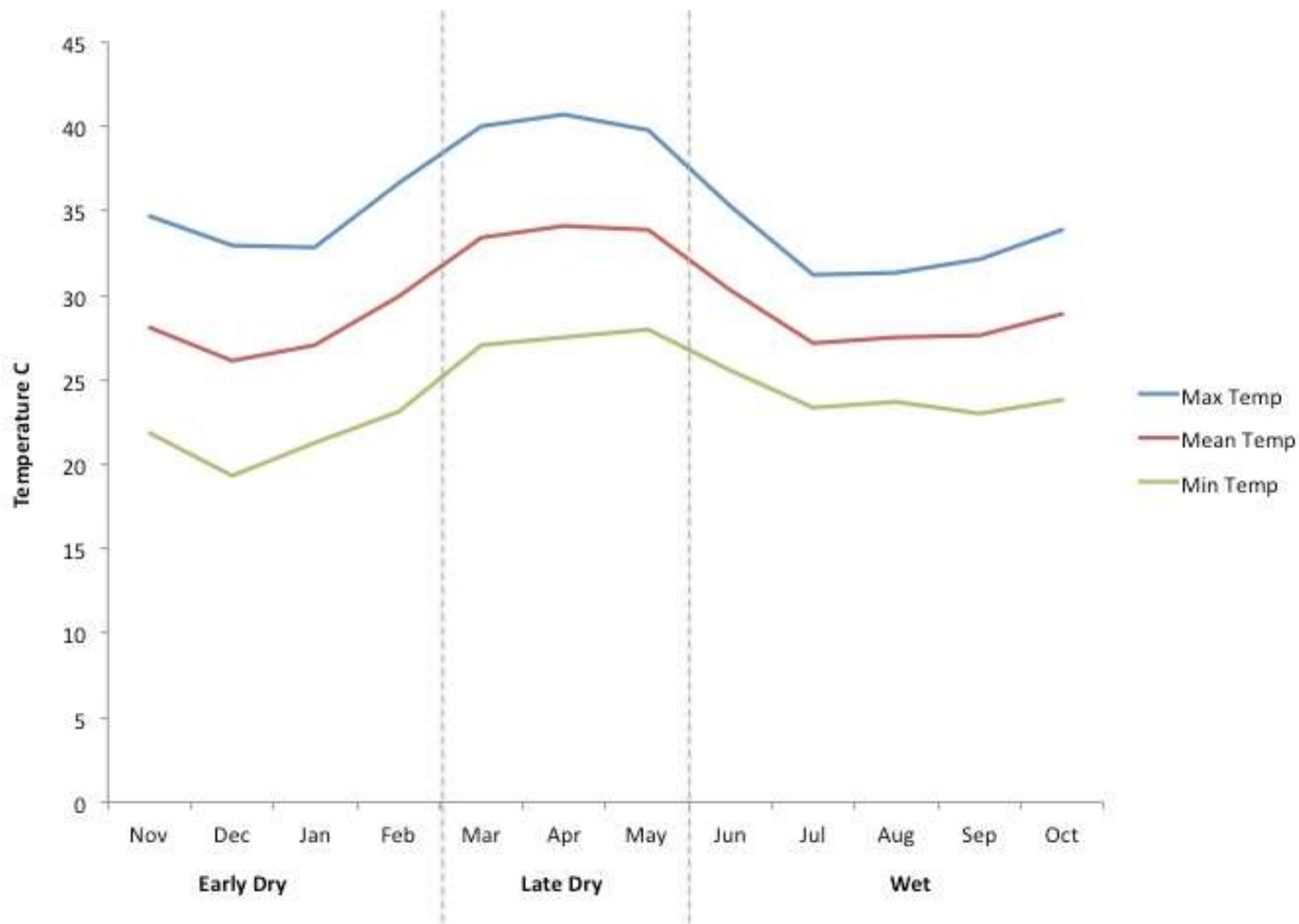

Figure 5.1 Average monthly temperatures for the early dry, late dry, and wet seasons in southeastern Senegal (NOAA, 2017)

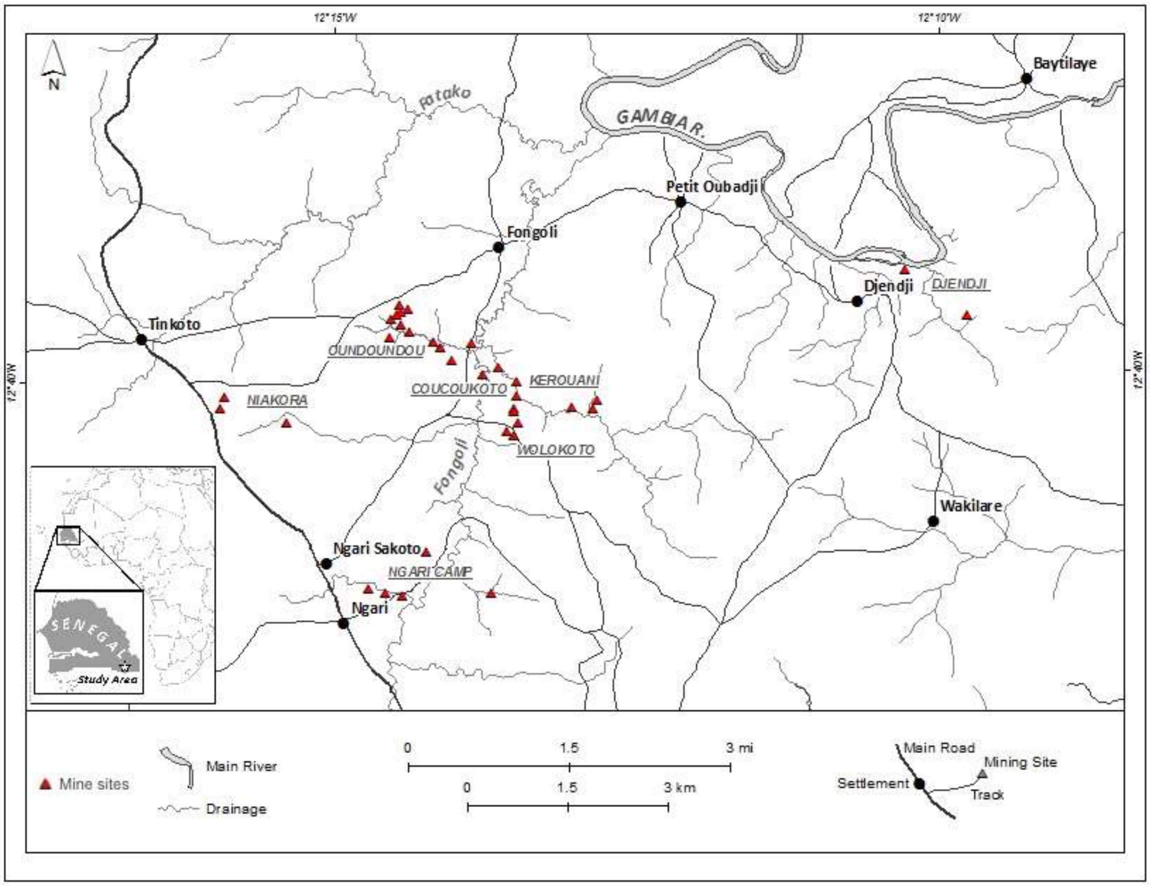

Figure 5.2 Fongoli study site with full extent of mining locations in 2014.

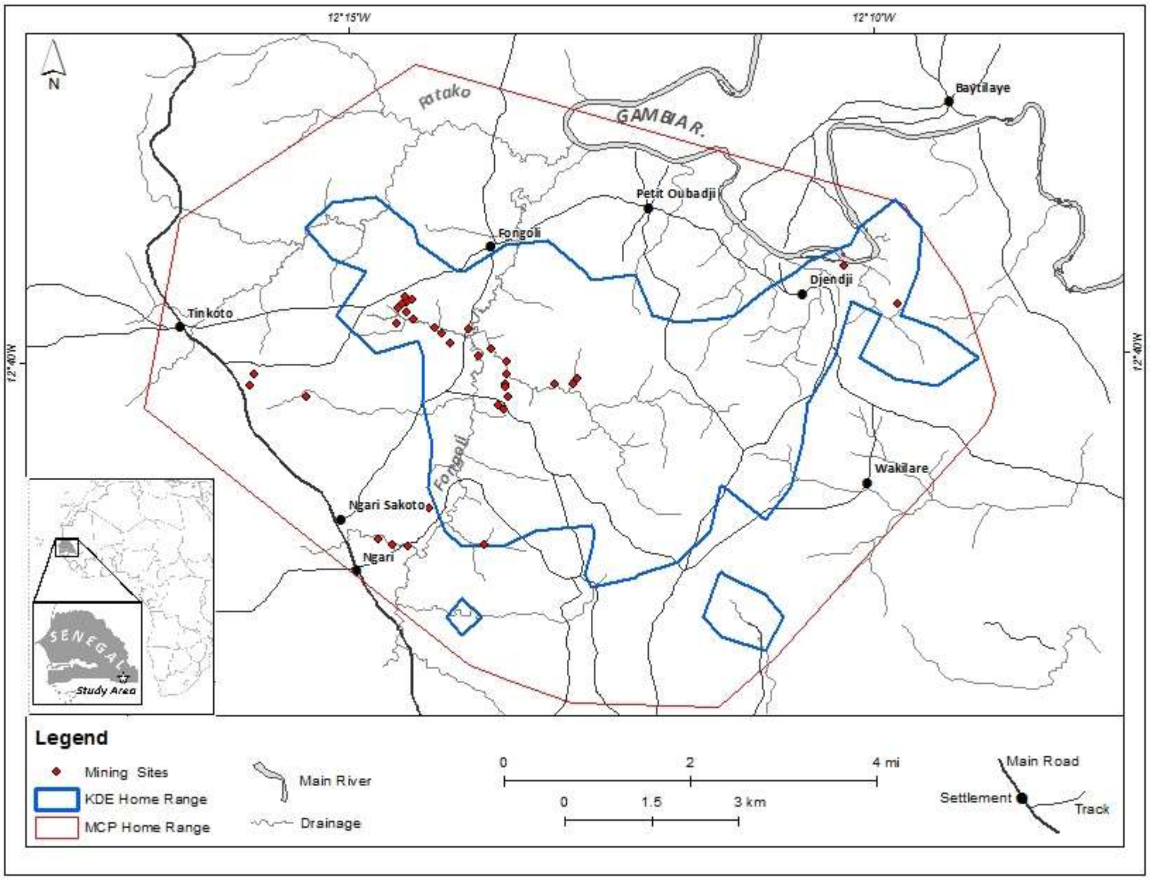

Figure 5.3 Ten-year home range estimates (100% MCP in red and 95% KDE in blue) for the Fongoli chimpanzees 2005-2014.

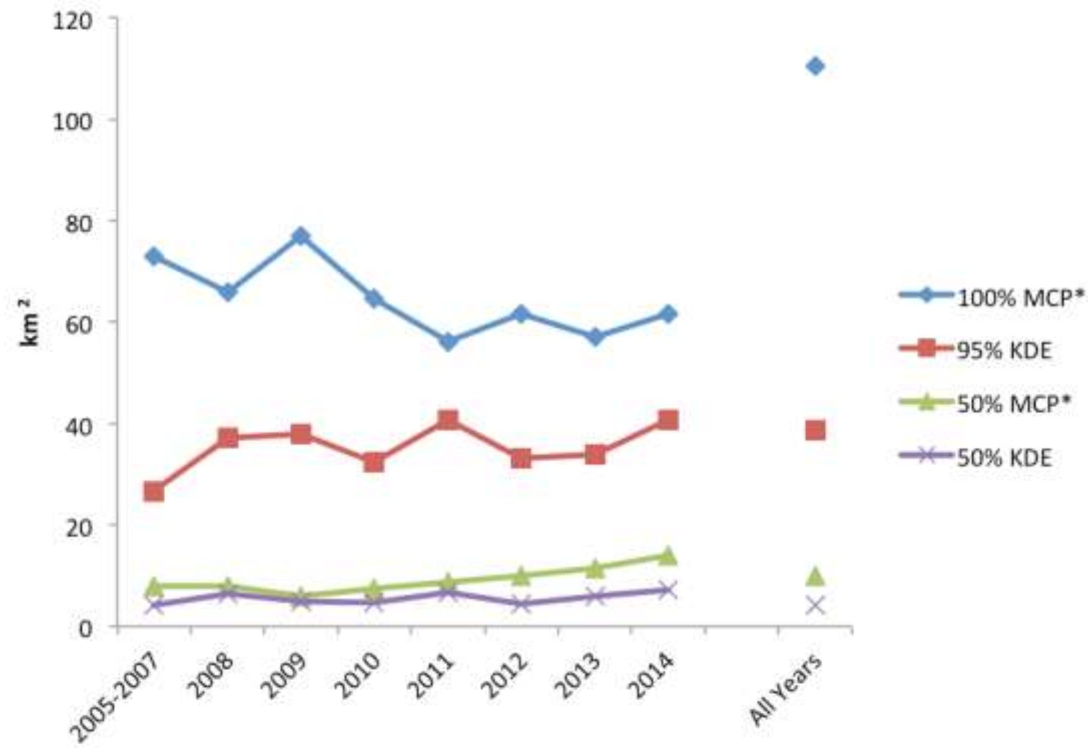

Figure 5.4 Home range areas in km^2 from pre-mining in 2005-2007 to latest mining level in 2014, including total range for all years.

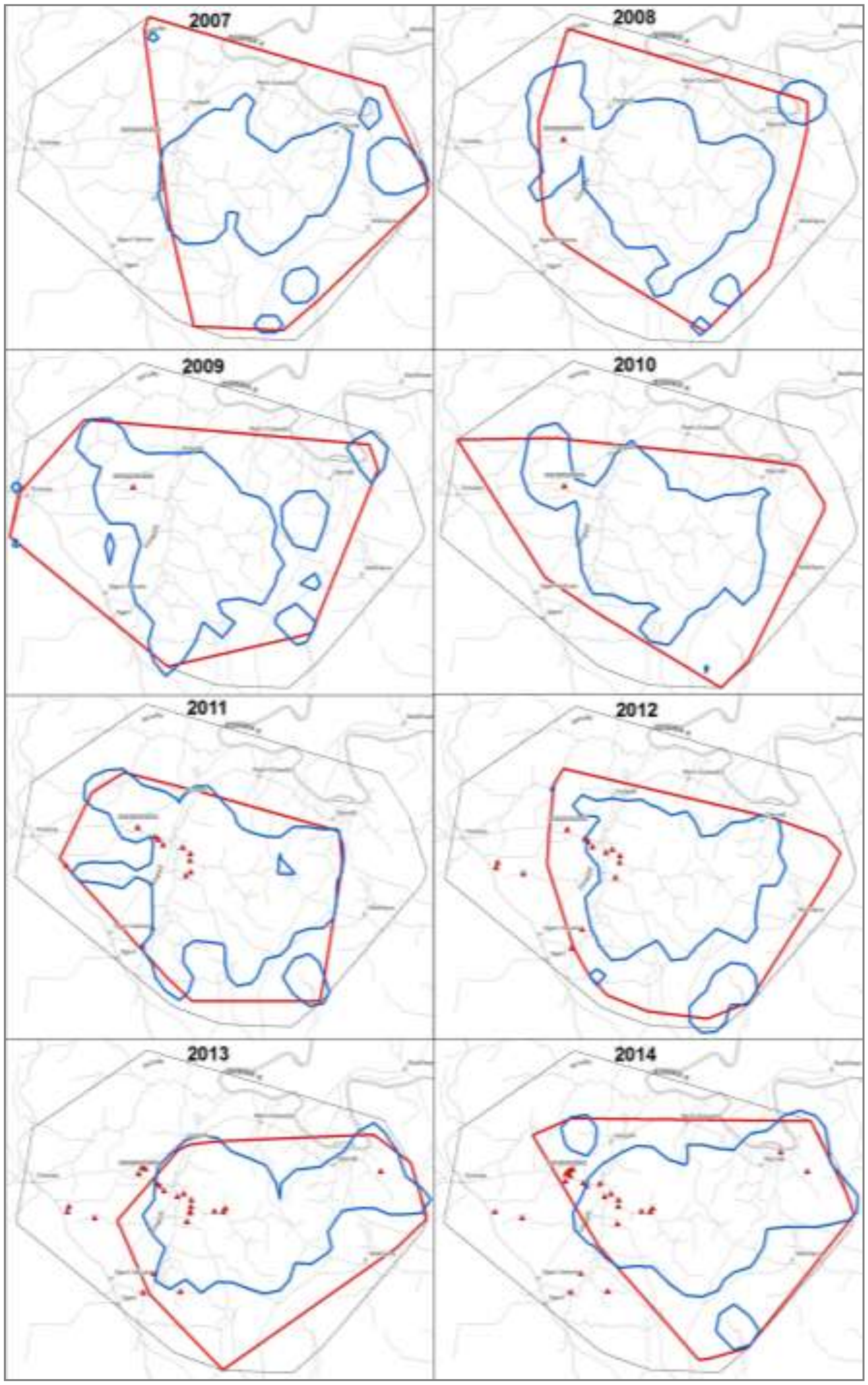

Figure 5.5 Home range estimates for each year of the study period using MCP and KDE estimator techniques, where 2007 includes all pre-mining data from 2005-2007. Red line = 100 MCP, blue line = 95 KDE, black line = cumulative 100 MCP for all years, and red triangles = mining sites

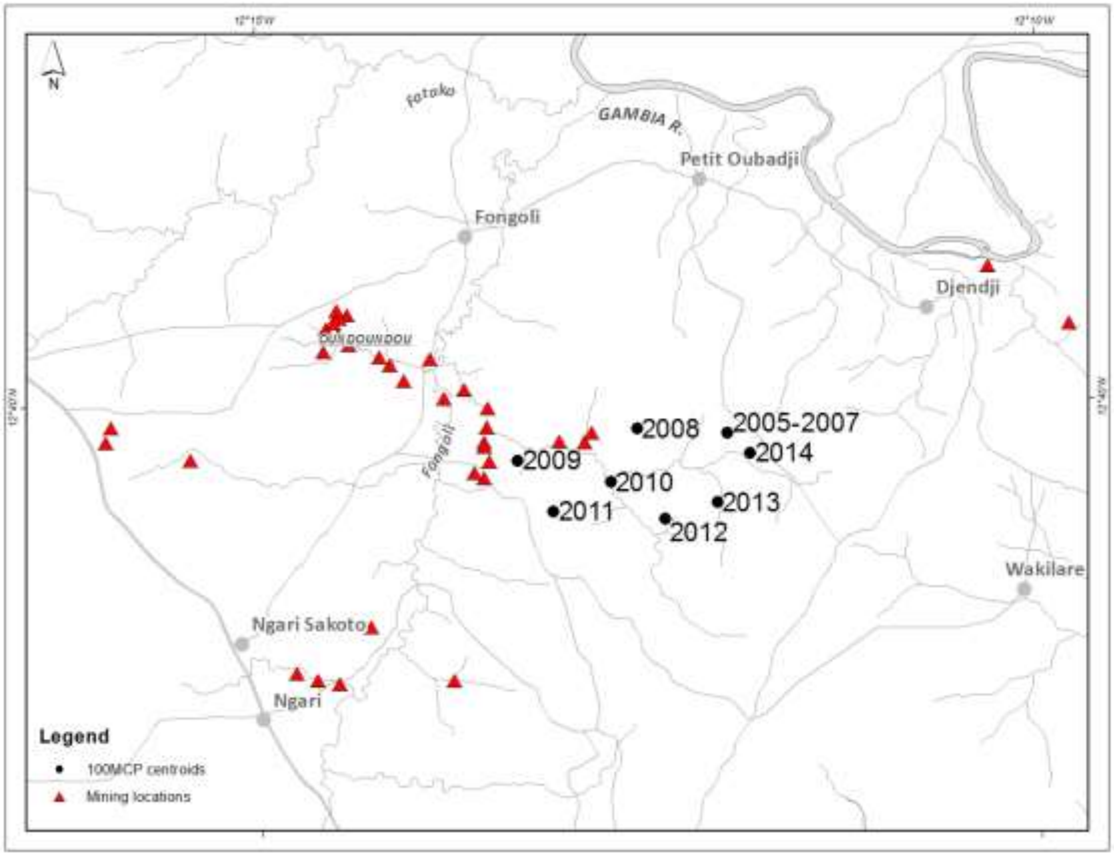

Figure 5.6 Centroids of 100MCP home range from pre-mining (2005-2007) through 2014.

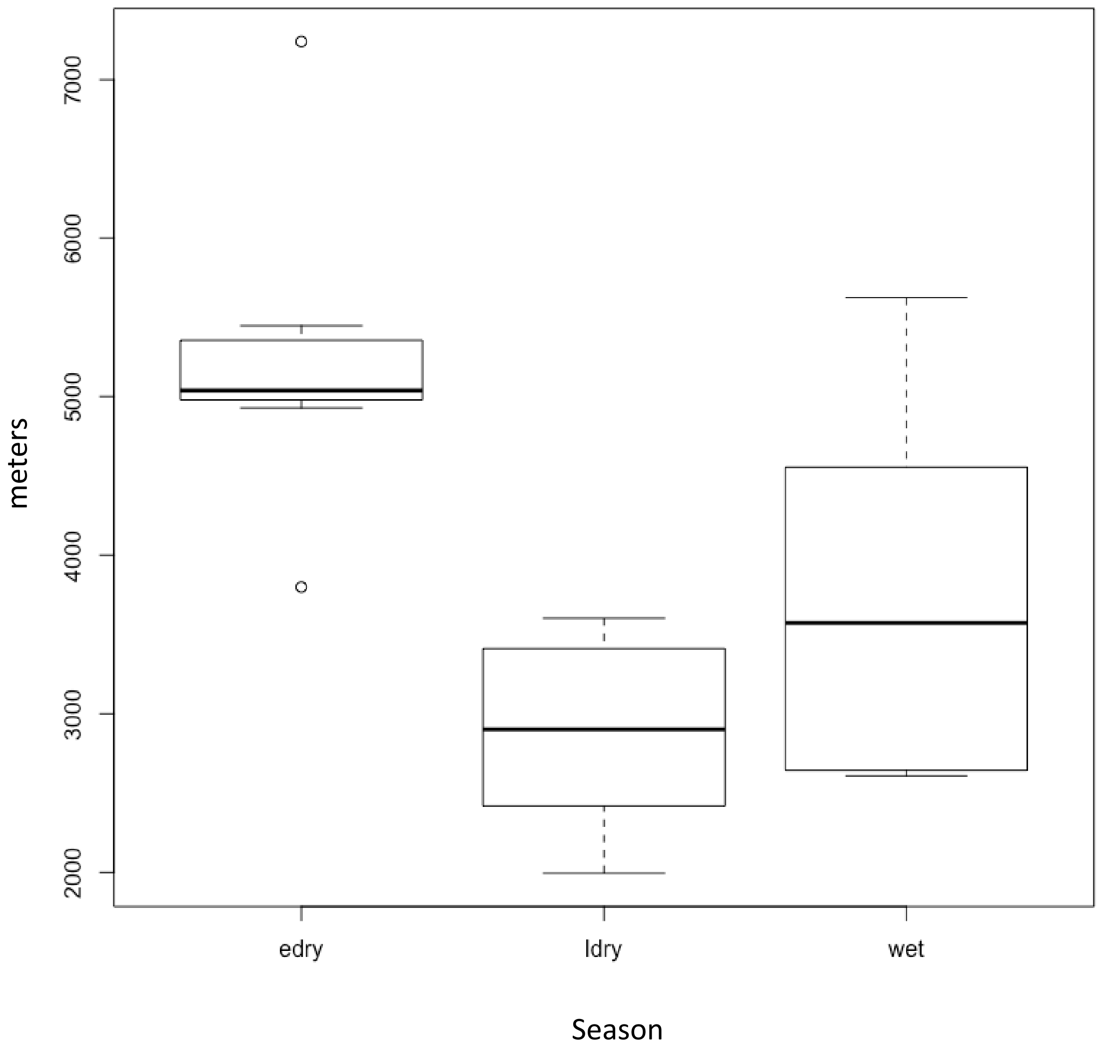

Figure 5.7 Boxplot showing seasonal home range estimates using 100% MCP for the early dry, late dry and wet seasons.

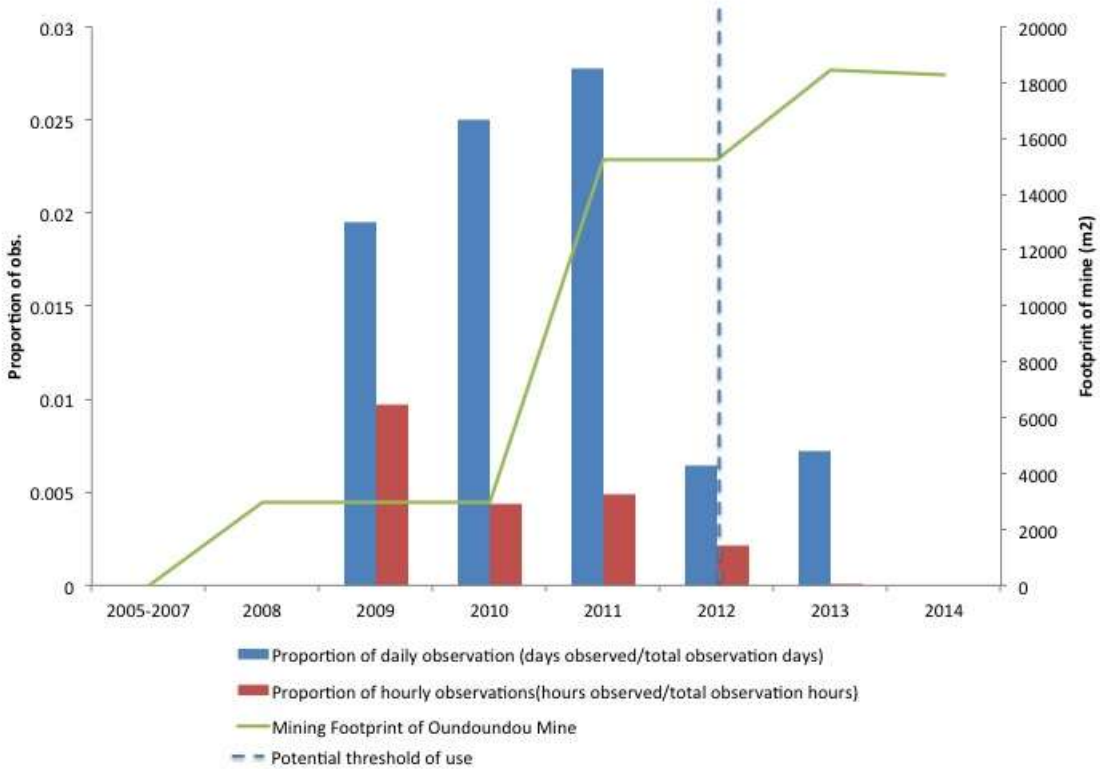

Figure 5.8 Proportion of daily and hour observations of chimpanzee locations at the Oundoundou mine relative to the accumulated footprint of the mine area for the course of the study period.

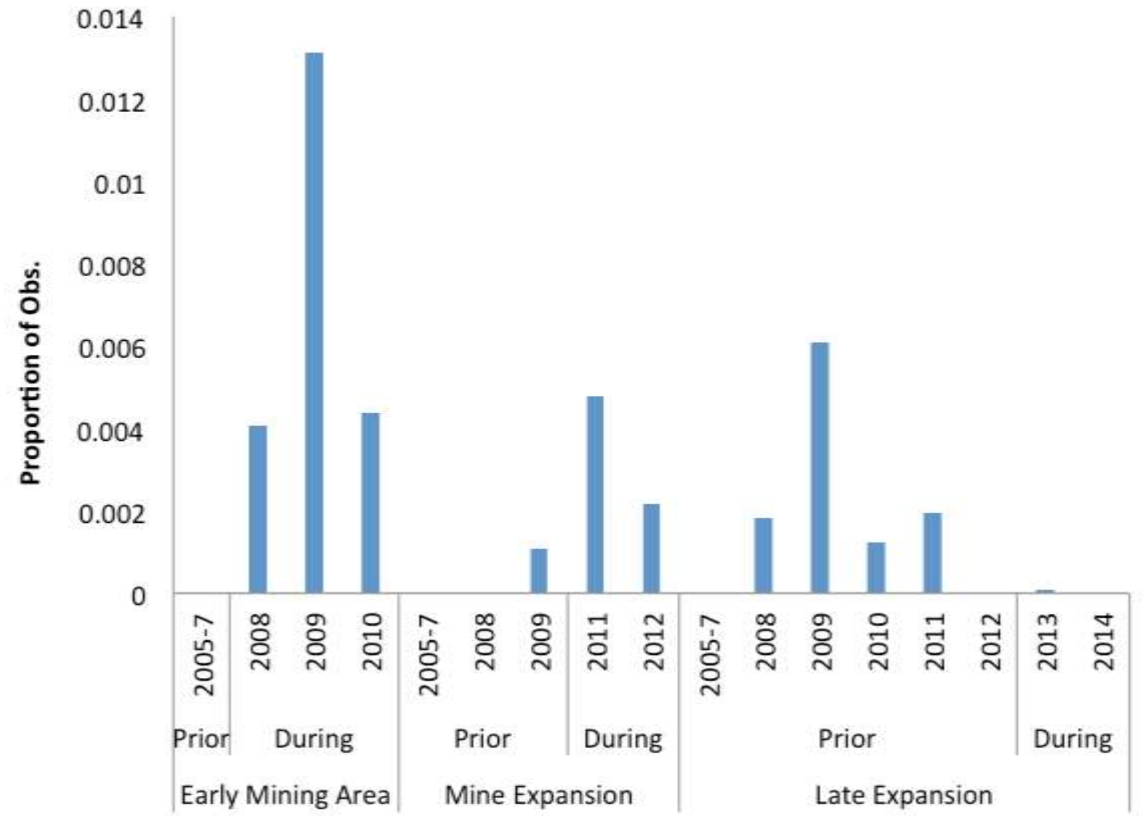

Figure 5.9 Use of the Oundoundou mining area prior to and during mining activities at the three levels of mining expansion.

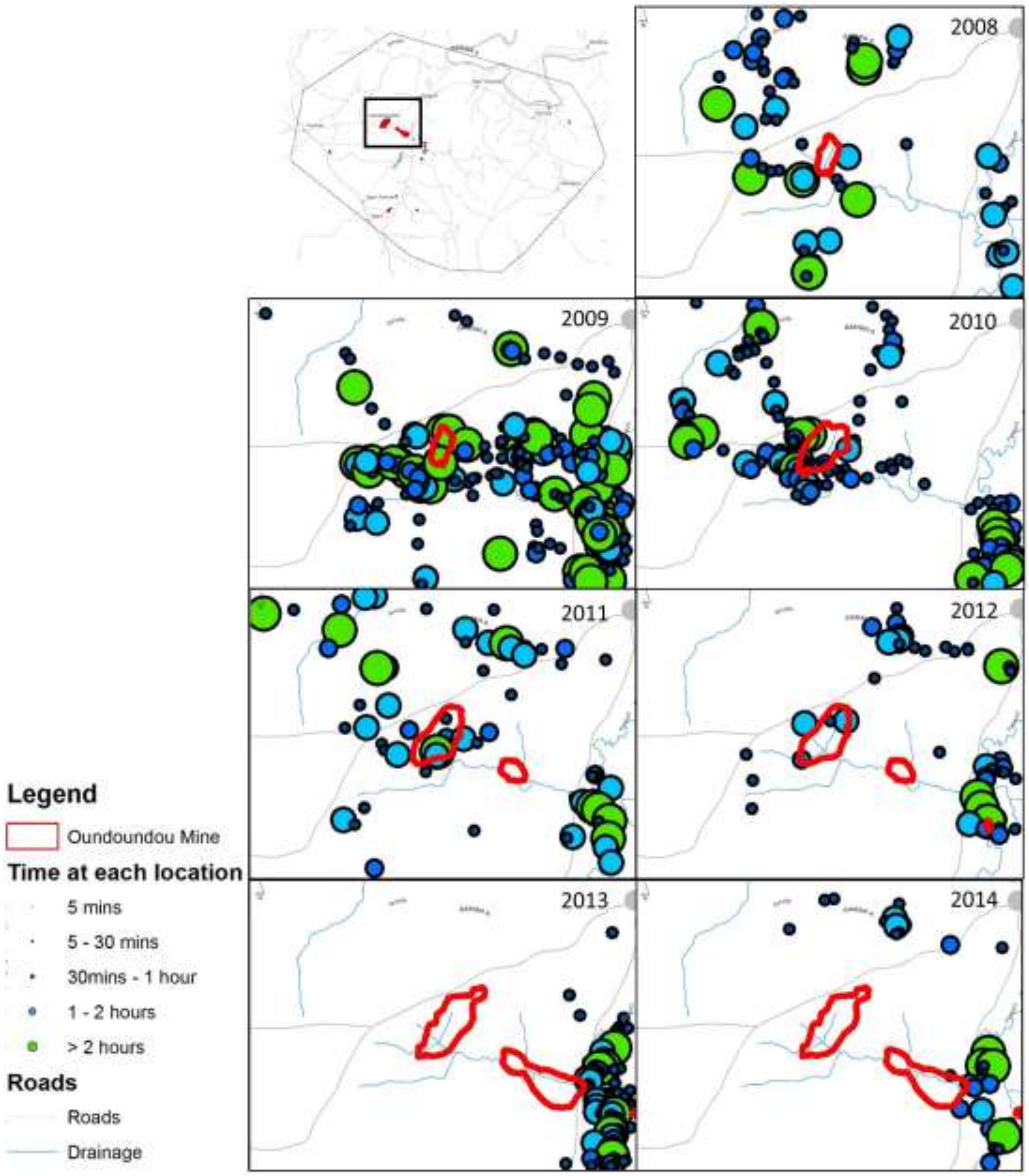

Figure 5.10 Chimpanzee locations at the Oundoundou mine for each year of mining across the study period.

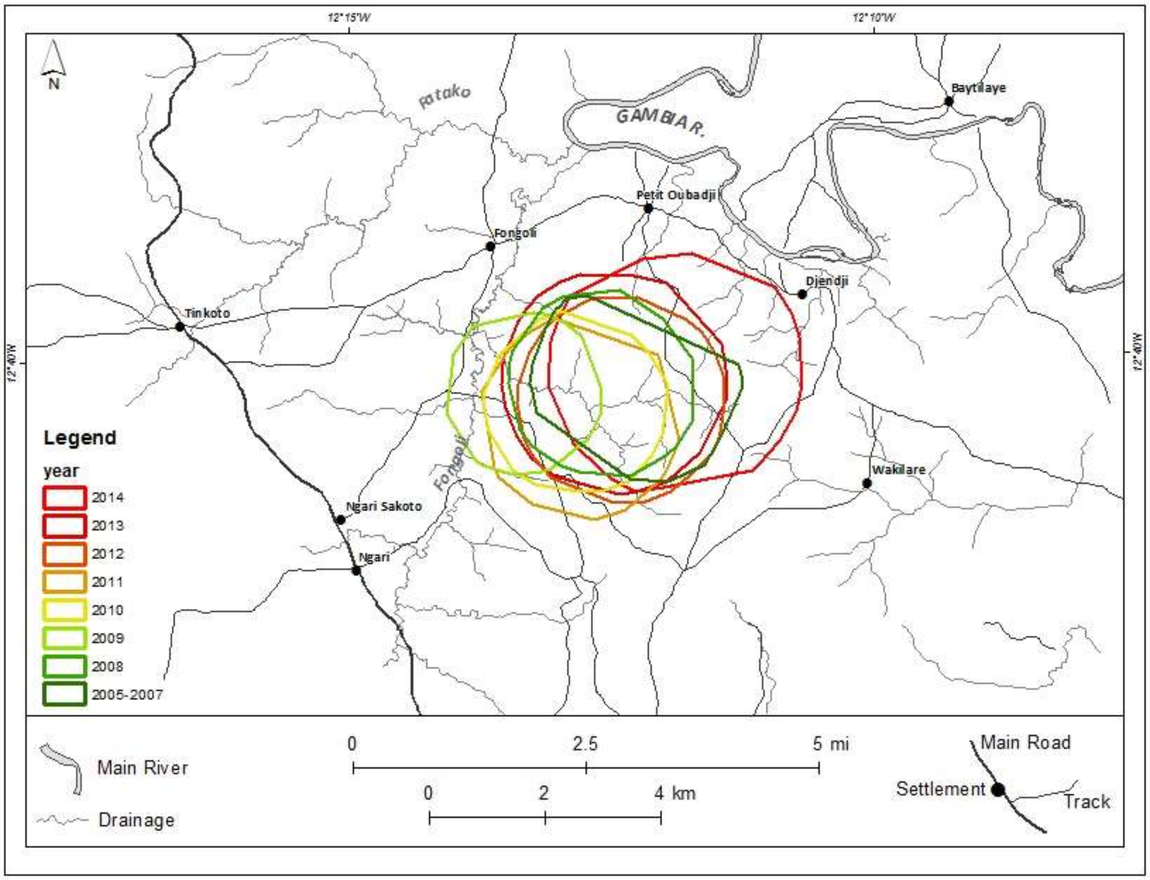

Figure 5.11 Core area estimates using the 50% MCP estimator method for pre-mining year and each following year of the study period.

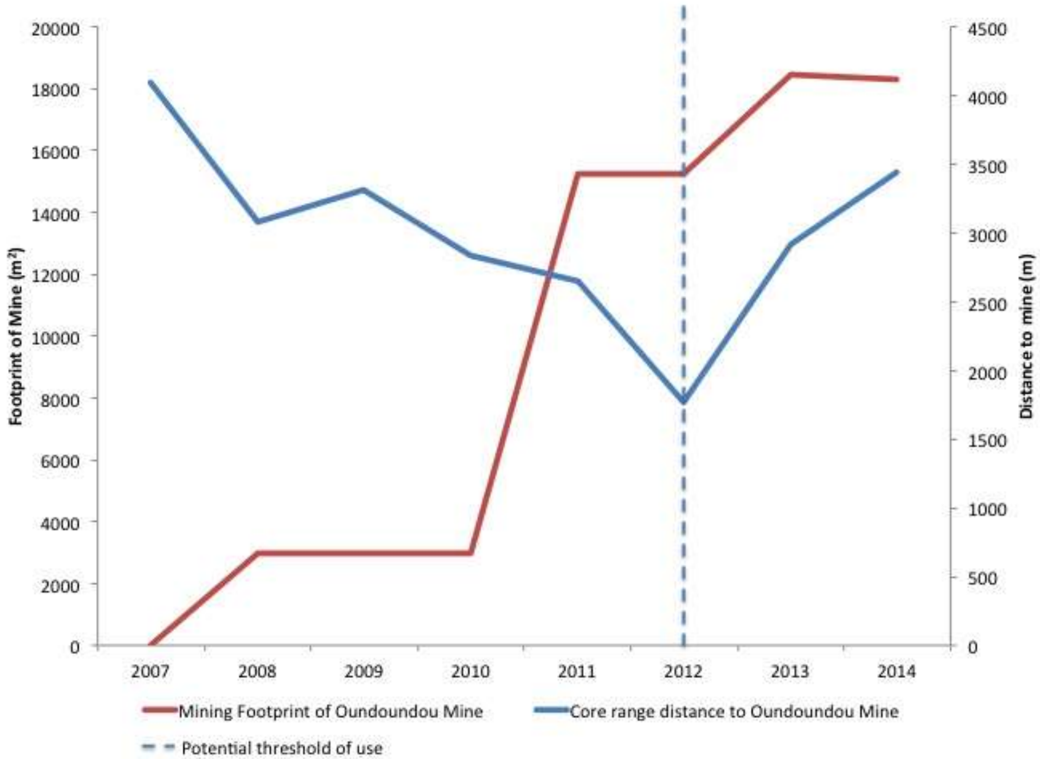

Figure 5.12 Distance of the core range to Oundoundou mine for each year of the study period and relative to the expanding footprint of the mine.

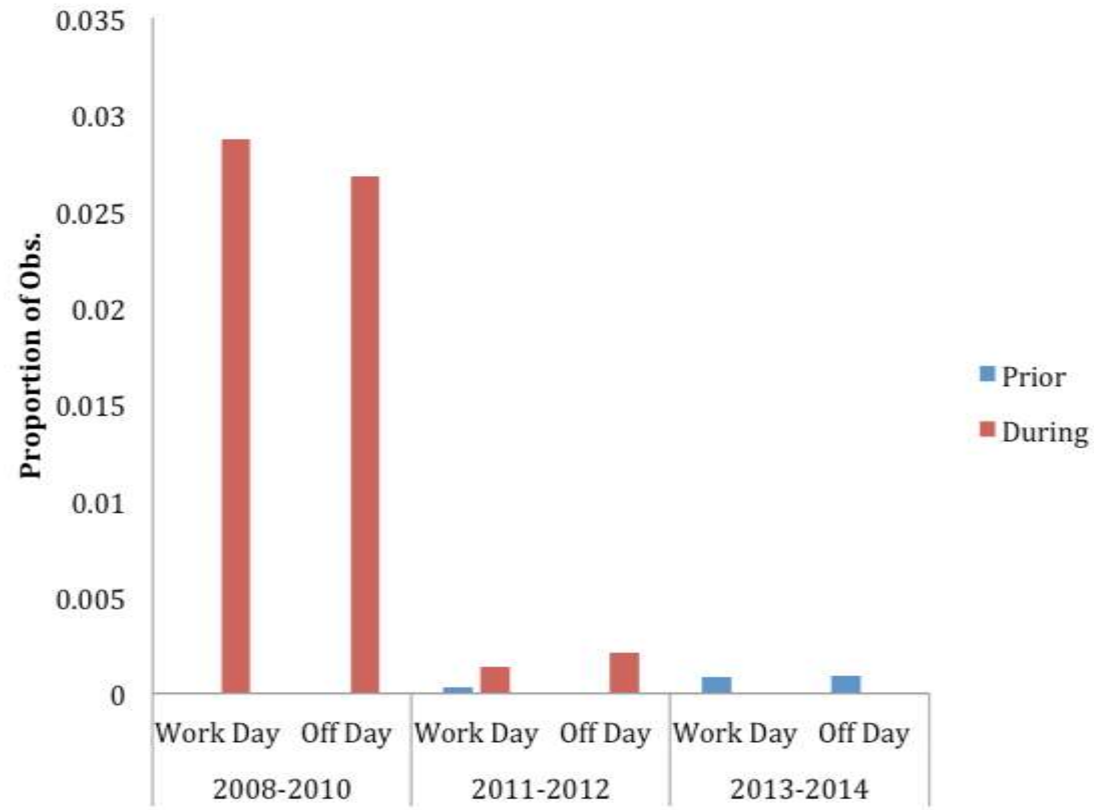

Figure 5.13 Chimpanzee use of the Oundoundou mining area with respect to miners' traditional work days and days off. Blue columns indicate chimpanzee use of the mining area prior to the onset of gold mining and red columns indicate use during active mining at the same location for the given years.

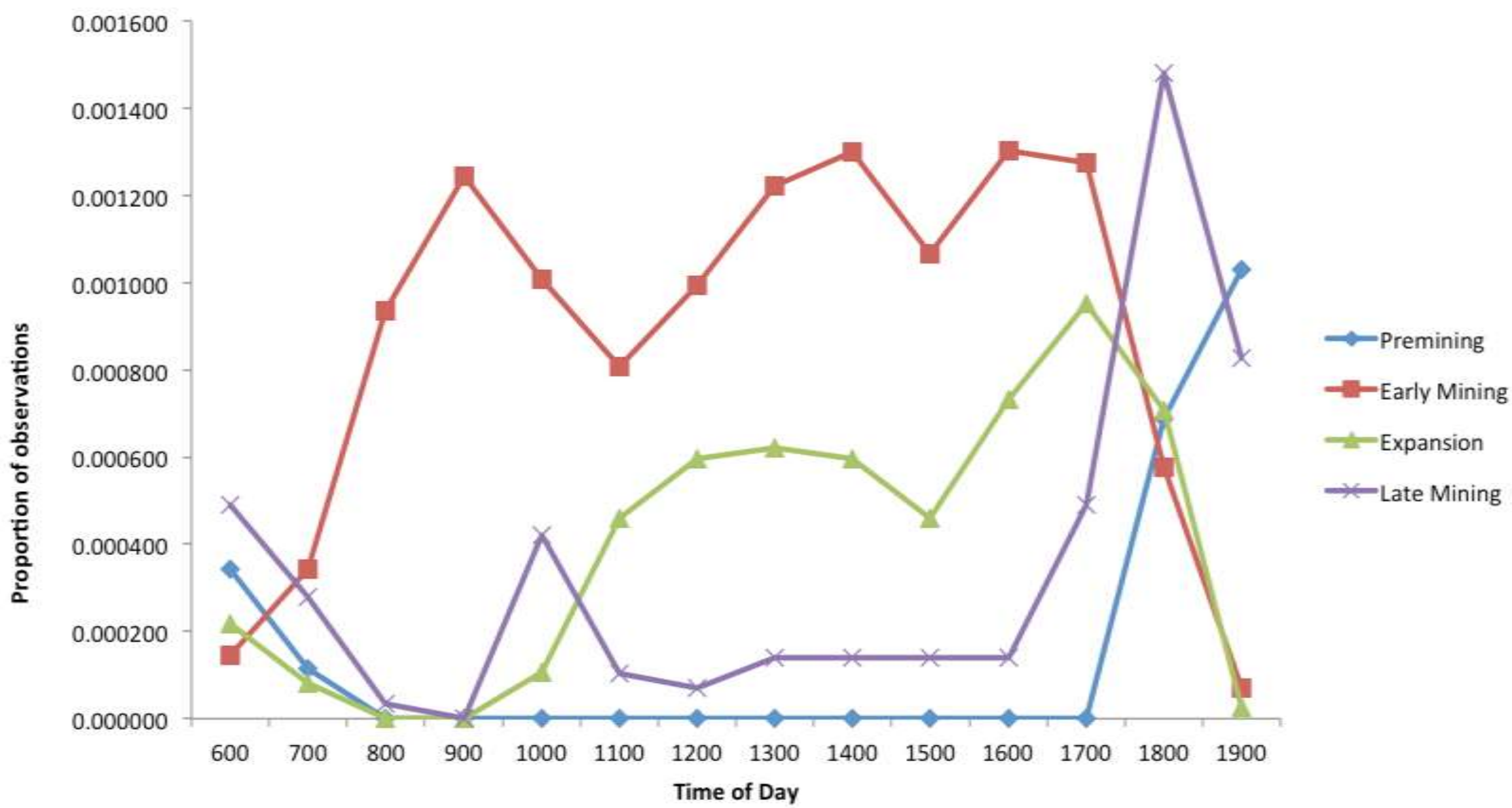

Figure 5.14 Proportion of chimpanzee observations within 150 m of the Oundoundou mine during the daytime during each level of mining.

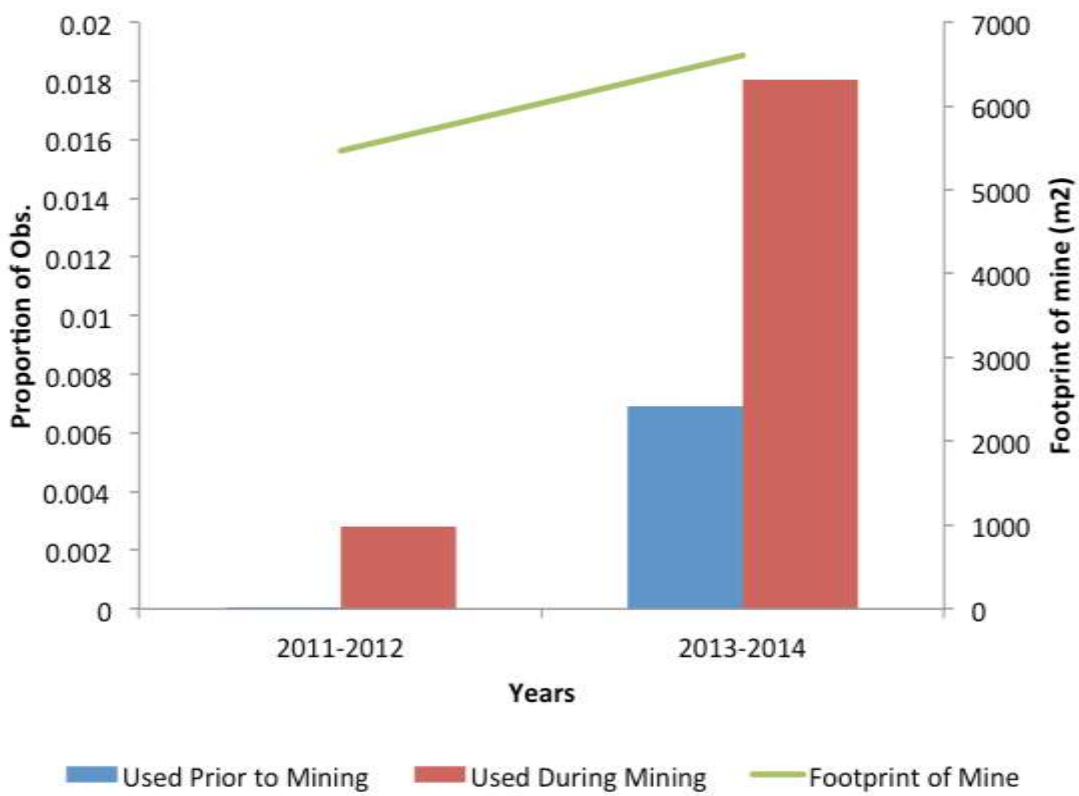

Figure 5.15 Proportion of daily observations of chimpanzee locations at the Kerouani mining area prior to and during mining activity.

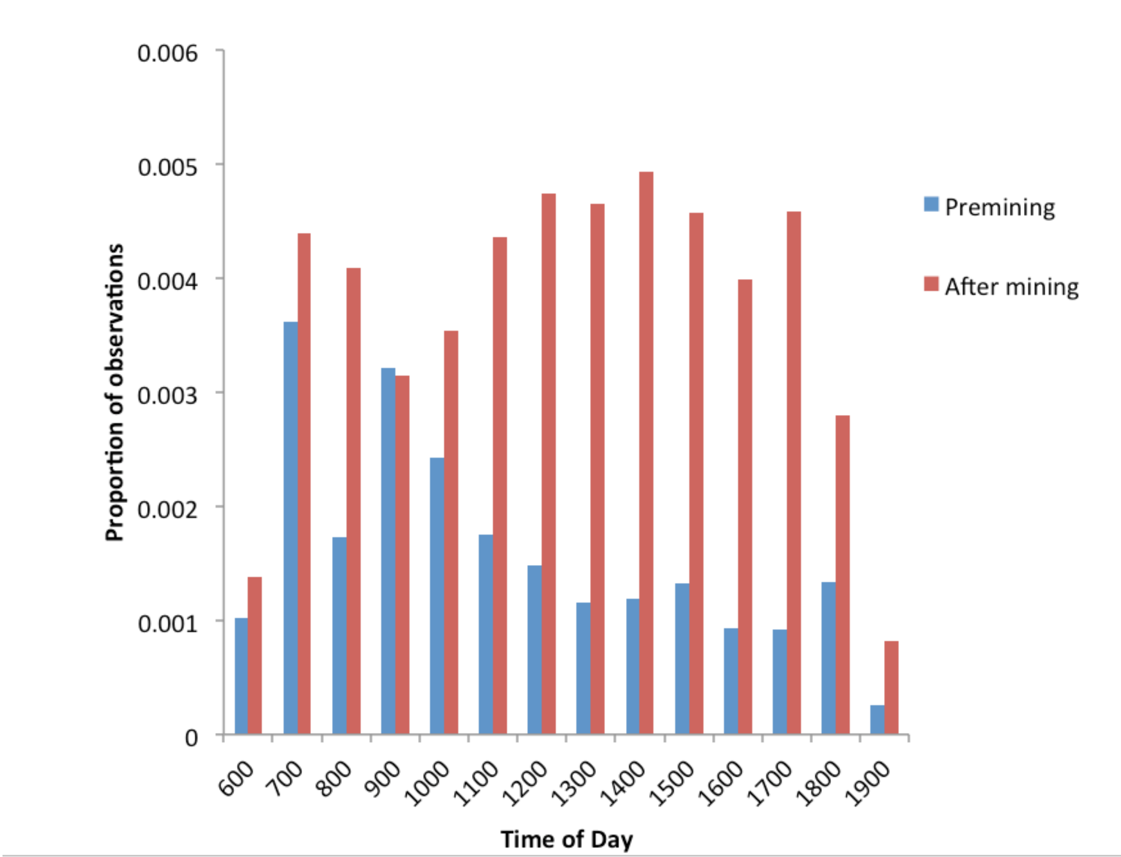

Figure 5.16 Chimpanzee activity at the Kerouani mine during the daytime.

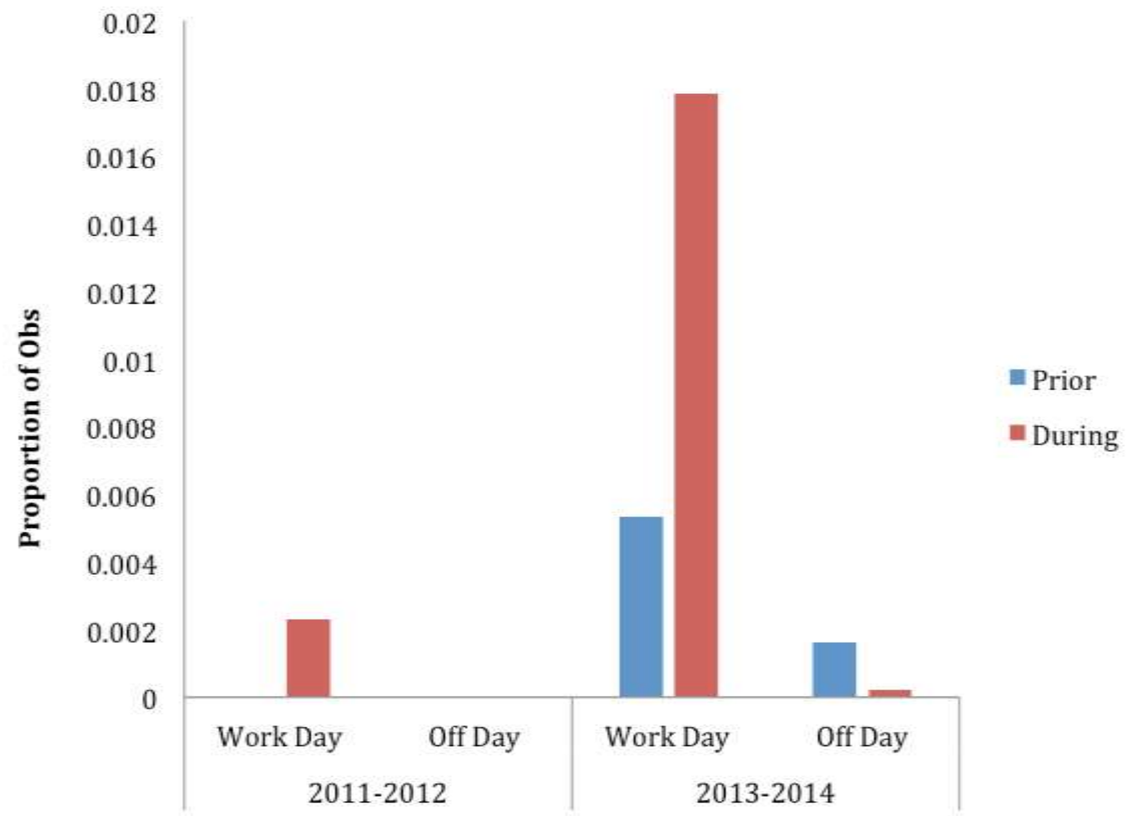

Figure 5.17 Chimpanzees use of the Kerouani mining area with respect to miners' traditional work days and days off.

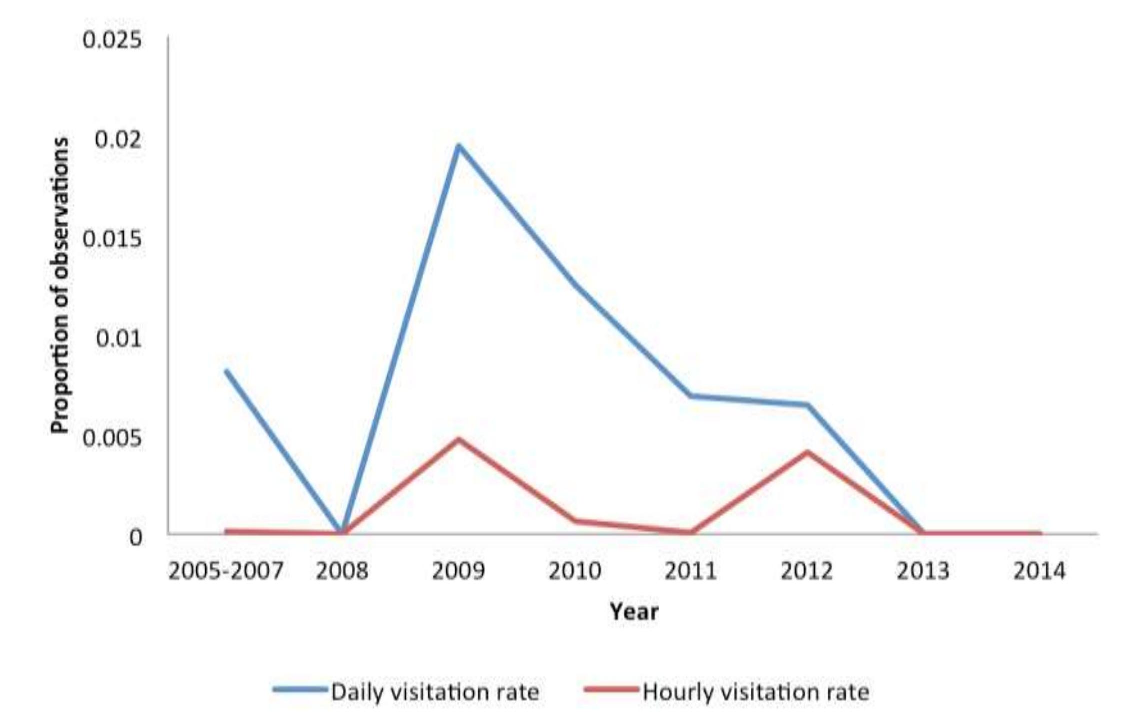

Figure 5.18 Proportion of daily and hour observations of chimpanzee locations at the Coucoukoto mining area.

CHAPTER VI

IMPACTS OF ARTISANAL SMALL-SCALE GOLD MINING ON CHIMPANZEE HABITAT USE AND BEHAVIOR

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Abstract

Human activity can degrade habitat through agricultural and extractive industries. Primates show resiliency by adjusting their behaviors to anthropogenic disturbance when not directly threatened. In this study we investigate the behavioral impacts of an anthropogenic disturbance, artisanal and small-scale gold mining (ASGM), on chimpanzee habitat selection in southeastern Senegal. ASGM is a widespread practice but little quantitative data has been collected on its impacts on wildlife behavior and habitat use. We used logistic regression resource selection functions (RSFs) to assess critical factors of chimpanzee habitat selection at the Fongoli study site in Senegal over a 10-year study period, during the establishment of seven new ASGM sites. RSF models were performed at temporal scales (seasonally and over four growth phases of the mines) and spatial scales (home range and ASGM sites). For each RSF model, we included landscape, anthropogenic, and temporal variables. The effect of ASGM on habitat selection was complex on both spatial and temporal scales. At the home range level, our models demonstrate a decrease in preferred woodland habitat use as mining activity intensified and an increase in savanna use. On a finer spatial scale, the chimpanzees used ASGM sites more during active mining periods relative to use prior to the onset of mining. At the mines, they used human disturbed areas to feed, rest and socialize. The chimpanzees inspected the mine areas and drank water from mining pits. Evidence from the largest mine, however, suggested that mine attraction is limited to low intensity mining..

Introduction

In recent years there has been increasing interest in the study of human–wildlife systems, particularly to understand the dynamic relationship between anthropogenic activity and its impacts on wildlife (Woodroffe et al., 2005; Liu et al., 2007; McKinney, 2015; Dirzo et al., 2014; Ceballos et al., 2017). In the case of non-human primates (hereafter primates), many populations have suffered as the human population and destructive activities have increased (Estrada et al., 2016; Goossens et al., 2006; Campbell et al., 2008). Human activity can degrade habitat through traditional practices of harvesting or hunting and through agricultural and extractive industries (Estrada et al., 2016; Hockings and Humle, 2009). In some instances, however, when not directly threatened primates have showed resiliency by adjusting their behavioral responses (Hockings et al., 2015; McCarthy et al., 2016; McLennan, 2013; Yamakoshi, 2011; Reynolds, 2005). For example, at a socioecological level, the chimpanzees (*Pan troglodytes verus*) in Bossou, Guinea increased their cohesiveness when crop raiding in agricultural fields (Hockings et al., 2012). At a spatiotemporal level, chimpanzees (*P.t. schweinfurthii*) in Uganda altered their behavior from crop raiding in the daytime to nighttime when there was less risk of human encounters (McLennan, 2013). Primates also illustrate flexibility in habitat and resource selection in human-altered landscapes, particularly in dietary shifts, as illustrated in the previous example from Uganda and others (Nowak and Lee, 2013). In Madagascar, rapid deforestation and habitat degradation has altered the behavior of the Sahamalaza sportive lemurs (*Lepilemur sahamalazensis*), who changed their resting patterns with respect to forest fragments (Seiler et al., 2013).

At the Fongoli field site, chimpanzees have been observed adjusting their feeding behavior when foraging in the presence of humans near villages and gold mining sites (Lindshield et al., 2017). Here, the apes exhibited anti-predator responses when foraging alongside anthropogenic landmarks by increasing food intake and feeding times. Anthropogenic disturbances not create behavioral changes but also can change the availability of food, water, tree cover, and other resources important in wildlife resource selection. For the chimpanzees in Senegal, the availability of food, water, and shade are paramount to habitat selection and vary seasonally (Pruetz and Bertolani, 2009). In the early dry season, when temperatures are cooler and water is widely available, the Fongoli apes are less constricted to closed-canopy areas and permanent water sources. Rather, their ranging behavior is often guided by the availability of ripening baobab fruits (Lindshield, 2014). During the heat of the late dry season, the Fongoli chimpanzees use habitats near water sources with closed-canopy cover to decrease the prevalence of dehydration and heat stress (Pruetz and Bertolani, 2009). At the onset of the wet season, when water is more abundant on the landscape and temperatures begin to decline, the apes spent less time in woodland and forested habitats (Pruetz and Bertolani, 2009).

The chimpanzee diet consists primarily of fruits, but also includes herbaceous matter and vertebrate and invertebrate prey (Pruetz, 2006, Bogart, 2009). At Fongoli, most of the plant species within the chimpanzees' diet are located in woodland land cover types (Pruetz, 2006). Fewer dietary plant species are located in closed-canopy forested areas; however, *Saba senegalensis* and *Cola cordifolia* grow here and are important food items during the late dry and wet seasons (Waller and Pruetz, 2016; Bogart, 2009). Because food availability varies both spatially (in land cover types) and temporally (seasonally and annually), it is important to include these variables when assessing habitat selection. (McLoughlin et al., 2010).

Quantifying ecological parameters of primate habitat use in anthropogenic landscapes is necessary in addressing the conservation needs of primate populations. Habitat selection, and any alterations to it, is related to a species' reproductive and survival rates. Selection of suboptimal habitat can reduce nutrient and caloric intake and increase stress (Cowlishaw and Dunbar, 2000). It is additionally important to address the impacts of anthropogenic change at multiple scales, both at the landscape level as well as the micro- and meso-scales (Sawyer and Brashares, 2013). Behavioral changes that occur at finer scales may be missed in analyses focused at the coarser landscape level, which is particularly true for species that are patchily distributed (Sawyer et al., 2011). By understanding behavioral responses to anthropogenic activity we can provide useful information to inform community land use and conservation decisions.

Artisanal and small-scale gold mining and great apes

In West Africa, a great deal of research has focused on understanding the interface between humans and apes (Hocking et al., 2006; Hocking and Sousa, 2011; Bryson-Morrison et al., 2016; Pruetz, 2014; Waller and Pruetz, 2016). However, information is lacking on the impacts of extractive industries. Little is known in general about the impacts of artisanal and small-scale gold mining (ASGM) on great apes, despite documentation of ASGM activity in great ape habitat (Guesnet et al., 2009; Cartier and Burge, 2011; Humle and Kormos, 2011; Villegas et al., 2012). ASGM is known to negatively impact the environment, human health, and human social systems (Alvarez-Berríos and Aide, 2014; Villegas et al., 2012; Arcus Foundation, 2014) with impacts on the environment including erosion, deforestation, landscape destruction, and pollution. Perhaps the greatest risk associated with ASGM is related to the use of mercury to extract gold from ore. While small-scale mining activities do not create as many pollutants as large-scale corporate mines, the latter are subject to government environmental regulation and are more likely to employ mitigation strategies, whereas ASGM mines are not (McMahon et al., 1999).

The societal impacts of ASGM may also have direct impacts on chimpanzee lives. The gold rush in southeastern Senegal caused an influx of people from neighboring countries where hunting chimpanzees for food and medicinal purposes occurs (Republic of Senegal, 2011; Kormos et al., 2003). Further, areas with ASGM sites in the Democratic Republic of Congo and Sierra Leone have seen an increase in chimpanzee orphans, pet trade and bushmeat activities (Hicks et al., 2010; Kabasawa, 2009). Behavioral impacts of ASGM have yet to be quantified and are necessary to create and implement chimpanzee conservation strategies. This is of particular importance as the status of West African chimpanzee populations decline. The West African subspecies of chimpanzee had been listed as Endangered on the IUCN Red List of Threatened Species™ since 1988; however, as their numbers have continued to decline, they are now considered Critically Endangered (Humle et al., 2016; Kühl et al., 2017).

In Senegal, perhaps the most limiting resource for people and chimpanzees is access to water in the dry season (Pruetz & Bertolani, 2009; Republic of Senegal, 2011). From March to April most water sources dry completely, leaving few permanent sources over which many species compete, including humans (Pruetz & Bertolani 2009). ASGM miners are a growing source of competition for water in the dry season. Miners affect water sources by (1) using water for panning and gold-washing, (2) diverting waterways to access mineral deposits, and (3) dumping wastes and tailings into waterways (Villegas et al., 2012). At the Fongoli chimpanzee study site alone, seven ASGM sites have appeared within these apes' home range since 2008.

Here, we investigate chimpanzee habitat selection and behavior in association with ASGM activity at multiple scales in the first effort to assess the behavioral impacts of artisanal mining on a critically endangered wildlife species. To do this, we sought to answer the following questions: 1. Which variables contributed the greatest effect on chimpanzee habitat use over the 10-year study period? 2. Did these variables and/or habitat selection change as mining activity increases on the landscape? Additionally, we analyzed all chimpanzee activity at two mining sites, Oundoundou and Kerouani, to assess patterns or changes in chimpanzee behavior at each site. Drinking behavior is of particular interest due to the scarcity of water in the Fongoli home range during the driest times of the year. We used a multi-scale approach, including a coarse-scale analysis at the level of home range, and two finer scale analyses at the level of mining site for the Oundoundou and Kerouani mining areas. For both scales, we also examined multiple temporal scales, including season and mine expansion. Results of this study not only provide quantitative data on the impacts of ASGM on chimpanzee habitat selection and behavior but also are informative for wildlife conservation strategies, Environmental Impact Assessments, and policies for large scale gold mining societies, particularly with respect to water resource competition.

Hypotheses

Previous studies have shown the importance of land cover type (Pruetz et al., 2002; Pruetz and Bertolani, 2009; Bogart, 2009), baobab fruit availability (Lindshield, 2014), seasonality (Pruetz and Bertolani, 2009; Bogart, 2009), and water availability (Pruetz and Bertolani, 2009) on chimpanzee habitat selection at the Fongoli field site and we expected to see the same in our study. Due to the small footprint of ASGM activity on the landscape (0.04% of the cumulative home range; see Chapter 5), we did not expect to see a significant change in preferred or avoided land cover types as mining increased at the landscape level. However, other studies of chimpanzees have shown an avoidance of human-dominated areas (Hicks et al., 2010), therefore we expected to see the Fongoli chimpanzees avoid anthropogenic areas at a finer scale, particularly ASGM sites, as mining increases within the chimpanzees' home range. Knowing that people are not always at the mines, we predicted that the chimpanzees would be more likely to use these areas on days when miners were not present (Mondays and Fridays) as well as during times of the day when miners were not present (early in the mornings and late in the evenings). At these sites, we expected that chimpanzees would increasingly avoid the mines as mining increased. We predicted that chimpanzees would continue to use the mined areas while adjusting their behavior by decreasing stationary activities, from feeding, resting, and socializing, to simply feeding and then leaving the site, as seen at the Bossou field site where chimpanzees continue to cross and use risky anthropogenic areas (Hocking et al., 2006),

Methods

Study subjects

Within West Africa, Senegalese chimpanzees are listed with the highest level of priority for conservation by the IUCN (Kormos & Boesch, 2003). Chimpanzees in this country live at the northernmost geographic limit of the species' global range, in an environment that is hotter and drier than almost any other chimpanzee habitat (McGrew et al., 1981; Pruetz & Bertolani, 2009; Hunt and McGrew, 2002). Adjustments to this ecosystem result in unique behaviors not yet seen in other chimpanzee populations, including hunting mammals with tools (Pruetz & Bertolani, 2007), soaking in pools of water (Pruetz & Bertolani, 2009), engaging in nocturnal activity (Pruetz & Bertolani, 2009), using caves (Pruetz, 2007), and predicting the movement of fires (Pruetz & Laduke, 2010).

Dr. Jill Pruetz initiated the Fongoli Savanna Chimpanzee Project (FSCP) in 2001 (Pruetz et al., 2002; Pruetz, 2014) and succeeded in habituating males of the resident chimpanzee community to systematic data collection during all-day follows by early 2005 (Pruetz & Bertolani, 2007). All individuals in the group were identified by January 2006. Females were more timid than males during much of the study, but data on females was collected opportunistically when they were in sub-groups with adult males. The research protocol at the Fongoli site included daily all-day focal-subject follows of adult male chimpanzee subjects and their sub-groups or 'parties'. The basic research objective of the FSCP was to study the behavioral ecology of savanna chimpanzees, specifically in relation to that of forest-dwelling chimpanzees in the interest of shedding light on the earliest hominins' behavioral ecology in similar habitats (i.e., relational form of a referential model *sensu* Moore, 1996).

The average annual chimpanzee community size at Fongoli from 2006 through 2013 was 31.6 individuals, with a minimum of 29 individuals in 2010 and a maximum of 36 individuals in 2012. In 2014, there were 32 individuals in the Fongoli chimpanzee community, comprised of 12 adult males, seven adult females, two subadult males, two subadult females, and eight juveniles and infants. Observational data on 16 individual adult males from 2005 through 2014 were used in this study. Due to variation in the number of males for each year, all male data were pooled and used as a representation of the entire chimpanzee community's habitat use.

Study site

The study site is located at Fongoli (12°400 N, 12°130 W, Figure 1.) in the Department of Kedougou where the vegetation cover is classified as a mosaic of Sudanian woodland-savanna and Guinean forests (Frederiksen & Lawesson, 1992; Tappan et al., 2004). The region is characterized by a short wet season from June through September (average rainfall is less than 1000mm per year, Pruetz unpublished data) and a long dry season from October through May, with maximum temperatures frequently reaching over 40 degrees Celsius (Pruetz, 2007; Pruetz and Bertolani, 2009). For the purposes of this study, we have further subdivided the dry season into two categories: the early dry season from November through February and late dry season from March through May (see Chapter 5, Figure 1). The Fongoli research site is located in close proximity (15 km) to the administrative capital city, Kedougou, and encompasses five villages and seven ASGM sites (see Chapter 5, Figure 2). Two mining areas of major interest to this study were Oundoundou and Kerouani. The Oundoundou mine was the first to appear in the home range and also became the largest mine. The Kerouani mine was the only mine consistently located within the apes' core range from its inception through the end of the study period (see Figure 9 in Chapter 5). The Fongoli study group's home range is approximately 39 km^2 based on a 95% kernel density estimate and the total area of use is approximately 110 km^2 using a 100% minimum convex polygon around all observed locations from 2005 to 2014 (this study; see Chapter 5).

Data collection and variables

In order to assess changes in chimpanzee behavior as ASGM activity increased within the Fongoli home range, we used data collected on adult male chimpanzees between 2005 and 2014. Data collection began in April 2005 after adult male chimpanzees where habituated to nest-to-nest follows. However, data collection was not consistent until 2006, as chimpanzees became better habituated. The data collection protocol for Fongoli included daily focal-subject follows (Altmann, 1974) of adult male chimpanzee and their sub-groups or 'parties' and included instantaneous recording at five minute intervals (hereafter 'observations') on ranging, social interactions, and basic activities such as traveling, feeding, drinking, resting, and nighttime nesting sites. When feeding was recorded as the activity, the food species consumed was also recorded. Due to the risk of hunters targeting females and their infants for the illegal pet trade (Pruetz and Kante, 2010), female chimpanzees were not subject to focal-subject follows. An attempt was made by observers to follow male subjects on a rotating schedule for at least 20 days a month; however, seasonal conditions and weather do not always allow for this. When possible, a focal male subject was followed as he emerged from his night nest in the morning until he again made a new nest at the end of the day. If the focal subject was lost during the daily follow, the observer selected the next male in the rotation who was present in the party after approximately 20 minutes of searching for the lost subject. Our dataset accounts for 32% of all possible days over the ten-year study period.

At each 5-minute interval, the observer recorded the focal subject, date, time, activity, food species consumed when available, and location as determined by handheld GPS devices. We standardized the data from all years to use common food and activity codes and converted all spatial data into Universal Transverse Mercator (UTM) format. Spatial data were imported into ArcMap 10.4.1 (Environmental Systems Research Institute, Redlands, CA) and assigned to the UTM WGS-84 reference system for Zone 28N. To ensure accuracy of point data, all spatial data points were plotted using ArcMap and outliers and other incorrectly entered data were excluded from further analysis. Additionally, all observations without a GPS location or a focal adult male subject were removed from analysis. The resulting data set included over 9,900 hours of observation on Fongoli chimpanzee subjects (Table 1). For each GPS location, corresponding landscape and anthropogenic variable data were also included. The landscape and anthropogenic variables used in the habitat selection modeling included: land cover type, slope, and distance to year-round water sources, baobab (*Adansonia digitata*) trees (a major food source), villages, roads and walking paths, and ASGM sites.

To develop the land cover type variable, we established a preliminary geospatial coverage product of the main land cover types present in the Fongoli study area. Land cover types were based on visual image interpretation of Landsat 7 images from 2011 available through the World Imagery Map (ESRI-Digital Globe partnership program).

The product depicts land cover classes that can be consistently identified at a scale up to 1/5000. Image interpretation and classification was assisted by the incorporation of other remote sensed maps of ancillary vintages to detect seasonal or ephemeral differences in the vegetation, and by available relevant published data and reports concerning the characterization of the main vegetation types of the region (CILSS, 2016; GLCN, 2008; Stancioff et al., 1986; Tappan et al., 2004). The resulting land cover types for the Fongoli field site included six basic categories (anthropic, forest, grassland, savanna, woodland, and water) and 22 land-cover types (Table 2; Figure 1).

Estimations of distance to water, baobab trees, villages, and mining areas were calculated using the 'Near' function in ArcMap. This function calculates the distance from each observed chimpanzee location or randomly generated location to the nearest specified feature. Distances to water sources were difficult to estimate as actual distance varies annually based on timing of first rainfall and quantity of seasonal rainfall. To best approximate the locations of year-round water sources, we plotted drinking locations during the month of April through May 15, as this is the end of the dry season and the time period when all but the year-round water sources have dried. Using these drinking locations as a starting point, we then used clear point clusters and satellite imagery in ArcMap to estimate the locations of regularly used year-round water sources and then extracted distance metrics. Distance to baobab trees was included as a variable as baobab fruit is an important food resource for much of the year, and the top food resource consumed in the early dry season (Pruetz, 2006; Lindshield, 2014). Additionally, baobab trees represent large food patches in discrete locations throughout the home range and in a variety of land cover types (Lindshield et al., 2017; Bogart, 2009).

To account for other annual variations in food availability, we separated our RSF models for three different seasons related to periods of annual food availability (McLoughlin et al., 2010). We also included land cover as an explanatory variable for habitat use, as land cover types have been shown to correlate with food availability at the Fongoli field site (Bogart, 2009; Pruetz, 2006; Lindshield, 2014). In Bogart (2009), six habitat classes were defined as bamboo woodland, forest ecotone, gallery forest, tall grassland, short grassland-savanna (formerly plateau), and woodland (open and closed) and surveyed for feeding tree abundance per hectare. To illustrate the relative food availability in each of the land cover types classified in this study, we first matched our land cover definitions to those provided in Bogart (2009), although not all land cover types form this study could be assigned to the Bogart class system (i.e. anthropic land cover types). We then assigned food availability rankings based on the feeding tree abundances per hectare established in Bogart (2009) (Table 2).

To spatially quantify the locations of the gold mining sites, we combined data from FSCP data books, local knowledge, and satellite imagery. The researchers and staff of the FSCP have maintained detailed documentation of the Fongoli field site and changes within the site since research was initiated. The FSCP records provided us with information about the onset of mining activities and the general location of each mine. In addition, we used local knowledge from FSCP staff, which was verified via satellite imagery, to determine the start dates of mining activity. ASGM activities cause deforestation and deep pits with associated mounds of soil, creating visible markers of the mining sites in the satellite imagery, allowing us to delineate the boundaries in ArcMap. From here we estimated four mining time periods: pre-mining from 2005 through 2007, early mining from 2008 through 2010, mining expansion from 2011 through 2012 and late mining from 2013 through 2014 (Table 1 and see Chapter 5). Combining years into time periods for habitat selection models can help decrease the likelihood that areas marked as “unused” were actually “used”, resulting in a more accurate and robust model (Manly et al., 2002). The locations of mining activity during the pre-mining, early mining, mining expansion, and late mining time periods were included as an anthropogenic variable to model the driving factors of chimpanzee habitat selection over the course of the four time periods. Another temporal factor in mining activity occurs at the weekday level and was related to the presence or absence of gold miners. Mining activity is contingent on a traditional workweek, with Mondays and Fridays serving as rest days. We have therefore included ‘miner presence’ as a predictor variable to determine changes in chimpanzees’ behavior and habitat use, particularly at the spatial scale of mining site.

Data analysis

To assess spatiotemporal variation in chimpanzee habitat selection over the 10-year study period, we used a logistic regression resource selection probability function (Manly et al., 2002; Johnson et al. 2006). We fitted the model using a generalized linear model with a binary response variable (1 = used, 0 =available). Explanatory variables used included landscape indicator variables (i.e. basic land cover – six categories, distance to year-round water sources, distance to baobab trees, and slope), anthropogenic indicator variables (i.e. distance to villages, roads and paths, and ASGM sites), and temporal factors (i.e. miner presence by day of the week, level of mining, season, and hour of day).

Total available habitat was estimated by generating 10,000 random points from within a minimum convex polygon (MCP) of all chimpanzee locations (see Chapter 5). To evaluate Fongoli community-level habitat selection we pooled all adult male chimpanzee locations for each time period, as only six of the 16 males in the study were observed every year of the study period. 'Used' areas were defined as chimpanzee locations from the 5-minute observations. To reduce spatial and temporal autocorrelation of the data, we rarified the data by randomly selected 10,000 observations to be used in the RSF analysis (Swihart & Slade, 1985). Data sets for nesting and drinking were also rarified to include only one observation per location. Additionally, linear mixed-effects models were run using the 'lme4' package in R (Bates et al., 2015) with 'date' as a fixed effect to account for remaining autocorrelation in the subset and for the models at finer scales that were not rarified or subselected (mining areas). The addition of the fixed effect to account for autocorrelation did not change model selection, as is the case in some situations (Boyce, 2006), and we have therefore reported the best-fit generalized linear models. Due to the small size of the Kerouani mine, the random variables did not accurately assess the range of available habitat and therefore only data points for used habitat were used in analyses.

To further investigate the impacts of ASGM on chimpanzee habitat use under different levels of mining intensity and environmental conditions, we repeated the RSF analyses on different data subsets. Prior research at Fongoli reported seasonal differences in ranging behavior related to heat stress and food and water availability (Pruetz & Bertolani, 2009); therefore, for each time period, we modeled habitat selection for the early dry season (November – February), late dry season (March – May) and wet season

(June – October).Each season dataset, 10,000 observations were subselected from the full data set to reduce spatial and temporal autocorrelation of observations. Distance to water differed drastically between seasons and was predicted to be a driving factor in habitat selection, particularly during the late dry season but may not be a factor at other times of the year. In total, we produced 10 models to determine the driving variables in chimpanzee habitat selection and the impacts of ASGM on chimpanzee behaviors. We included two spatial scales (home range and mining areas), and two temporal scales (mining periods and seasons; Table 3).

All RSF analyses were performed in R version 3.3.1 (R Core Team, 2016), using function 'glm' with a binomial distribution from the 'lme4' package. Continuous variables were scaled for each dataset. Model fit and rank were assessed using Akaike's Information Criterion (AIC) and Bayesian information criterion (BIC) (Burnham and Anderson, 2002; Manly et al., 2002). We defined the best model as have both the lowest AIC and BIC values. We validated our models using area under the receiver operating characteristic curve (ROC) analyses. For each analysis, similar models were compared using analysis of variance chi-squared tests. For those that did not differ significantly, the simpler of the two was selected. Additional post hoc Pearson's Chi-Squared analyses were also run in R, and for all analyses significance was set at $\alpha < 0.05$.

Results

Overall habitat selection

Resource selection by the Fongoli chimpanzees showed non-linear relationships with distances to nearest baobab tree, human settlements, mining locations, the Oundoundou mine, and year-round water sources (Figures 2 – 4). The likelihood of chimpanzees using a location with respect to distance to baobabs and water sources changed with the season. During the early dry season, the probability that the chimpanzees used a location less than 200 m from a baobab tree increased as distance to the baobab tree decreased; whereas the contrary occurs in the late dry and wet seasons, when this food is less often eaten (Figure 5). Chimpanzees were also more likely to use areas near year-round water sources in the late dry season and less likely in the wet season when water is more abundant across the home range (Figure 6). We saw a similar pattern in the early dry season to the wet season but not as pronounced. The chimpanzees' use of the habitat within their home range varies nearly linearly with the slope of the landscape, with chimpanzees more likely to use areas with a greater slope (Figure 7). The probability of chimpanzees habitat use relative to their distance to roads and walking paths fluctuated around 0.50; therefore, this variable was not retained in the final model.

A significant predictor of chimpanzee ranging was land cover type (Figure 8). Preferred land cover types, defined as being used more than expected based on the proportion of each land cover type within the home range, were closed-canopy habitats classified as woodland or forest physiognomies (i.e. woodland, gallery forest, forest, open or degraded gallery forest, mature forest, mature gallery forest, and riparian forest; see Figure 9). Chimpanzees also preferred wooded savanna with bamboo and valley bamboo thicket. Land cover types avoided were primarily open-canopy and human-altered land cover types (i.e. tree savanna, wooded savanna, bowé, shrub savanna, degraded tree savanna, active cropland, thicket, and inactive cropland). The Fongoli chimpanzees did not use or rarely used, bare ground, seasonally flooded herbaceous savanna, settlements, water, or wetland floodplains, although these land cover types are also rare in the home range.

The best-fit model for overall habitat selection included basic land cover categories, season, distance to settlements, distance to water, distance to baobabs, distance to the Oundoundou mine, as well as interaction terms between basic land covers and season, distance to water and season, distance to baobabs and season, and distance to Oundoundou and season (Table 4). Mining level was not included in the best-fit model, suggesting that changes in mining activity across the study period did not influence habitat selection at the home range level. Overall, the chimpanzees were most likely to be observed in the forested land cover types, followed by woodlands. They were also more likely to use habitat near to baobab tress in the early dry season when the fruit is ripe, and to avoid settlements, as predicted. The parameters included in the best-fit RSF models for each mining level were the same as those in the overall model (Table 5).

When modeling use for each mining level and each season, we found an influence of mining activity on habitat selection (Table 5 and 6, Figure 10, Appendix 1). Use of savanna physiognomies increased from pre-mining through late mining across all seasons, with the greatest increase occurring in the late dry season. Conversely, the use of woodland habitats decreased across the mining periods, also with the greatest decline in the late dry season. Forested land covers were preferred habitats across mining levels and seasons, with the highest likelihood of use in the late dry season. Chimpanzee use of grasslands did not show a clear trend over the mining periods but varied between seasons. Chimpanzees were more likely to use grasslands in the late dry and wet seasons and avoided these land covers in the early dry season. Anthropic physiognomies remained less preferred across all mining levels; however, as mining intensity increased across mining levels, the chimpanzees increased early dry season use of human dominated land cover types. The likelihood of use of human landscapes was lowest in the late dry during the late mining phase. Additionally, our results indicated that chimpanzees prefer to use habitat near to roads and paths. This did not change across mining levels and did not differ between seasons.

Oundoundou mine

Within the Oundoundou mining area, land cover types, slope, and distance to settlements, water, and baobab trees were strong predictors of habitat selection. The chimpanzees used habitats with trees (i.e. forest, woodland and woodland savanna with bamboo), more often than expect based on their representation on the landscape (Figure 11). We also saw a preference for anthropic land cover; specifically bare ground, where vegetation had been removed through mining practices. The best-fit model for the Oundoundou area also included mining level. Although not significant, the likelihood trend for mining level suggests that the chimpanzees were less likely to use the mined area during mine expansion (Table 7). The chimpanzees were most likely to be observed in woodland habitat. The forested habitat was used more than expected relative to its representation on the landscape, however, it was less likely to be used at the mine relative to use of woodland habitat. Open-canopy land cover types, grassland and savanna physiognomies, were avoided at Oundoundou. Although the mine is located along a ravine, the chimpanzees preferred to use land with a smaller slope, avoiding steeper areas and contradicting the general trend observed in the home range.

Observers recorded the chimpanzees engaging in drinking, feeding, resting, self-grooming, traveling and socializing while at the Oundoundou mine (Table 8). All behaviors were observed during the early and late dry season, and in the early and expanding mining levels. Chimpanzees spent the most time resting (41%), followed by feeding (32%), socializing (12%), traveling 9%), self-grooming (0.5%), drinking (0.5%). Most of the activity took place in the savanna (40.5%), followed by forest (32.5%) and anthropic (27%). Drinking only occurred on a Friday when people were not present at the mine.

We hypothesized that, if the chimpanzees continued to use the mined area as mining expanded, they would spend less time in stationary activities at or near the Oundoundou site when people were working and more time traveling to and from the area to feed. Our results indicate that, as mining progressed between 2008 and 2012, the chimpanzees increased their use of the mine affect area, both in stationary behaviors (feeding, drinking, socializing, and resting) and active behaviors (traveling), relative to their use of the area prior to mining (Figure 12). Day of the week and the associated presence of miners did not affect the trend. On days when miners were present chimpanzees would feed, rest, and socialize alongside of the mining area, with people working and passing less than 50 meters from them (Table 9). We did, however, see an interaction between land cover and the presence of gold miners that revealed an avoidance of human disturbed areas while people were present (Figure 13). A Pearson's chi-square test showed a significant difference between chimpanzee use of the Oundoundou area on miners' workdays versus their days off [$X^2(1, N=222) = 57.86$, $p = 2.82e-14$]. For each of the physiognomies, we found that chimpanzees used the anthropic and savanna areas significantly more when miners were absent [$X^2(1, N=44) = 18.29$, $p = 1.90e{-}05$ and $X^2(1, N=49) = 7.053$, $p = 0.008$, respectively], and forested areas were used more when miners were present [$X^2(1, N=35) = 20.51$, $p = 5.93e{-}06$].

At the Oundoundou mine the chimpanzees fed on 12 plant species and one animal species, termites (Table 10). The apes only fed on the fruit of *A. digitata* (baobab) on Mondays and Fridays when miners were not present, and 68.9% of their time feeding on baobabs was in the anthropic area of the mine. Overall, 50% of their time feeding at the Oundoundou mine occurred within the anthropic mining area. Feeding bouts over 30 minutes long were either in habitats with trees and seasonal canopy cover (i.e. forest and woodland physiognomies) or took place on the miners' days off.

Kerouani mine

The best-fit RSF model for habitat selection at the Kerouani mining area differed from the Oundoundou mine model and the overall model, including only three explanatory variables: land cover type, mining level and season. The RSF model for this area was calculated using only used data points because the random variables generated for the entire home range (110 km^2) did not accurately represent the Kerouani mining area, as it measures only 0.05 km^2 (Table 11).

Mining activity in the Kerouani began during the period of mining expansion in 2011. Fongoli chimpanzees used the Kerouani area regularly throughout the study period, but we found variation relative to mining locations and the onset of mining (Figure 14). Mining activity began in 2011 with two small sites (totaling 5.5 km^2), however, prior to 2011, no observations of chimpanzee activity had been recorded in our dataset within those two areas before they were mined. As mining began, the chimpanzees began using the area around mining sites for feeding, resting, socializing and traveling. As mining expanded along the Kerouani into areas of regular chimpanzee use, we saw an increase in chimpanzee use of the area, contrary to our hypothesis. This trend was only seen in forest and woodland physiognomies, and we saw no change in the use of grassland or savanna physiognomies. Visits to the mine were primarily on traditional mining days of the week. Only one visit totaling 30 minutes was observed on a Friday, and none were observed on Mondays. Nearly all of the visits were in forest and woodland physiognomies; only six (about 1%) of the 620 observations at the Kerouani mine were within savanna land cover types.

At the Kerouani mine, the chimpanzees spent just over half their time resting (58%), followed by social behaviors (19%) and feeding (11%) (Table 12). The remainder of their time was spent traveling (6%), self-grooming (2%) and drinking (2%). The majority of activity at Kerouani was in the late dry season (89.5%). Late dry season activity increased significantly as mining increased [X^2 (2, N=522) = 11.578, p = 0.003]. Additionally, as mining increased at the Kerouani site, the chimpanzees increased their use of woodland and forest physiognomies (i.e. gallery forest, mature gallery forest, open or degraded gallery forest and woodland land covers) in the late dry season. In the wet season, they increased their use of mature gallery forest. Overall, their use of woodland and forest physiognomies at the Kerouani mine significantly increased over the study period, from early mining to late mining [X^2 (2,N=600) = 751.99, p< 2.2e-16]. The chimpanzees did feed, rest, and travel briefly in the open savanna habitats in the late dry season after mining had increased; however, there was no significant difference in savanna use overall. Another impact of increased mining was the increased observations of chimpanzees drinking at the mining site and in mining pits (Table 13). Overall, the majority of their time at Kerouani across all seasons was spent engaging in stationary activities (93.7%).

At Kerouani, the chimpanzees consumed *Saba senegalensis* (25%), termites (19%), *Ficus* species (16%), *Piliostigma thonningii* (14%), *Oncoba spinosa* (13%), *Baissea multiflora* (6%)*, Parkia biglobosa* (3%)*, Bombax costatum* (2%), *Daniellia olivieri* (2%)*,* and *Gardenia erubescens* (2%) (Table 14). Of the 10 food items, only *G. erubescens* was eaten in savanna; the others were all consumed in either forest or woodland physiognomies. Of their time spent feeding, 87.5% was during the late dry season and only 12.5% in the wet season. Prior to mining activities, the chimpanzees consumed nine other plant species at the Kerouani mine site that they did not consume once mining began. The only species consumed both prior to mining and during mining were *Saba senegalensis*, *Ficus* species, and termites.

Discussion

ASGM is a widespread practice around the world, but little quantitative data has been collected on its impacts on wildlife behavior and habitat use. This study used RSFs to assess critical factors of chimpanzee habitat use over a 10-year study period at the Fongoli field site, Senegal at two temporal scales (seasonal and multi-year gold mine growth phases) and two spatial scales (home range and gold mining sites). Our study also assessed behavior observed at the mining sites (feeding, nesting, resting, socializing, and drinking). For each RSF we included landscape, anthropogenic, and temporal variables. Due to the richness of our models, we were able to investigate the impacts that ASGM has had on chimpanzee habitat use from before the onset of a gold mining boom and through growth and expansion of the mining areas. Our findings suggest that despite the small footprint of ASGM activity, the impacts of gold mining activities can be seen at spatial and temporal scales.

At the spatial scale of the chimpanzees' home range, the influx of the seven mining locations shifted habitat use of preferred land cover types to avoided ones. On a finer spatial scale, mining activity appeared to attract chimpanzees to the mining areas. We saw this on a temporal scale of mining periods as mining increased, as well as at seasonal and weekly levels. Evidence from the largest mine, Oundoundou, however, suggests that attraction to a mine appears to have a threshold related to mining intensity. Additionally, increases in ASGM may also be impacting chimpanzee activities, as evidenced by shifting use of land cover types for feeding and increased water consumption within the mines.

As expected, we found that land cover types and seasons are significant drivers of chimpanzee habitat selection. This corroborated previous studies that showed a preference for forested land covers, despite their rarity on the landscape (Pruetz, 2002; Pruetz and Bertolani, 2009; Bogart, 2009; Lindshield, 2014). We also saw seasonal variation in land cover use that appears to be related to food and water availability, which fluctuates seasonally (Pruetz, 2006; Pruetz and Bertolani, 2009, Bogart, 2009; Lindshield, 2014). The highest probability of use in forested habitats occurred in the late dry season and appears to be associated with water availability, as these forest types often included permanent spring locations. In the wet season, habitat use varies over more land cover types as the availability of water is more evenly spread across the landscape and no longer a limiting factor as it is in the late dry season. Overall, the chimpanzees were most likely to select forest and woodland physiognomies, which is likely related to the availability of fruiting tree availability within these land cover types (Pruetz, 2006; Bogart, 2009). As mining activity expanded and intensified, the apes' range shifted eastward (see Chapter 5), and the likelihood of use in woodlands decreased while the use of poorer quality (in terms of canopy cover, water availability, and presumed food availability) land covers increased (i.e. savanna physiognomies).

Changes in land cover use were also apparent at the finer scale of mining sites. At the Oundoundou mining site we saw an increased use of anthropic land cover types, particularly in the use of bare ground. Bare ground at Oundoundou included areas that had been or were being actively mined. During the phase of mine expansion, we saw increased use of the bare ground area from 2009 through 2012. Vegetation data was collected from 2011 satellite imagery and therefore may underestimate the use of anthropic areas in 2012. If apes had been using the same area in previous years and were deterred by mining activity, we would have expected to see a decrease in activity. Contrary to our hypothesis, our results indicate the opposite, that chimpanzees used the mined area more as mining increased. However, in concordance with our hypothesis that chimpanzees would use the mine when miners were not present, we saw that the anthropic areas of the mine were only used on days when people were not working at the mine, on Mondays and Fridays. This may be an artifact of a learning period for the chimpanzees to become familiar with the miners' weekly use of the land. It may also be related mine expansion that engulfed preferred resources, particularly baobab trees. Overall, Fongoli chimpanzees used the Oundoundou area more when miners were not present. Miner presence, however, was not the only factor contributing to chimpanzee use of the mining area: land cover type also played a role. When chimpanzees were observed using the mining area while people were working in or near the mine, they were more likely to be in closed forest and woodland habitats than open savanna habitat.

The lack of evidence of habitat use around the Oundoundou mine in the pre-mining period may be a result of a smaller data set, which accounted for only 13% of all possible observation days from 2005 through 2007. As mining intensified in 2008, chimpanzees traveled toward the mined area and used the actively mined area through 2012. The paucity of activity at Oundoundou in the late mining period suggests a threshold of human activity that was not tolerated by the chimpanzees. Further expansion and intensification from 2012 into 2013 included a greater use of mechanization and vehicles (Chapter 2), which may have spurred the complete avoidance of the area by the Fongoli community. The avoidance of mining activity in the late mining period supports our hypothesis of increased mining activity deterring chimpanzee use of the area. However, the initial apparent attraction to the mine was counter to our hypotheses and suggests that it is not mining activity itself, but rather the intensity of the mining that deters chimpanzee use.

Further support of mine attraction and increased use of a mined area was found at the Kerouani mine, located at the center of the chimpanzees' home range (see Chapter 5, Figure 1). Observations of chimpanzee at the first Kerouani mining pits only began when mining activity began. As mining expanded to the east into areas previously used by the chimpanzees, we found that the apes not only continued to use the area but increased their usage... The greatest level of activity observed at the Kerouani mine was during the late dry season and may be related to the creation of waterholes by the miners. On multiple days, the chimpanzees were recorded entering the mined area and drinking from the mining pits. Attraction to the mine, however, may have also been related to curiosity (Byrne, 2013). Observers recorded the chimpanzees looking “surprised” when they first encountered mining at the Kerouani location. Further, data entries reported chimpanzees investigating materials left behind by the gold miners. The sheer novelty of the disturbance at Kerouani may have drawn the chimpanzees toward the ASGM sites in an effort to obtain information and assess possible risks (Byrne, 2013; Griffin, 2004).

Behavioral impacts

The impacts of ASGM on Fongoli chimpanzees’ drinking were most pronounced at the mining sites. At both Oundoundou and Kerouani, chimpanzees drank directly from excavated mining pits. The creation of water sources in the hot, dry landscape of southeastern Senegal is significant. Much of the chimpanzees’ ranging behavior in the late dry season is related to access to water (Pruetz and Bertolani, 2009). The creation of water sources provides the chimpanzees more flexibility in ranging during the late dry season, as it allows them to use portions of their home range otherwise unavailable during the dry season. There are risks, however, associated with water consumption at the mines. The greatest risk is conceivably the risk of consuming fecal coliform bacteria from human excrement. With no sanitation at mining sites, people use the surrounding forested and savanna areas for defecation (Persaud et al., 2016; Long et al., 2013; Small, 2012). Both the Kerouani and Oundoundou mines are located in ravines with seasonal waterways located in the valleys. Runoff from the hillsides used for defecation may be infecting the chimpanzees’ water sources. Even before mines were established, yearly fecal coliform analyses of the Fongoli stream during the early rainy season showed contamination (Pruetz, unpublished data).

As gold mining continues to increase in Senegal and throughout chimpanzee habitat, changes in chimpanzee behavior and habitat use may put the species at risk. The Fongoli chimpanzees may be engaging in direct observational learning of the risks associated with ASGM as they approach and inspect the gold mining sites within their home range (Griffin, 2004). Unfortunately, the risks associated with ASGM activities may not be perceptible to the apes, including mercury toxicity, exposure to human fecal pathogens, and falling hazards associated with unreclaimed open pits. Research into risk factors associated with ASGM in Ghana found that non-miners were at risk for injuries, and even death, related to falling into uncovered and abandoned mining pits (Long et al., 2015).

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Table 6.1 Number of 5-minute interval sampling observations (obs.) for each year of the study period and each defined mining level in the dataset and in the data subset of 10,0000 random (available) observations used in analyses.

Mining Level	Year	Number of obs.	Number of obs. in subset	Total obs.	Total obs. in subset
Pre Mining	2005	151	14	7795	646
	2006	3088	261		
	2007	4556	371		
Early Mining	2008	12276	972	46376	3836
	2009	17060	1445		
	2010	17040	1419		
Expanded Mining	2011	18098	1556	36094	3088
	2012	17996	1532		
Late Mining	2013	13809	1197	28551	2430
	2014	14742	1233		
Total				118816	10000

Table 6.2 Categorization and descriptions of land cover types at the Fongoli field site. Food availability ranking derived from habitat classifications and feeding tree per hectares in Bogart (2009).

Basic Land Cover Categories	Land Cover Types	Description	Habitat Class and Food Avail. Ranking
Anthropic Physiognomies	Active Cropland	Active agricultural areas for the production of harvested row or field crops. These include field crops predominantly, as well as orchards.	Field - Low
	Inactive Cropland	Prior agricultural areas that have no physical indication of recent agricultural use. These areas include both abandoned cropland and fields left to fallow, as well as old fields or bush/shrubland where fields appear to be abandoned rather then left fallow for soil improvement. Variation on the percentage of bush cover, served as a factor to differentiate between the prior class and the current.	Field - Low
	Bare Ground	Surface with little to no vegetation cover, exposing the soil permanently. Often of anthropic origin.	NA - none
	Settlement	Built up areas comprising structures for human communities to live, in the form of a village or small town.	NA -none
Forest Physiognomies	Forest	Dense, closed-canopy forest formation of semi-evergreen broadleaf vegetation with scattered emergent trees, non-associated with valley conditions. May include secondary or primary stages, in its structure conditions.	Closed forest - High
	Gallery Forest	Semi-evergreen forest formation forming a band or corridor of dense vegetation along permanent or temporary watercourses, in valley topographic conditions; generally closed-canopy and similar in structure to semi-evergreen forest class; their width, extent, and luxuriance depend on the width, and depth of the valleys they follow, as well as the depth and dynamics of the water table.	Closed forest - High

Table 6.2 Continued

Basic Land Cover Categories	Land Cover Types	Description	Habitat Class and Food Avail. Ranking
	Gallery Forest, Open or Degraded	Originally a semi-evergreen broadleaf gallery forest with closed or partially closed-canopy whose integrity has been degraded by considerable anthropic interference. Degraded forest can also be immature forest, or forest in various stages of regrowth after disturbance.	Closed forest - High
	Gallery Forest, Mature	Gallery Forest land cover showing characteristics closer to a fully developed multi-strata formation (all areas include some level of anthropic impact). Similar to Forest, Mature, but occurring conspicuously along pronounced upper valley systems of the main drainage.	Closed forest - High
	Forest, Mature	Forest land cover showing characteristics closer to a fully developed multi-strata formation	Closed forest - High
	Riparian Forest	Heterogeneous tall semi-evergreen forest, with occasional palm trees, found bordering the edges of the main banks of Gambia river and immediate confluence areas of tributaries.	NA
Grassland Physiognomies	Bowe	Flat, open surfaces that generally occur by means of the presence of near-surface lateritic conditions; the skeletal, ferruginous soils form a hardened, impenetrable surface, generally absent of woody vegetation, but supporting varying magnitudes of herbaceous cover developed during the rainy season.	Short grassland - Low
	Wetland-Floodplain	Herbaceous or aquatic vegetation, in permanent or semi-permanent wetlands and swamps conditions.	NA - none
Savanna Physiognomies	Tree Savanna	Formation with scattered trees and shrubs with a continuous herbaceous understory usually dominated by grasses; woody cover between 1-25%.	Tall grassland - Moderate

Table 6.2 Continued

Basic Land Cover Categories	Land Cover Types	Description	Habitat Class and Food Avail. Ranking
	Shrub Savanna	Formation with scattered, or relatively clustered, shrubs dominating the woody vegetation, with continuous herbaceous cover mostly dominated by grasses; woody cover between 1-25%.	Short grassland - Low
	Thicket	Dense stand of shrubs, forming generally impenetrable cover, with minimal or no herbaceous ground cover. May in general be the result of anthropic factors.	NA
	Valley Bamboo Thicket	Dense stand of Bamboo, forming generally impenetrable cover, with minimal or no herbaceous ground cover. Present in valley bottom conditions.	Bamboo woodland - Moderate
	Tree Savanna, Degraded	Formation with scattered trees and shrubs with a continuous herbaceous understory usually dominated by grasses; woody cover between 1-10%, with extensive signs of anthropic disturbance.	Tall grassland - Low
	Herbaceous Savanna, Flooded Seasonally	Continuous herbaceous ground cover in gentle plateau depressions; trees and shrubs normally absent; with clear seasonal waterlogged conditions.	NA
Woodland Physiognomies	Woodland	Semi-open formation of small to medium height trees; tree cover generally between 50-70%; canopies can at times present a matrix of contiguous structure interspaced with open areas between trees; grass understory can be scattered to dense, often associated with other herbaceous plants.	Closed Woodland - High
	Wooded Savanna	Often a secondary stage of Woodland, defined by an open formation of small trees; tree cover generally between 25-50%; canopies are not contiguous, with large open areas between trees.	Open Woodland - High

Table 6.2 Continued

Basic Land Cover Categories	Land Cover Types	Description	Habitat Class and Food Avail. Ranking
	Wooded Savanna with Bamboo	Often a secondary stage of Woodland, defined by an open formation of small trees; tree cover generally not over 50%; canopies are rarely contiguous, with large open areas between tress and with noticeable presence of Bamboo (*Oxytenanthera abyssinic*a) stands.	Open Woodland - High
Water	Water	Areas with permanent or semi-permanent surface water	None

Table 6.3 Two scales of resource selection function modeling and the levels and sublevels for each scale.

Scale	Level	Sublevel
Spatial	Home Range	
	Major Mining Areas	Oundoundou
		Kerouani
Temporal	Mining periods	Pre-mining
		Early Mining
		Expanded mining
		Late Mining
	Seasons	Early Dry
		Late Dry
		Wet

Table 6.4 Parameter estimates for community-level resource selection function for the Fongoli chimpanzees from 2005 through 2014.

Parameter	**β**	S.E.	*p*	O.R.
Woodland (Intercept)	-0.19	0.06	<0.05	0.83
Forested	1.12	0.11	<0.001	3.06
Grassland	-0.42	0.10	<0.001	0.66
Anthropic	-1.80	0.22	<0.001	0.17
Savanna	-1.04	0.08	<0.001	0.35
Water	-11.51	120.12	0.924	0.00
Late dry season	-0.45	0.08	<0.001	0.64
Wet season	0.12	0.08	0.129	1.12
Dist. to settlements	0.91	0.03	<0.001	2.48
I(Dist_water^2)	-0.11	0.02	<0.001	0.90
Dist. to water	-1.45	0.05	<0.001	0.23
I(Dist_baob^2)	0.35	0.01	<0.001	1.42
Dist. to baobab	-1.55	0.05	<0.001	0.21
Dist. to Oundoundou	1.05	0.04	<0.001	2.87
Forested : late dry	0.88	0.15	<0.001	2.41
Grassland: late dry	-0.03	0.16	0.835	0.97
Anthropic: late dry	-0.04	0.33	0.896	0.96
Savanna: late dry	0.02	0.12	0.891	1.02
Water: late dry	13.16	120.12	0.913	519915.00
Forested : wet	-0.04	0.15	0.807	0.96
Grassland: wet	-0.49	0.15	<0.05	0.61
Anthropic: wet	-1.31	0.38	<0.001	0.27
Savanna: wet	-0.30	0.11	<0.05	0.74
Water: wet	0.18	189.31	0.999	1.20
late dry:Dist. to water	-0.90	0.07	<0.001	0.41
wet:Dist. to water	-0.18	0.06	<0.05	0.84
late dry:Dist. to baobab	0.75	0.06	<0.001	2.12
wet:Dist. to baobab	0.33	0.06	<0.001	1.38
late dry:Dist. to Oundoundou	-0.37	0.06	<0.001	0.69
wet:Dist. to Oundoundou	-0.37	0.06	<0.001	0.69

Table 6.5 Parameter estimates for community-level resource selection function for the Fongoli chimpanzees during each of the four levels of mining.

	Pre-mining			Early mining			Expanded mining			Late mining		
Parameter	**β**	S.E.	O.R.	**β**	S.E.	O.R.	**β**	S.E.	O.R.	**β**	S.E.	O.R.
Woodland (Intercept)	0.62**	0.13	1.85	-0.29**	0.06	0.75	0.08	0.06	1.08	-0.06	0.07	0.94
Forested	-0.44*	0.16	0.65	1.56**	0.10	4.77	1.01**	0.09	2.75	1.15**	0.13	3.15
Grassland	-1.65**	0.16	0.19	-0.92**	0.11	0.40	-1.46**	0.11	0.23	-0.83**	0.14	0.44
Anthropic	-4.55**	0.38	0.01	-1.77**	0.21	0.17	-2.21**	0.21	0.11	-0.44*	0.19	0.64
Savanna	-2.92**	0.14	0.05	-0.89**	0.07	0.41	-1.14**	0.07	0.32	-1.05**	0.09	0.35
Water	-12.36	206.20	0.00	-12.17	186.59	0.00	-11.79	159.92	0.00	-12.15	204.32	0.00
Late dry season	0.62*	0.25	1.85	-0.29**	0.09	0.75	-0.61**	0.10	0.54	-0.74**	0.09	0.48
Wet season	0.98**	0.16	2.66	-0.02	0.08	0.98	-0.15*	0.08	0.86	0.25*	0.08	1.29
Dist. to settlements	1.38**	0.04	3.99	0.91**	0.03	2.48	1.01**	0.03	2.75	0.75**	0.03	2.11
I(Dist_water^2)	0.06*	0.03	1.06	-0.22**	0.02	0.80	-0.12**	0.02	0.89	-0.29**	0.02	0.75
Dist. to water	-2.53**	0.07	0.08	-1.21**	0.04	0.30	-1.14**	0.04	0.32	-1.09**	0.06	0.34
I(Dist_baob^2)	0.43**	0.02	1.54	0.43**	0.02	1.54	0.18**	0.03	1.20	0.33**	0.01	1.39
Dist. to baobab	-1.81**	0.08	0.16	-1.84**	0.05	0.16	-1.80**	0.06	0.17	-1.45**	0.06	0.23
Dist. to Oundoundou	1.55**	0.07	4.72	0.81**	0.04	2.25	0.79**	0.03	2.20	1.14**	0.05	3.12
Forested : late dry	-0.24	0.32	0.25	-0.45*	0.15	0.64	0.70**	0.16	2.02	1.09**	0.16	2.97
Grassland: late dry	-1.20**	0.34	3.57	0.16	0.17	1.17	-0.01	0.21	0.99	0.58*	0.18	1.78
Anthropic: late dry	1.27*	0.63	0.79	0.14	0.31	1.15	0.32	0.37	1.38	-2.22**	0.37	0.11
Savanna: late dry	-1.40**	0.32	0.30	-0.08	0.12	0.92	0.14	0.13	1.15	0.72**	0.12	2.04
Water: late dry	-0.69	626.74	0.50	0.32	317.28	1.38	0.27	324.91	1.31	14.53	204.32	2.0E+06
Forested : wet	-0.82**	0.21	0.67	-0.63**	0.15	0.53	-0.16	0.14	0.85	0.12	0.16	1.13
Grassland: wet	-1.89**	0.22	0.10	0.02	0.17	1.02	0.41*	0.16	1.51	-0.29	0.17	0.75
Anthropic: wet	-2.35*	0.72	0.44	-2.28**	0.53	0.10	-2.50**	0.64	0.08	-1.92**	0.26	0.15
Savanna: wet	-0.39*	0.18	0.15	-0.38	0.12	0.68	-0.51**	0.11	0.60	-0.44**	0.12	0.65
Water: wet	-1.98	281.12	0.14	1.96	376.57	7.10	0.30	367.02	1.35	-0.34	234.06	0.71

Table 6.5 Continued

	Pre-mining			Early mining			Expanded mining			Late mining		
Parameter	**β**	S.E.	O.R.	**β**	S.E.	O.R.	**B**	S.E.	O.R.	**B**	S.E.	O.R.
late dry:Dist. to water	-0.35*	0.15	0.70	-1.30	0.08	0.27	-1.13**	0.08	0.32	-1.09**	0.08	0.34
wet:Dist. to water	0.63**	0.08	1.88	-0.69	0.08	0.50	-0.64**	0.07	0.53	-0.25**	0.07	0.78
late dry:Dist. to baobab	1.05**	0.11	2.87	0.90	0.06	2.46	0.72**	0.10	2.06	1.12**	0.07	3.07
wet:Dist. to baobab	0.56**	0.08	1.74	-0.02	0.08	0.98	0.30**	0.09	1.35	0.43**	0.06	1.54
late dry:Dist. to Oundoundou	-0.18	0.13	0.84	-0.41	0.06	0.66	-0.14**	0.07	0.87	-0.55**	0.07	0.58
wet:Dist. to Oundoundou	-0.95**	0.08	0.39	-0.24	0.06	0.78	-0.29**	0.06	0.74	-0.06	0.06	0.94

** = p <0.001, * = p < 0.05

Table 6.6 Parameter estimates for community-level resource selection function for the Fongoli chimpanzees during the wet, early dry and late dry seasons from 2005 through 2014.

	Wet			Early Dry			Late Dry		
Parameter	β	S.E.	O.R.	β	S.E.	O.R.	β	S.E.	O.R.
Woodland	1.80**	0.15	6.07	0.33*	0.12	1.39	-0.90**	0.20	0.41
Forested	1.34**	0.29	3.80	1.51**	0.22	4.52	2.20**	0.32	9.07
Grassland	-0.48	0.33	0.62	0.85**	0.19	2.35	0.38	0.32	1.46
Anthropic	-3.65**	1.06	0.03	-3.72**	1.02	0.02	-0.79	0.60	0.45
Savanna	-1.25**	0.19	0.29	-1.26**	0.17	0.28	-1.56**	0.33	0.21
Water	-13.90	222.27	0.00	-11.68	535.41	0.00	-11.55	305.81	0.00
Early mining	-1.26**	0.15	0.28	0.17	0.12	1.19	0.53*	0.20	1.70
Expanded mining	-0.68**	0.16	0.51	0.28*	0.12	1.33	0.60*	0.20	1.83
Late Mining	-1.22**	0.15	0.29	0.31*	0.13	1.36	0.17	0.20	1.19
Dist. to settlements	0.66**	0.02	1.94	0.65**	0.02	1.92	0.31**	0.02	1.37
I(dist_water^2)	-0.53**	0.02	0.59	-0.31**	0.01	0.73	-0.35**	0.02	0.70
I(Dist_baob^2)	-0.20**	0.01	0.82	-0.23**	0.01	0.79	-0.03**	0.01	0.97
Slope	0.08**	0.01	1.09	0.12**	0.01	1.12	0.24**	0.01	1.27
Dist. to roads	0.21*	0.10	1.23	0.12	0.07	1.13	0.59**	0.10	1.80
Dist. to Oundoundou	-0.32**	0.09	0.72	0.20*	0.08	1.22	-0.27**	0.02	0.76
Forest:early mining	0.17	0.30	1.18	0.09	0.24	1.10	-0.40	0.33	0.67
Grassland:early mining	-0.82*	0.34	0.44	-2.37**	0.21	0.09	-0.92*	0.34	0.40
Anthropic:early mining	-0.60	1.15	0.55	1.24	1.04	3.47	-1.23*	0.62	0.29
Savanna:early mining	-0.31	0.21	0.73	-0.02	0.18	0.98	0.68*	0.34	1.97
Water:early mining	-0.05	318.33	0.95	-0.97	557.14	0.38	-1.28	334.39	0.28
Forest: expanded	-0.27	0.30	0.77	-0.25	0.24	0.78	-0.45	0.34	0.64
Grassland: expand	-0.76*	0.35	0.47	-2.40**	0.22	0.09	-1.59**	0.35	0.20

Table 6.6 Continued

Parameter	Wet B	Wet S.E.	Wet O.R.	Early Dry B	Early Dry S.E.	Early Dry O.R.	Late Dry B	Late Dry S.E.	Late Dry O.R.
Anthropic: expanded	-1.13	1.21	0.32	1.56	1.04	4.74	-2.72**	0.73	0.07
Savanna: expanded	-0.86**	0.21	0.42	0.06	0.18	1.07	0.48	0.34	1.62
Water: expanded	0.52	343.30	1.69	-1.49	547.43	0.23	-1.39	354.19	0.25
Forest: late mining	0.47	0.30	1.59	-0.32	0.26	0.72	0.02	0.34	1.02
Grassland: late mining	-0.86*	0.35	0.42	-2.03**	0.25	0.13	-0.38	0.34	0.68
Anthropic: late mining	1.49	1.08	4.46	3.20*	1.04	24.56	-1.52*	0.65	0.22
Savanna: late mining	-0.24	0.21	0.79	-0.05	0.20	0.95	1.05*	0.34	2.84
Water: late mining	NA	NA	NA	-1.18	574.94	0.31	12.74	305.81	3.4E05
Dist. to roads: early mining	-0.70**	0.11	0.49	-0.48**	0.08	0.62	-0.89**	0.11	0.41
Dist. to roads: expanded minig	-0.54**	0.11	0.58	-0.30**	0.08	0.74	-0.71**	0.11	0.49
Dist. to roads: late mining	-0.40**	0.11	0.67	-0.49**	0.08	0.61	-0.86**	0.11	0.42
Dist. to Oundoundou: early mining	0.14	0.10	1.15	0.07	0.08	1.08	---	---	---
Dist. to Oundoundou: expanded minig	0.16	0.10	1.18	0.12	0.08	1.13	---	---	---
Dist. to Oundoundou: late mining	0.76**	0.09	2.15	0.18*	0.09	1.19	---	---	---

** = p <0.001, * = p < 0.05

Table 6.7 Parameter estimates for resource selection function for the Fongoli chimpanzees at the Oundoundou mining area.

Parameter	**β**	S.E.	*p*	O.R.
Woodland(Intercept)	130.37	21.16	<0.001	4.14E+56
Forest	-34.20	6.00	<0.001	0.00
Grassland	-42.13	8080.35	n.s.	0.00
Anthropic	38.04	69439.61	n.s.	3.31E+16
Savanna	-54.50	8.99	<0.001	0.00
Expanded mining	0.19	1.08	n.s.	1.21
Dist. to settlements	46.27	7.74	<0.001	1.24E+20
I(dist_water^2)	-195.19	31.93	<0.001	0.00
Late dry season	-139.90	2384.96	n.s.	0.00
I(dist_bao^2)	-28.66	4.98	<0.001	0.00
Slope	-2.77	0.87	<0.05	0.06
I(dist_water^2): late dry	225.44	2393.98	n.s.	8.11E+97
I(dist_bao^2): late dry	3.31	6440.33	n.s.	27.44

Table 6.8 Behaviors observed (in minutes) at the Oundoundou mining, arranged by physiognomies, seasons, and level of mining. No activity was observed during the wet season or in pre-mining levels. Presence or absence of miners when the activities were observed is given in parentheses.

			DR	F	R	SG	TR	Social	Totals
Anthropic									295 (A)
	Early	edry	0	0	0	0	0	0	
		ldry	0	30 (A)	10 (A)	0	5 (A)	0	
	Exp	edry	0	110 (A)	40 (A)	0	20 (A)	80 (A)	
		ldry	0	0	0	0	0	0	
Forest/Woodland									350 (P,A)
	Early	edry	0	65 (P)	0	0	0	0	
		ldry	5(A)	40 (A)	40 (A)	0	5 (A)	20 (A)	
	Exp	edry	0	25 (P)	115 (P)	0	15 (P)	15 (P)	
		ldry	0	0	0	0	0	0	
	Late	ldry	0	0	0	0	5 (P)	0	
Savanna/Grassland									425 (P, A)
	Early	edry	0	30 (A)	130 (A)	0	0	0	
		ldry	0	0	30 (P)	0	0	10 (P)	
	Exp	edry	0	60 (P, A)	95 (P)	5(P)	55 (P, A)	10 (P)	
		ldry	0	0	0	0	0	0	
Total			5 (A)	360 (P, A)	460 (P, A)	5 (P)	105 (P, A)	135 (P, A)	1070

DR = Drink; F = Feed; R = Rest; SG = Self groom; TR = travel; Social = socal behaviors
Early = early mining; Exp = expanded mining; Late = late mining;
P = miners present, A = miners absent; edry = early dry season, ldry = late dry season

Table 6.9 Select data book entries for December 5, 2012 describing the chimpanzees' reaction to mining activity at the Oundoundou mine. The chimpanzees were traveling in a large group of 17 to 21 individuals during this encounter.

12/5/2012 (Wednesday)	
1012	Siberut crossed the Fongoli-Kedougou road
1013	Aimee is the last to cross the road
1015	Siberut travels across the burned plateau
1020	Siberut travels across the burned plateau
1025	The chimpanzees cry very loudly at a rock crushing machine at the Oundoundou mine.
…	
1110	The chimpanzees are resting in the forest at 50 m from people in the *djurra* [ASGM mining site]. I can see Mody Camara, [a man from Fongoli village] clearing a place to look for gold
…	
1315	Eva is passed by men on bicycles from the *djurra* at about 15 m
1320	Siberut is eating ripe baobab fruit
…	
1337	Mike and Lily vocalize again at the noise of the machines
…	
1345	There is a bush fire between the men of the *djurra* and the chimpanzees
…	
1615	I think the chimpanzees are waiting for the men in the *djurra* to leave so they can go down to the baobab tree located inside the *djurra*.

Table 6.10 Occurrences of food species eaten at the Oundoundou mining area within woodland and forest physiognomies and grassland and savanna physiognomies, across mining levels, and either prior to mining activity or during mining activity.

Mining level	Land cover		Os	Ad	Bc	Fsp	Pt	Gan	Pe	Ba	Ss	Fu	Cc	Ti	Fs	**Tr**	Total
Early	Anthropic	prior	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		during	1	21	0	0	46	0	6	0	1	0	0	0	0	0	75
	Forest/Woodland	prior	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		during	18	19	0	12	0	0	0	2	9	5	3	0	0	0	68
	Savanna/Grassland	prior	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		during	3	6	1	0	0	1	0	0	0	0	0	4	0	0	15
Expand	Anthropic	prior	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		during	1	21	0	0	0	0	0	0	0	0	0	0	0	0	22
	Forest/Woodland	prior	0	0	0	0	0	0	0	0	0	0	0	0	0	18	18
		during	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	Savanna/Grassland	prior	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
		during	2	0	1	0	0	1	0	0	0	0	0	0	0	6	10
Late	Anthropic	prior	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		during	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Forest/Woodland	prior	4	30	0	0	1	0	0	0	0	0	0	0	5	11	51
		during	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Savanna/Grassland	prior	2	0	0	0	1	0	0	0	0	0	0	0	0	2	5
		during	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total		35	97	2	12	48	3	6	2	10	5	3	4	5	37	269

Os = *Oxytenanthera abyssinica;* Ad = *Oxytenanthera abyssinica*; Bc = *Bombax costatum*; Fsp = Ficus sp.; Pt = *Piliostigma thonningii*; Gan = 'gangach'; Pe = *Pterocarpus* erinaceus; Ba = *Borassus aethiopum* or *akeassii*; Ss = *Saba senegalensis*; Fu = *Ficus umbellate*; Cc = *Cola cordifolia*; Ti = *Tamarindus indica*; Fs = *Ficus sycomorus*; Tr = termites, unknown species

Table 6.11 Parameter estimates for resource selection function for the Fongoli chimpanzees at the Kerouani mining area.

Parameters	β	p-value
LCGallery Forest (Intercept)	1.00E+00	<0.001
LCGallery Forest, Mature	-9.39E-17	0.97
LCGallery Forest, Open or Degraded	2.29E-15	0.111
LCTree Savanna	-1.44E-16	0.981
LCWooded Savanna	-1.44E-16	0.991
LCWoodland	-1.44E-16	0.925
mine_levelexpan	4.30E-16	0.964
mine_levellate	2.43E-15	0.799
subseasonldry	6.01E-19	1
subseasonwet	-7.03E-17	0.996

Table 6.12 Occurrences of behaviors observed at the Kerouani mining area in physiognomy groups, across mining levels, and subseasons.

		DR	F	Social	NEST	R	SG	TR	Total
Forest/Woodland									
early	edry	0	0	0	0	0	0	0	0
	ldry	0	0	0	0	0	0	**2**	**2**
	wet	0	0	0	0	0	0	0	0
expand	edry	0	0	0	0	0	0	0	0
	ldry	**1**	**9**	**29**	**1**	**37**	**3**	**5**	**85**
	wet	0	0	0	0	0	0	0	00
late	edry	0	0	0	0	0	0	**1**	**1**
	ldry	**11**	**48**	**70**	0	**267**	**6**	**21**	**429**
	wet	0	**8**	**10**	**1**	**35**	0	**5**	**59**
Savanna/Grassland									
late	edry	0	0	0	0	0	0	0	0
	ldry	0	**1**	0	0	**2**	0	**2**	**6**
	wet	0	0	0	0	0	0	0	0
Total		**12**	**66**	**109**	**2**	**341**	**9**	**36**	**583**

DR = Drink; F = Feed; R = Rest; SG = Self groom; TR = travel; Social = socal behaviors;
Early = early mining; Exp = expanded mining; Late = late mining;

Table 6.13 Data book entries for drinking activity at the Kerouani mining area

3/23/11 (Wednesday)	
855	Bilbo digs a hole to **drink**
1430	Chimpanzee is disturbed by a fire that was set by miners from the new *djurra* [ASGM mining site] at Kerouani
(no mention of mining activity at this location)	
5/2/2013 (Thursday)	
1257	Mike and KL continue to travel toward the Kerouani *djurra*.
1309	Mike **drinks** from a mine hole in the *djurra*.
1310	Mike climbs out of the mining hole
(no mention of people at the mine that day)	
5/9/2013 (Thursday)	
1050	The chimps **drink** water from a mining hole in the *djurra*. There are no people here today.
5/15/2013 (Wednesday)	
1045	David travels in the direction of the Kerouani *djurra*.
1051	David climbs down into a mining hole to **drink**.
1053	He climbs out with his cheeks full of water.
(no mention of people at the mine that day)	
5/16/2013 (Thursday)	
1026	Diouf **drinks** water from inside the mine
1027	He climbs out with his cheeks full of water.
1232	The sound of voices (approximatel 300 m away)
1245	Diouf leaves the *djurra*. There are some people who have come to the *djurra*.
1249	The people are collecting honey. The chimps run by the people do not yell at them.
1258	There are also some people looking for gold with machines [metal detectors]
4/22/2014 (Tuesday)	
1055	The chimpanzees look at the people at the Kerouani *djurra*, but no one is bothering the chimps; also the chimps are not vocalizing at them.
1107	Siberut digs a hole to **drink** water in the *djurra*
1110	Siberut still **drinking** water from his well
1125	Siberut walks away from the group (about 50m) but I don't want to leave the others next to the people at the *djurra* because there are some people passing by.
1127	There is one person who passed at 15m on the path, the chimps hid in the ravine.
1705	Siberut is sitting in a tree 30m from men at the djurra. I am in the middle of them.
1710	He stays in the same place (me too)

Table 6.13 Continued

1714	Diouf **drinks** from the interior of a mining hole in the djurra
1727	Siberut moves to termite fish. I stay between the female chimpanzees and the men of the *djurra*.
1745	The chimpanzees leave the *djurra*.
4/23/2014 (Wednesday)	
1212	The chimps **drink** from the same place as yesterday at the djurra
1230	DV **drink**
(no mention of people)	
4/29/2014 (Tuesday)	
957	The chimps **drink** water at the Kerouani *djurra*. There are not many people today.

Table 6.14 Proportion of time spent consuming food products at the Kerouani mining area within forest and woodland versus grassland and savanna land cover categories, across mining levels, and either prior to mining activity or during mining activity.

	Expanded Mining				Late Mining				
	Forest/Woodland		Savanna/Grassland		Forest/Woodland		Savanna/Grassland		Total
Food spp.	prior	during	prior	during	prior	during	prior	during	
Oa	0	0	0	0	0.00222	0	0	0	0.00222
Ad	0	0	0	0	0.00047	0	0	0	0.00047
Cp	0	0	0	0	0.00011	0	0	0	0.00011
Bc	0	0	0	0	0	0.00017	0	0	0.00017
Bm	0	0	0	0	0	0.00069	0	0	0.00069
Dm	0	0	0	0	0.00021	0	0.00005	0	0.00026
Os	0	0	0	0	0	0.00137	0	0	0.00137
Fsp	0	0	0	0	0	0.00172	0.00047	0	0.00219
Pt	0	0.00122	0	0	0.00248	0	0	0	0.0037
Honey	0	0	0	0	0.00005	0	0	0	0.00005
Pe	0	0	0	0	0.00174	0	0.00005	0	0.00179
Pr	0	0	0	0	0.00016	0	0	0	0.00016
Pb	0	0	0	0	0	0.00034	0	0	0.00034
Rsp	0	0	0	0	0.00005	0	0	0	0.00005
Ss	0	0	0	0	0.00011	0.00274	0	0	0.00285
Do	0	0	0	0	0	0.00017	0	0	0.00017
Ge	0	0	0	0	0	0	0	0.00017	0.00017
Termites	0	0	0	0	0.00042	0.00206	0	0	0.00248
	0	0.00122	0	0	0.0076	0.00926	0.00058	0.00017	0.01883

Os = *Oxytenanthera abyssinica;* Ad = *Oxytenanthera abyssinica*; Cp = *Cissus populnea;* Bc = *Bombax costatum*; Bm = *Baissea multiflora* ; Dm = *Diospyros mespiliformes*; , Os = *Oncoba spinosa* Fsp = *Ficus* species; Pt = *Piliostigma thonningii*; Honey = honey gathered from beehive; Pe = *Pterocarpus* erinaceus; Pr = *Phoenix reclinata*; Pb= *Parkia biglobosa*; Rsp = *Raphia* species; Ss = *Saba senegalensis*; Do = *Daniellia olivieri*; Ge = *Gardenia erubescens,* Termites = unknown species

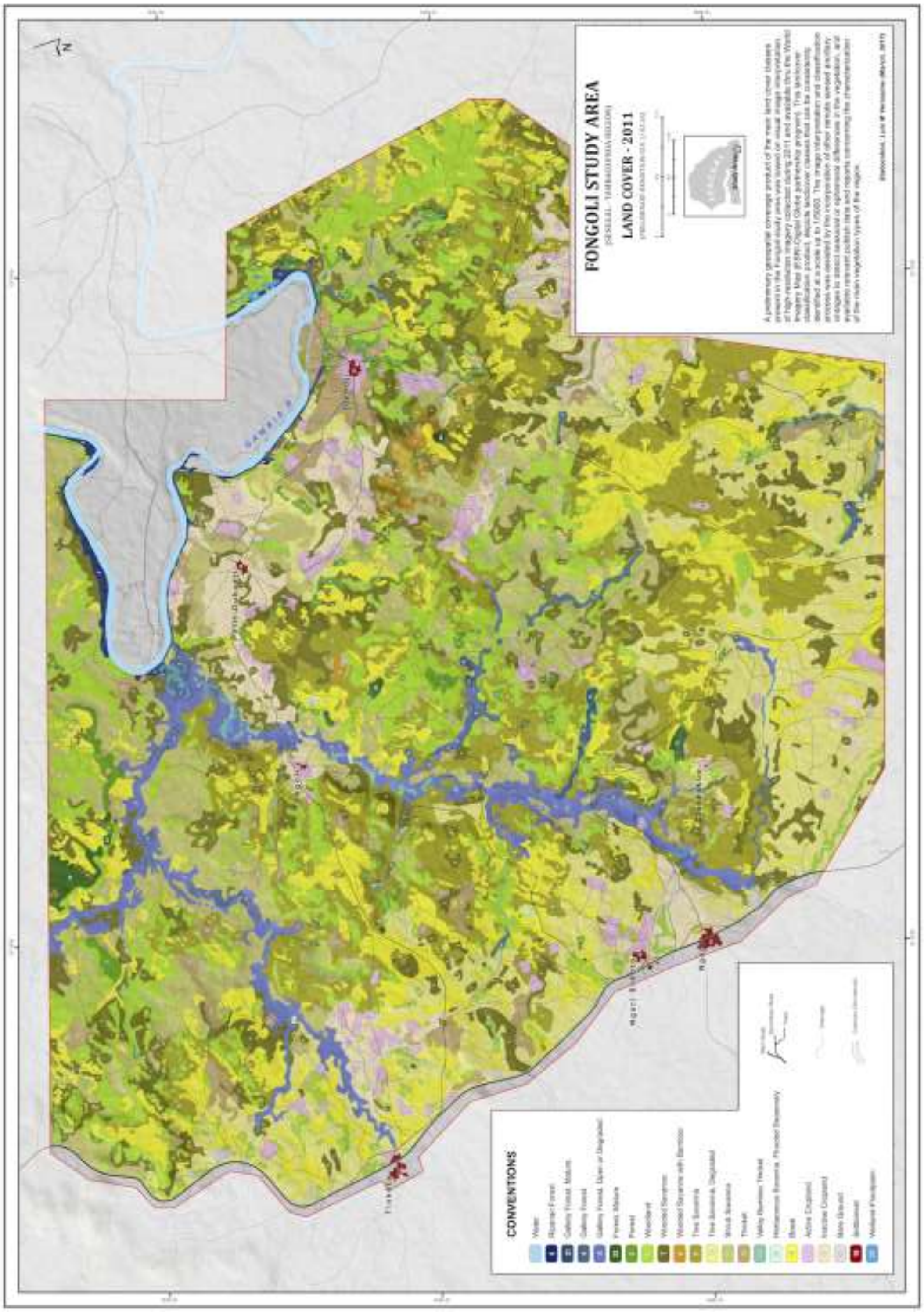

Figure 6.1 Fongoli field site land cover map

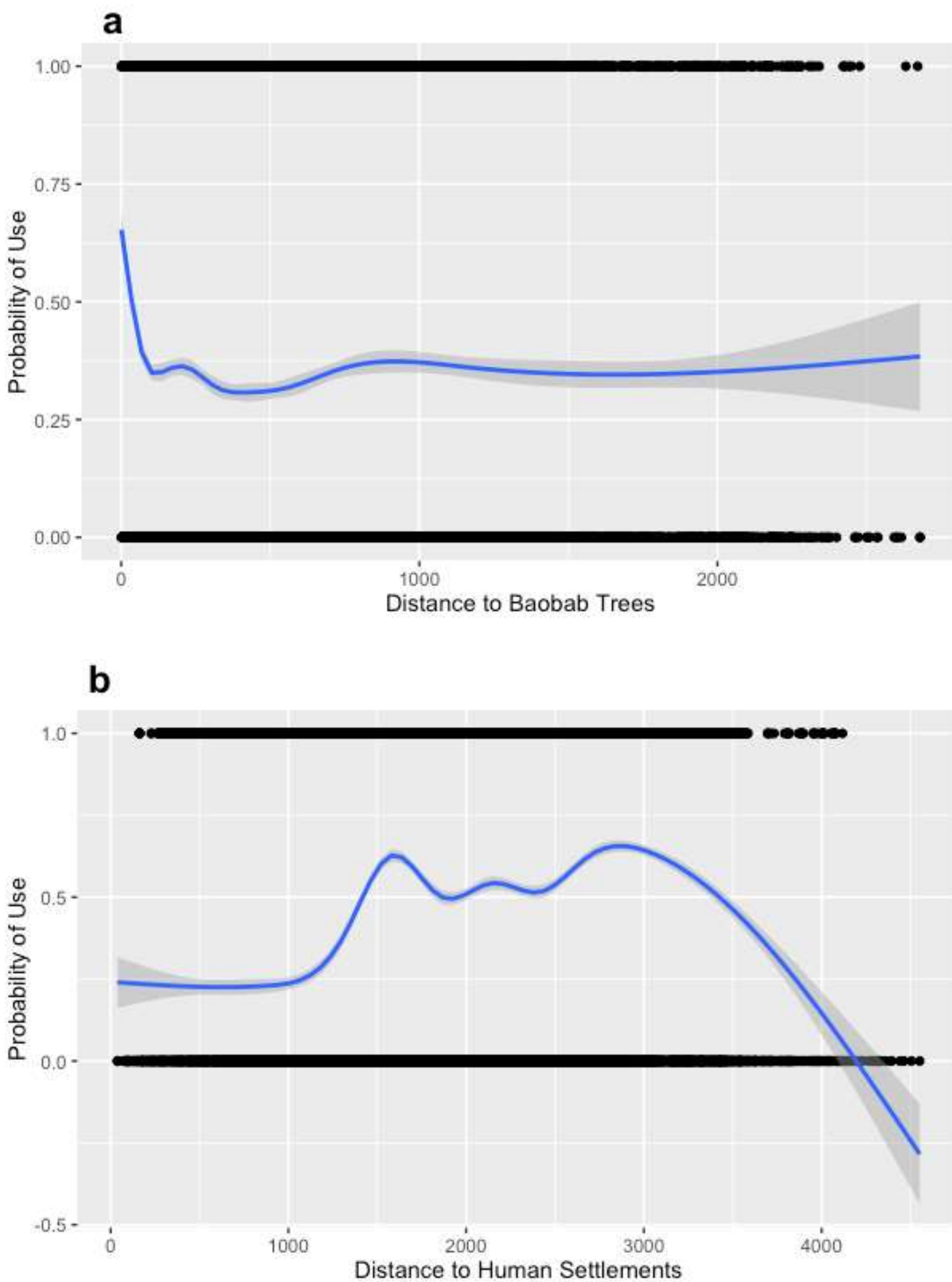

Figure 6.2 Probability of chimpanzee habitat use within the Fongoli home range in relation to (a) distance to baobab trees (*Adansonia digita*) and (b) distance to human settlements.

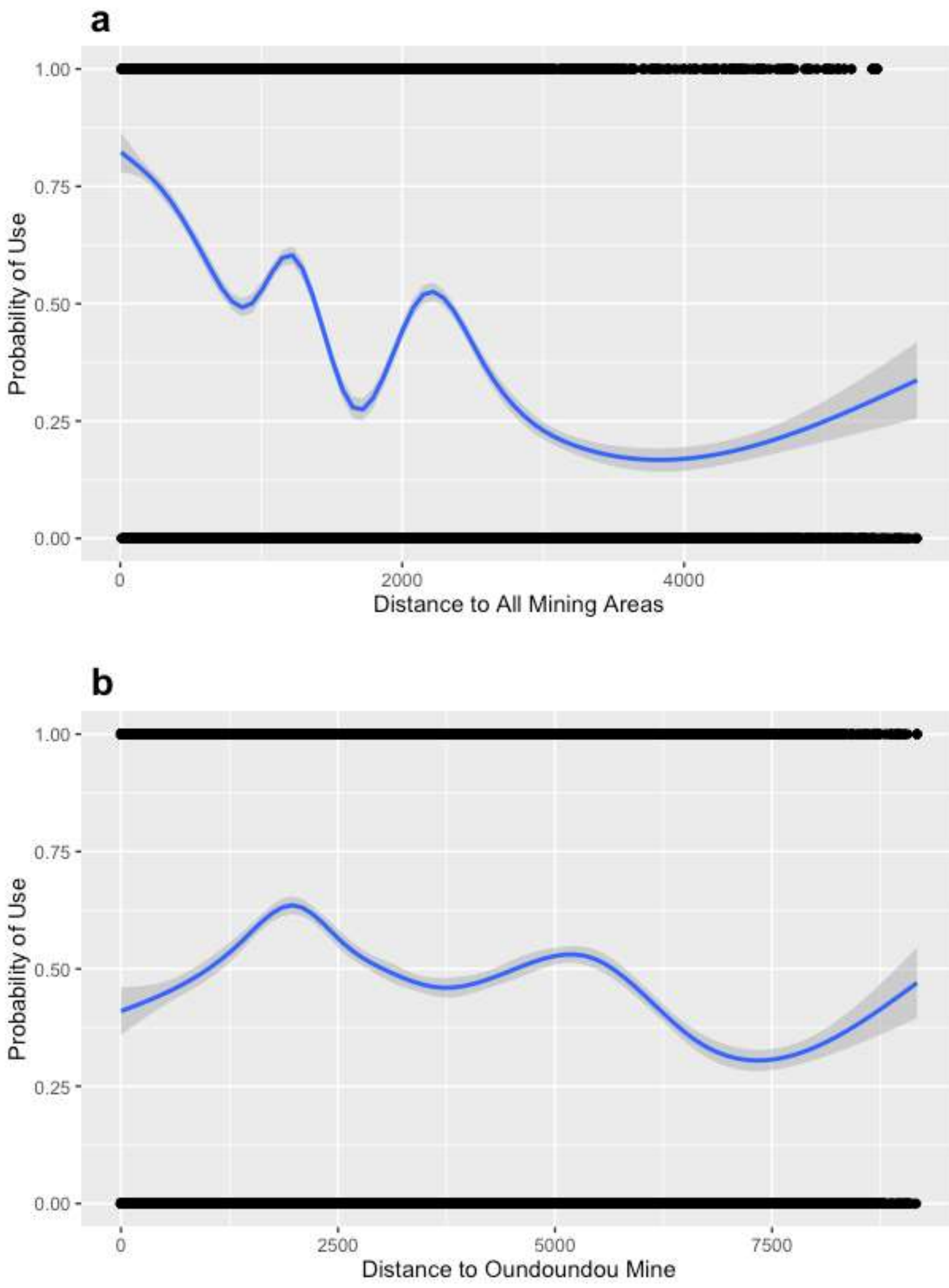

Figure 6.3 Probability of chimpanzee habitat use within the Fongoli home range in relation to (a) distance to all mining areas and (b) distance to the Oundoundou mine.

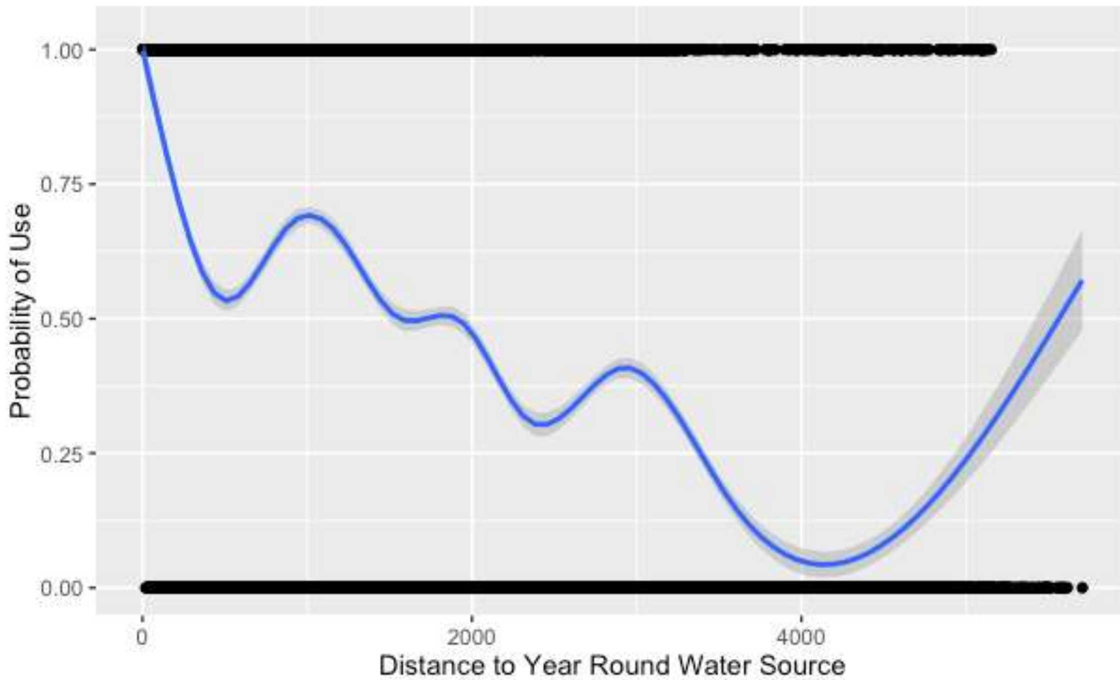

Figure 6.4 Probability of chimpanzee habitat use within the Fongoli home range in relation to distance to year-round water sources.

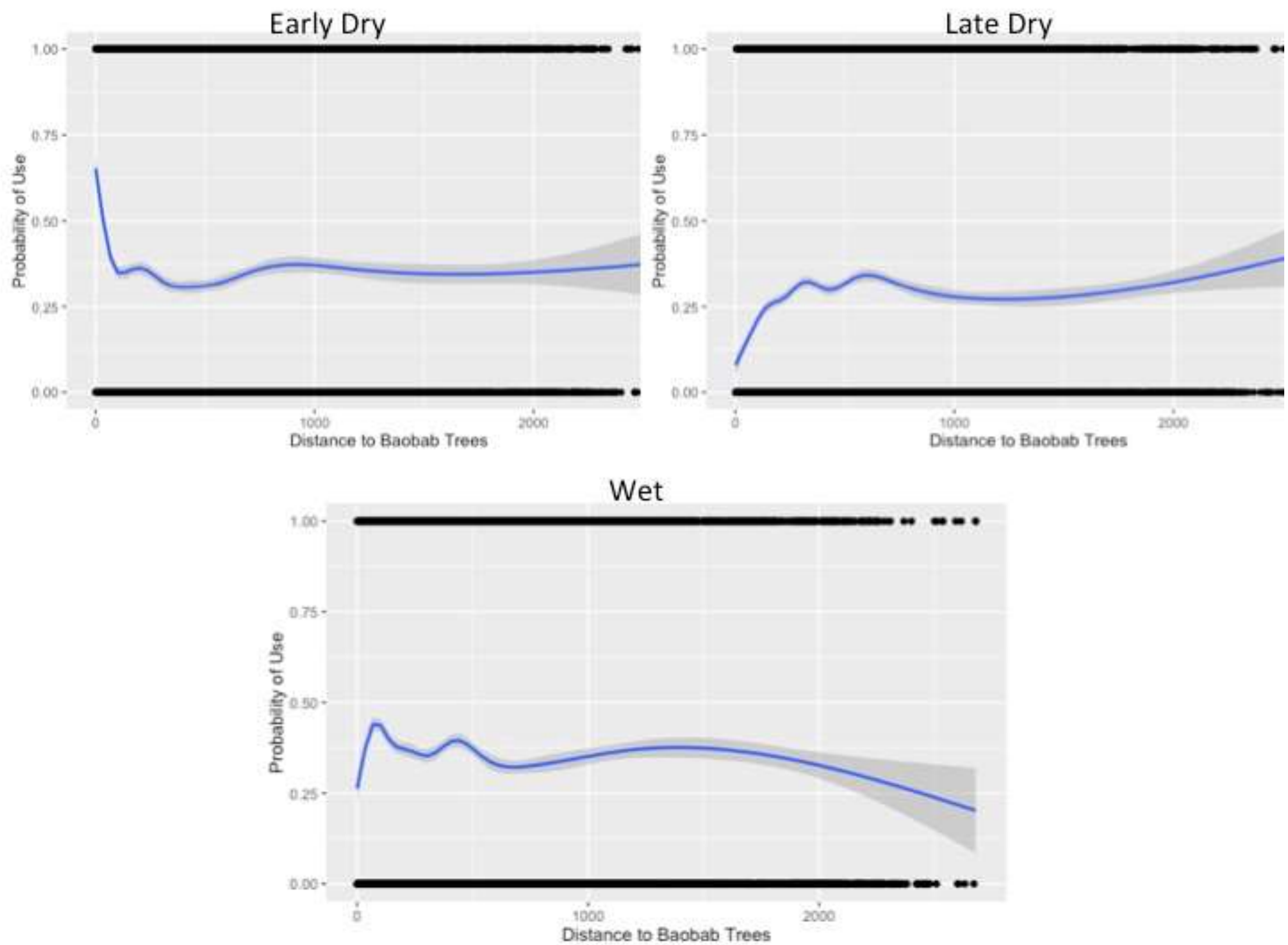

Figure 6.5 Probability of chimpanzee habitat use in relation to the distance to the nearest baobab tree for the three seasons.

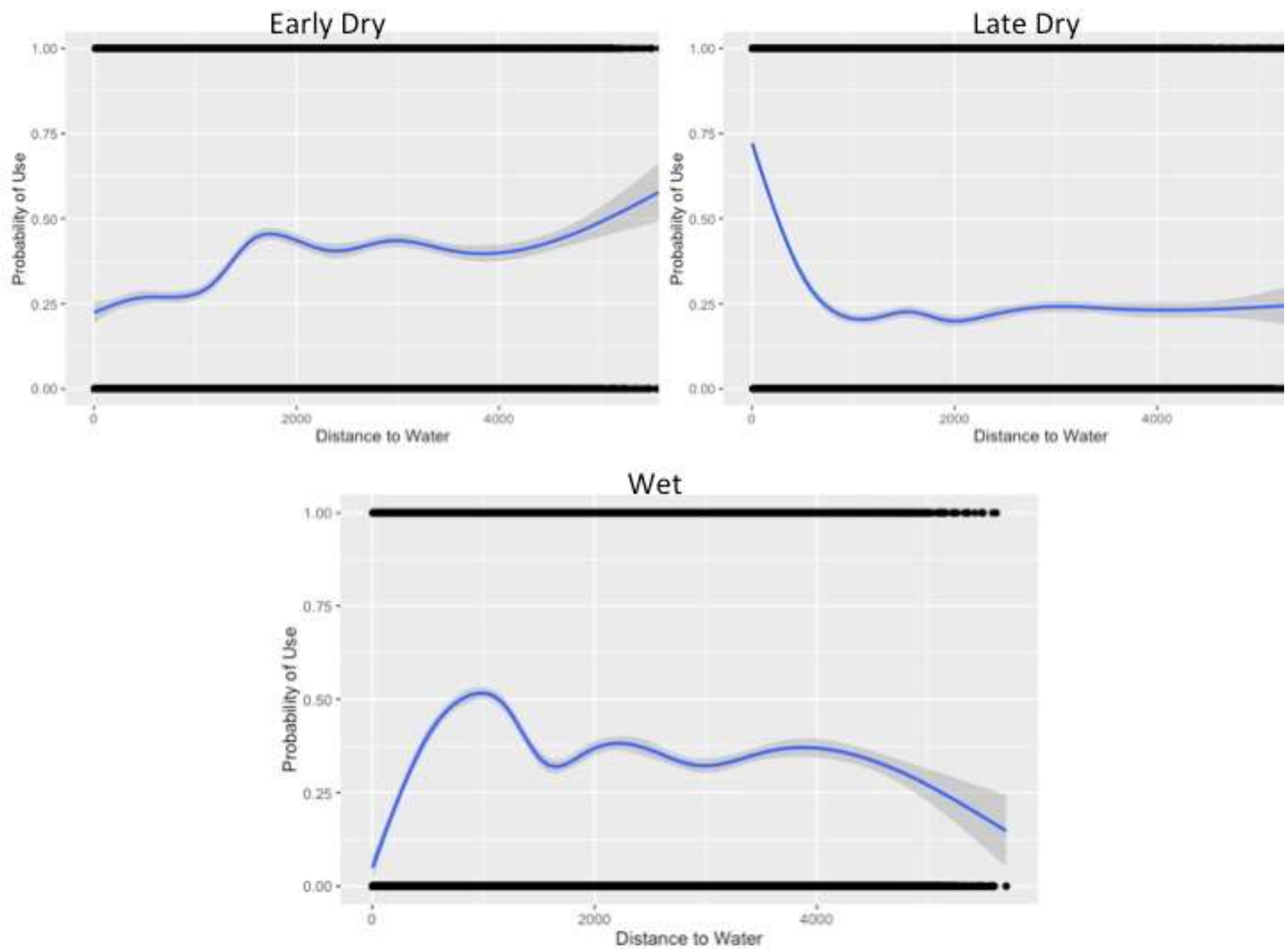

Figure 6.6 Probability of chimpanzee habitat use in relation to the distance to the nearest year-round water source for the three seasons.

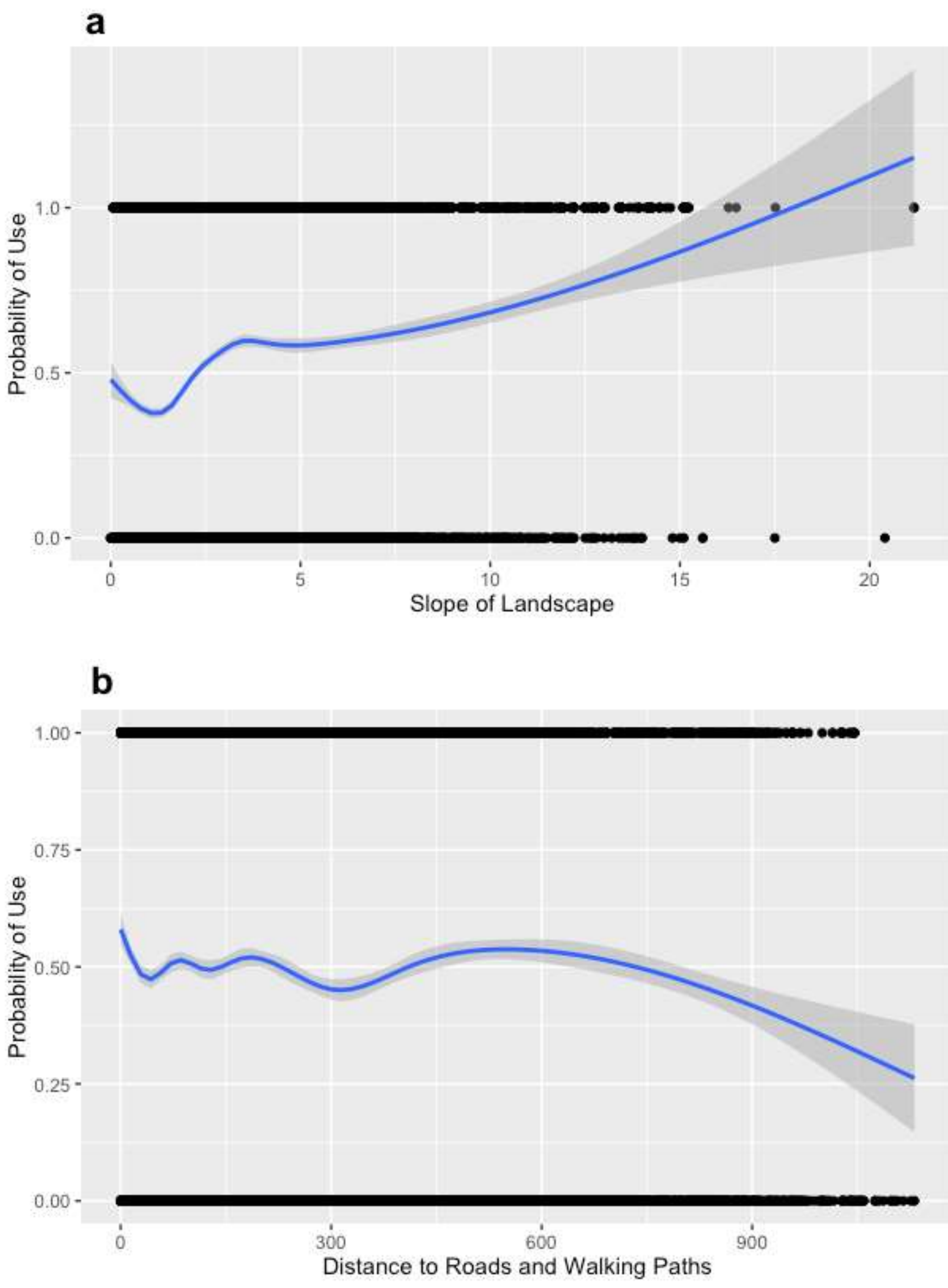

Figure 6.7 Probability of chimpanzee habitat use within the Fongoli home range in relation to (a) slope and (b) distance to roads and walking paths.

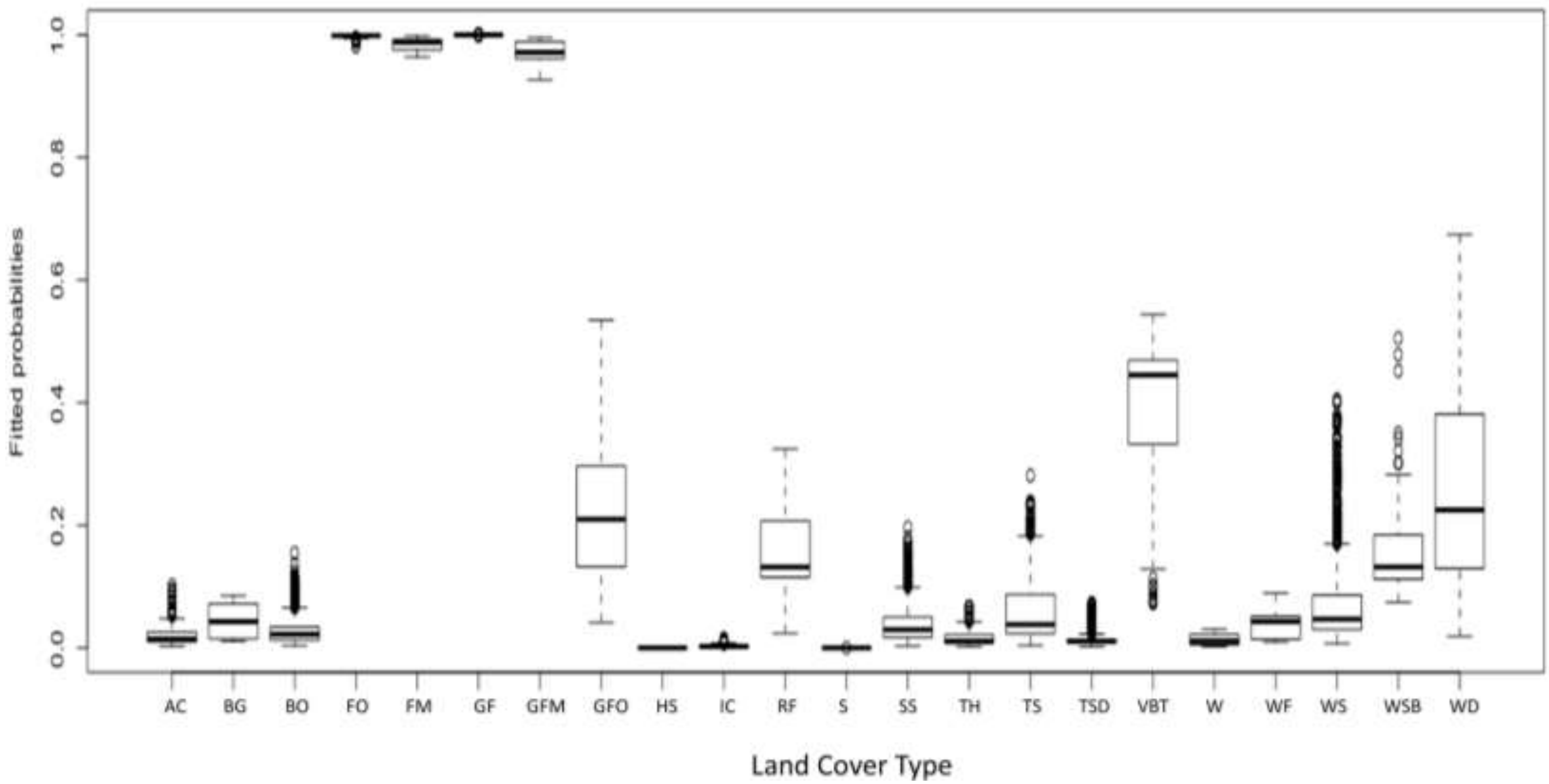

Figure 6.8 Probably of use for each land cover type.
AC = Active Cropland; BG = Bare Ground; Bo = Bowe; FO = Forest; FM = Forest, Mature; GF = Gallery Forest, GFM = Gallery Forest, Mature; GFO = Gallery Forest, Open or Degraded; HS = Herbaceous Savanna, Flooded Seasonally; IC = Inactive Cropland; RF = Riparian Forest; S = Settlement; SS = Shrub Savanna; TH = Thicket; TS = Tree Savanna; TSD = Tree Savanna, Degraded; VBT = Ravine bamboo Thicket; W = Water; WF = Wetland-Floodplain; WS = Wooded Savanna; WSB = Wooded Savanna with Bamboo, WD = Woodland

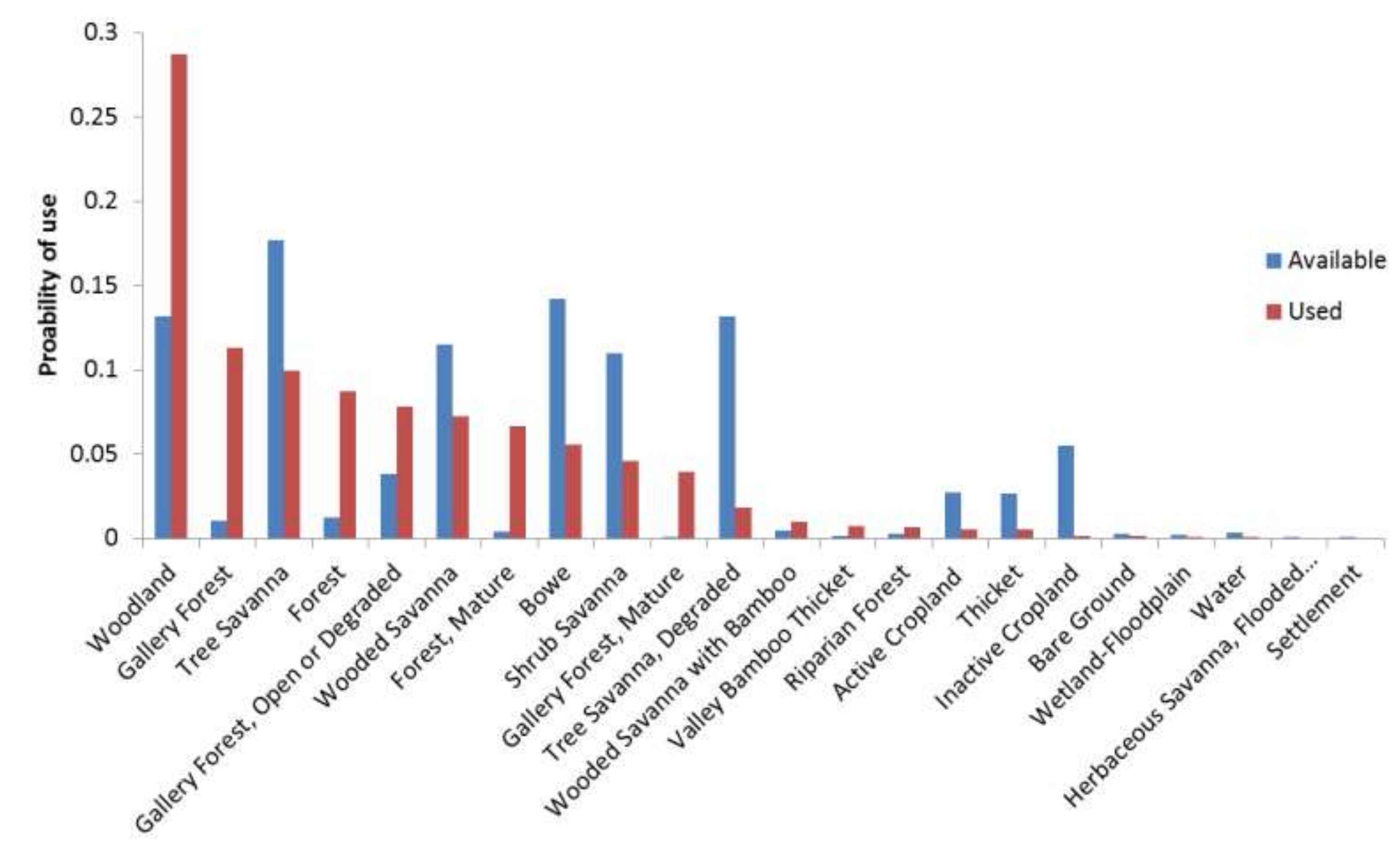

Figure 6.9 Proportion of land cover vegetation types used by the Fongoli chimpanzees compared to available proportions within the community home range, as defined by a MCP of all chimpanzee locations.

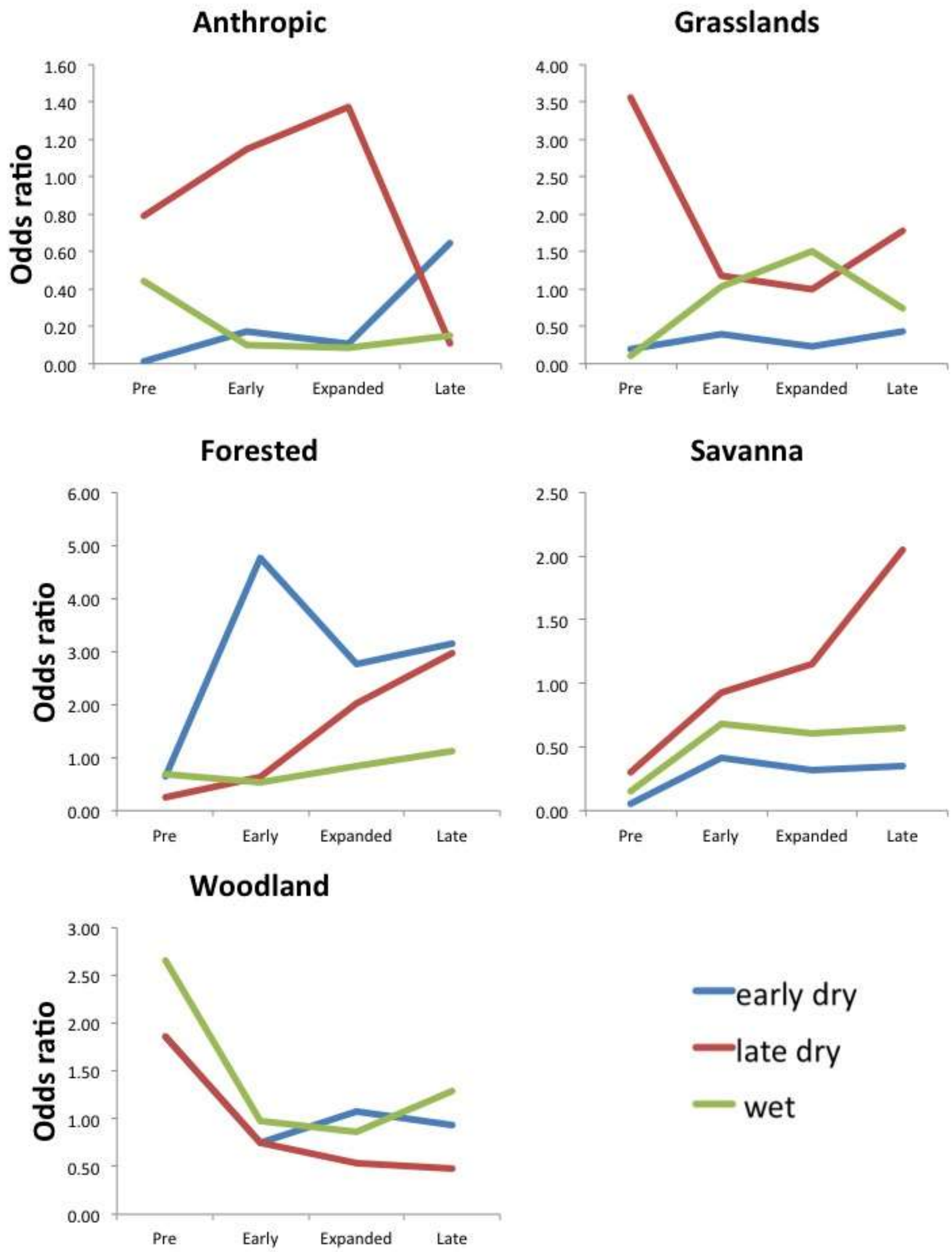

Figure 6.10 Changes in odds ratio likelihood for chimpanzees' use of each physiognomy classification across the four mining periods and three seasons.

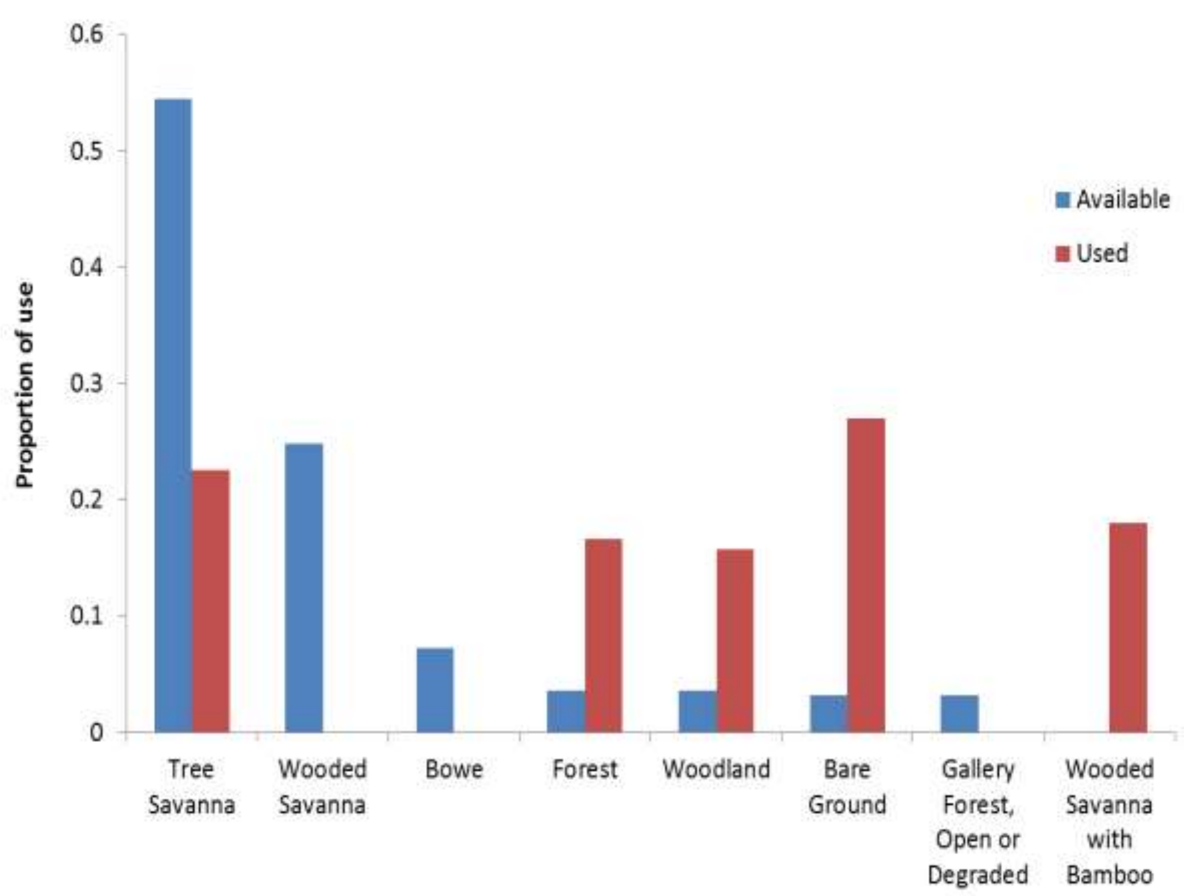

Figure 6.11 Use and availability of land cover types at less than 10 meters from the Oundoundou mining area

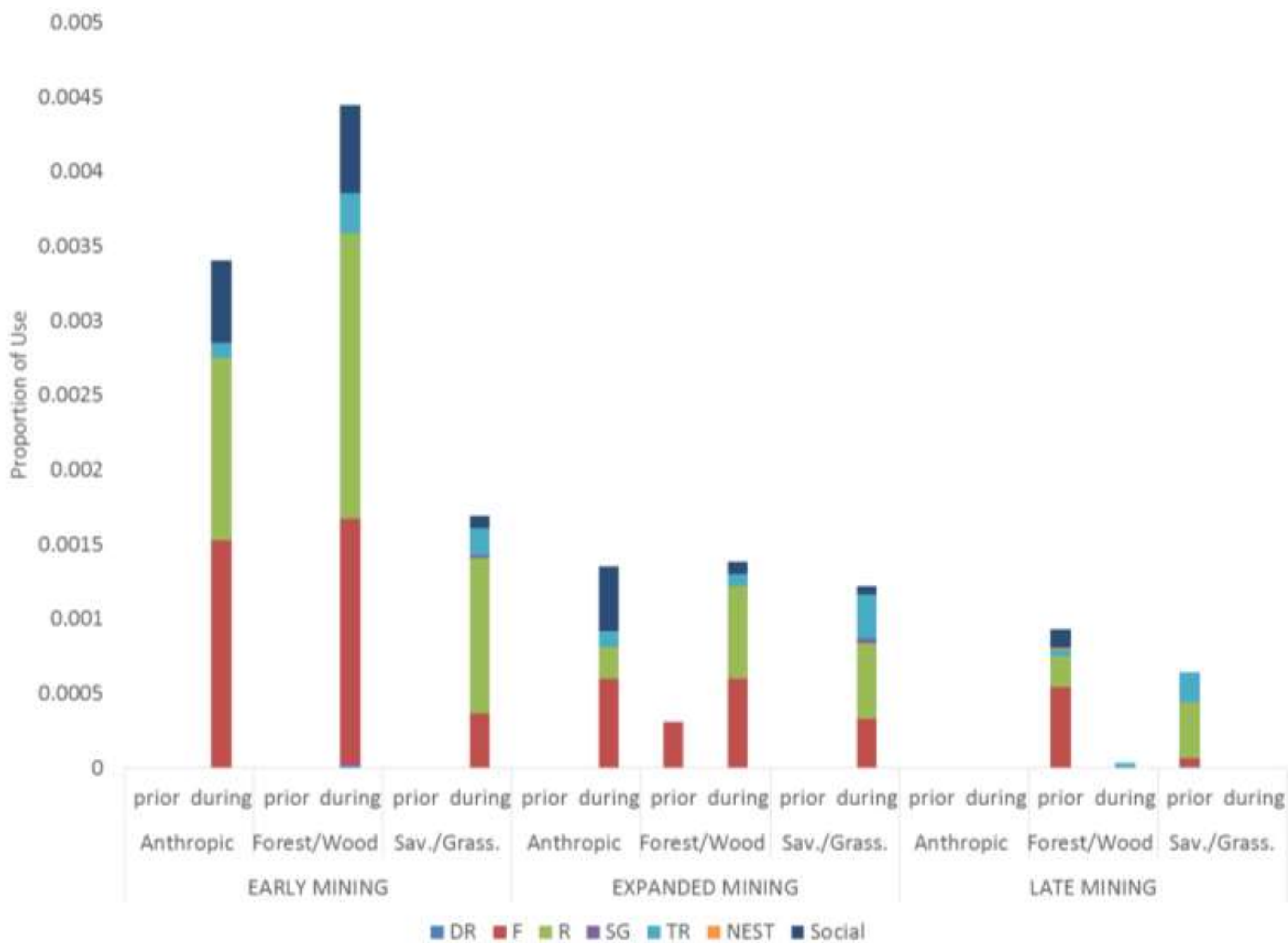

Figure 6.12 Chimpanzee use at the Oundoundou mine as mining expands over the study period.

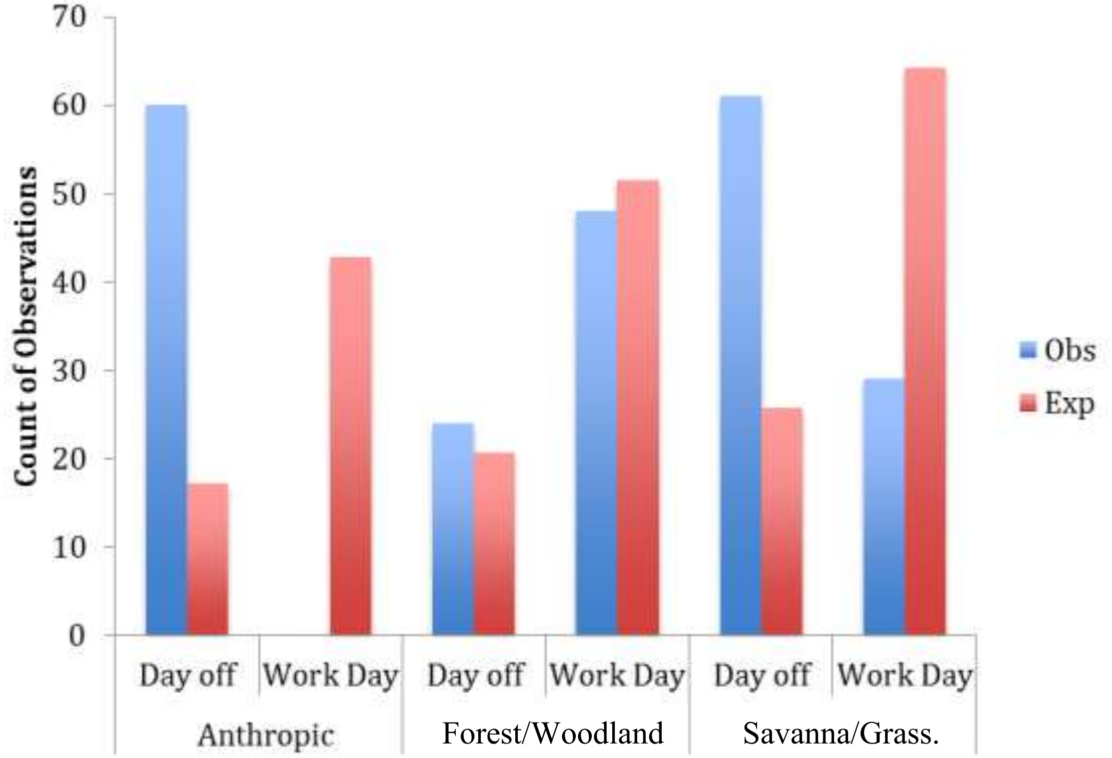

Figure 6.13 Use of anthropic, forest and woodland, and savanna and grassland land cover types at the Oundoundou mine on days when miners were working (Tuesday, Wednesday, Thursday, Saturday and Sunday) or had days off (Monday and Friday).

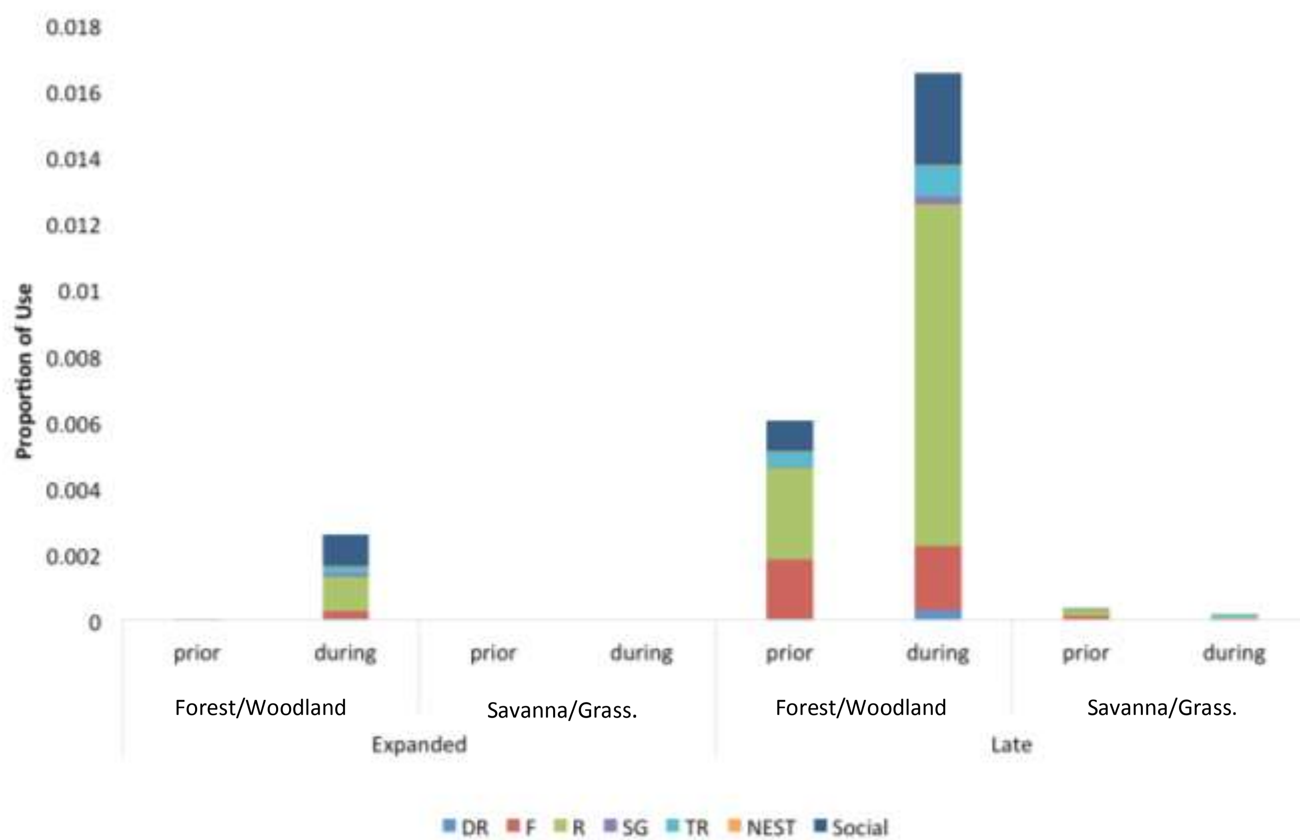

Figure 6.14 Chimpanzee use of the Kerouani mining area as mining increased.

Appendix 1

Table A1.1 Habitat preferences and avoidance of the 22 land cover types for each season and behavioral activity. Intensity of preference or avoidance, relative to the other seasons or behaviors, is indicated by number of symbols shown

	Land Cover Types	Early Dry	Late Dry	Wet	Feeding	Drinking	Nesting
Anthropic	Active Cropland	-	- - -	- - -	-	-	-
	Inactive Cropland	-	-	-	-	-	-
	Bare Ground	-	=	nu	-	-	-
	Settlement	nu	nu	nu	Nu	nu	nu
Forest	Forest	+	+	++	+	+	+
	Gallery Forest	+	+	+	+	++	+
	Gallery Forest, Open/ Degr.	=	+	=	+	++++	+
	Gallery Forest, Mature	+	+	+	+	++	+
	Forest, Mature	+	++	+	+	+	+
	Riparian Forest	+	+	-	+	=	+
Grassland	Bowe	-	-	-	-	-	-
	Wetland-Floodplain	nu	=	nu	-	+	-
Savanna	Tree Savanna	-	-	-	-	-	-
	Shrub Savanna	-	-	-	-	-	-
	Thicket	-	- - -	- - -	-	-	-
	Ravine bamboo Thicket	+	++++	nu	+	+	+
	Tree Savanna, Degraded	-	-	- - -	-	-	-
	Herb. Sav., Flooded Season.	nu	nu	nu	Nu	nu	nu
Woodland	Woodland	+	+	+	+	-	+
	Wooded Sav. w/ Bamboo	+	+	+	+	+	+
	Wooded Savanna	=	-	-	-	-	-
Water	Water	nu	-	nu	Nu	nu	nu

- avoid; + prefer; = as expected; nu, no use

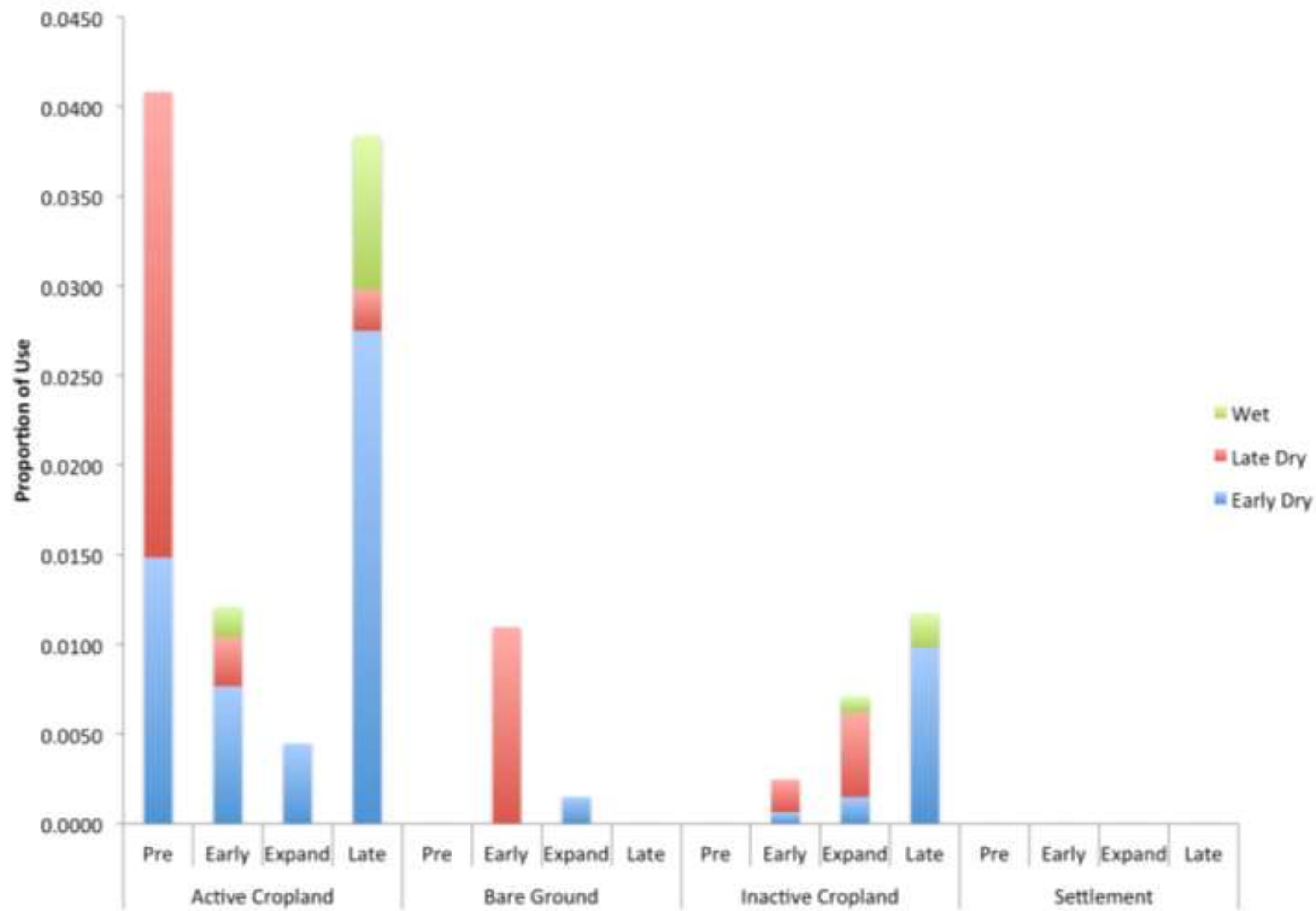

Figure A1.1 Chimpanzee usage of anthropic land cover types across mining levels and seasons

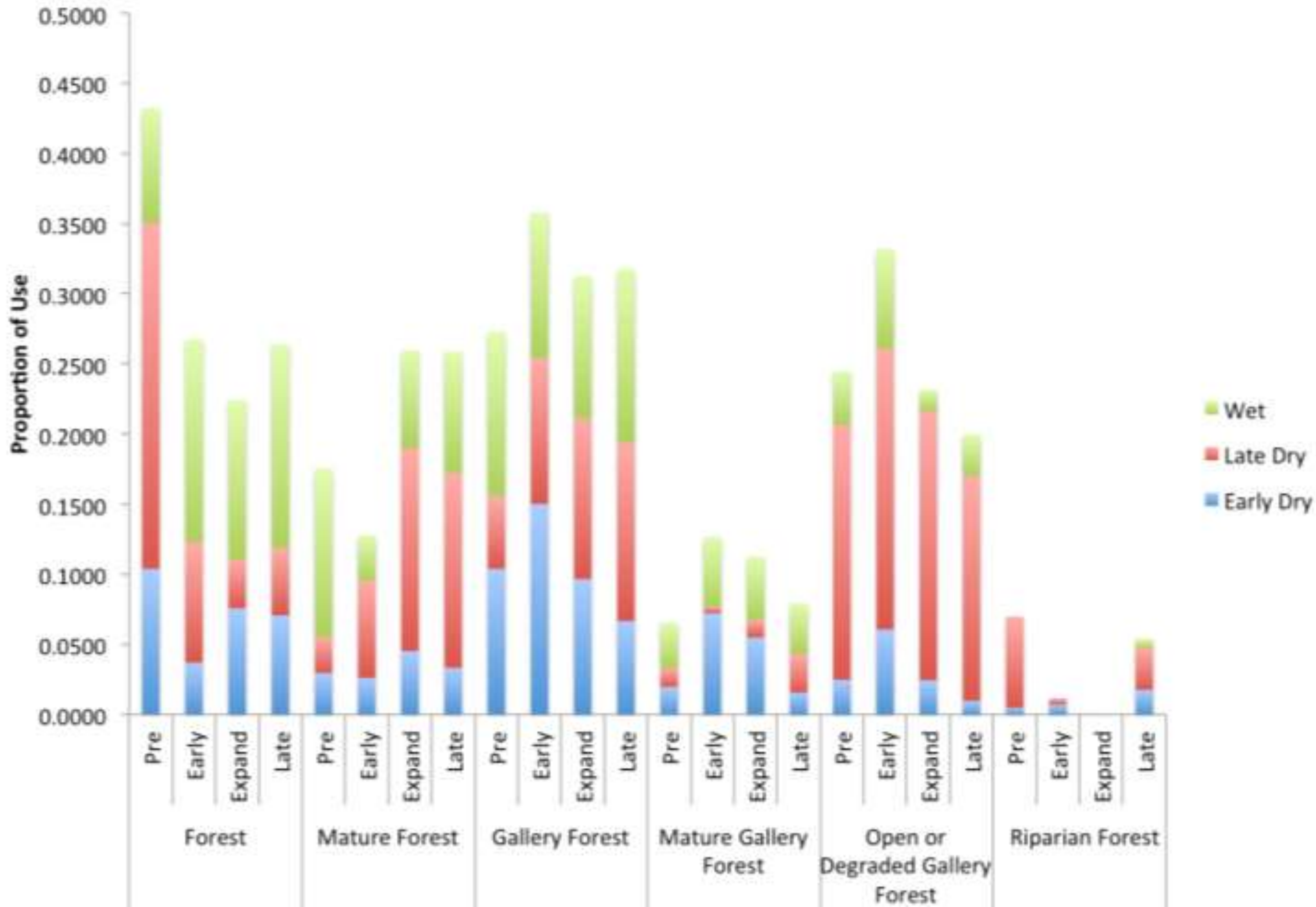

Figure A1.2 Chimpanzee usage of forest land cover types across mining levels and seasons

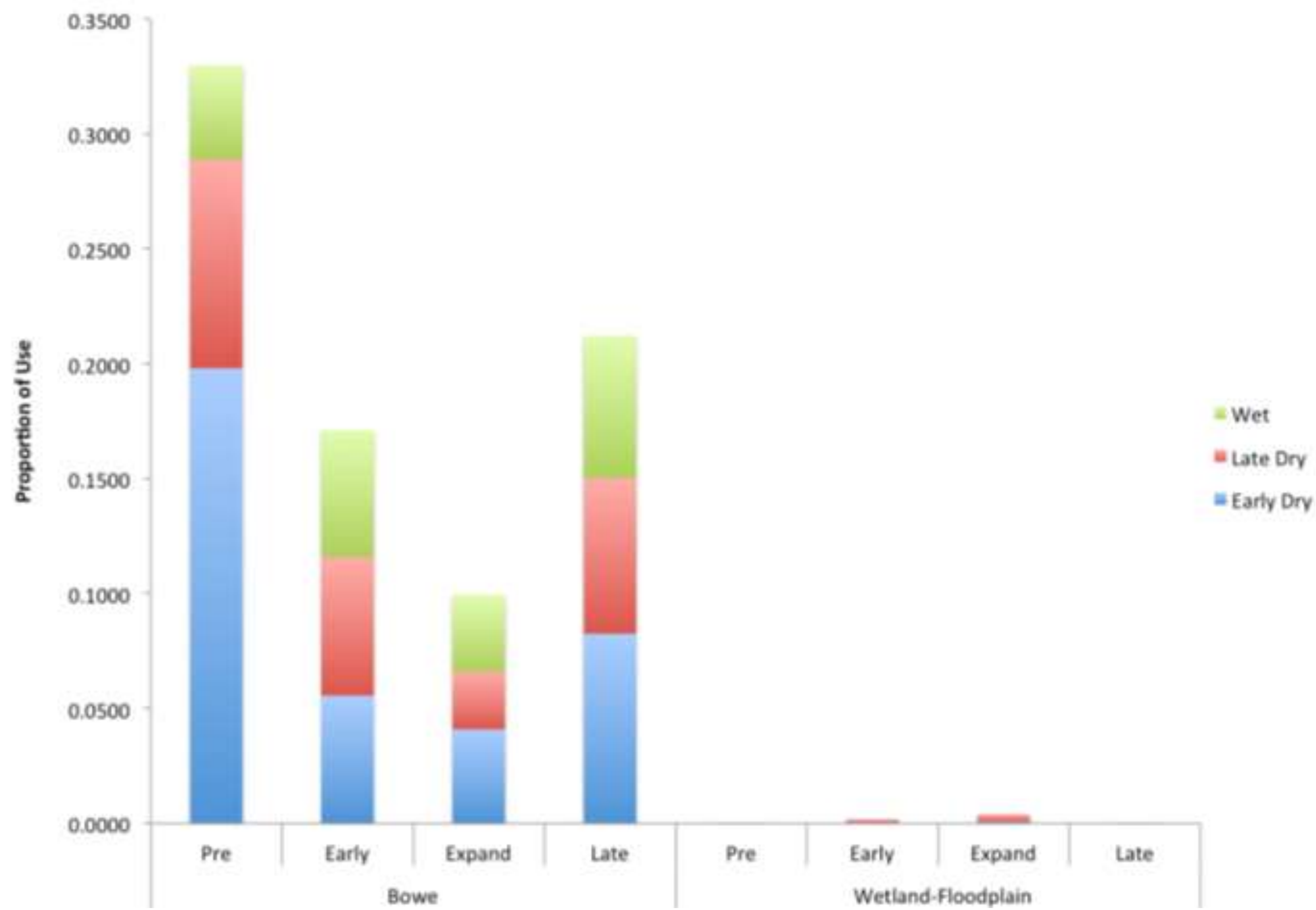

Figure A1.3 Chimpanzee usage of grassland land cover types across mining levels and seasons

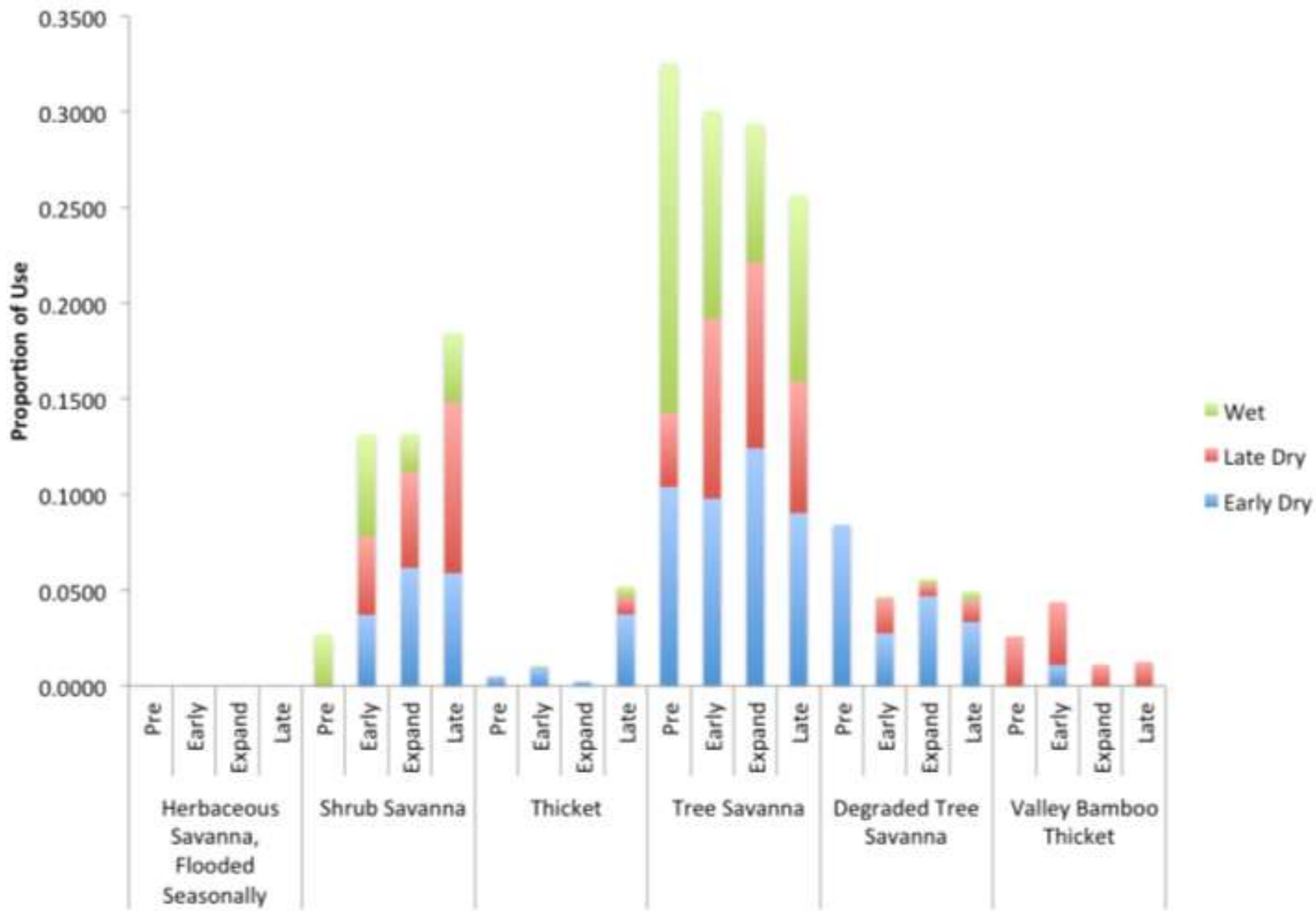

Figure A1.4 Chimpanzee usage of savanna land cover types across mining levels and seasons

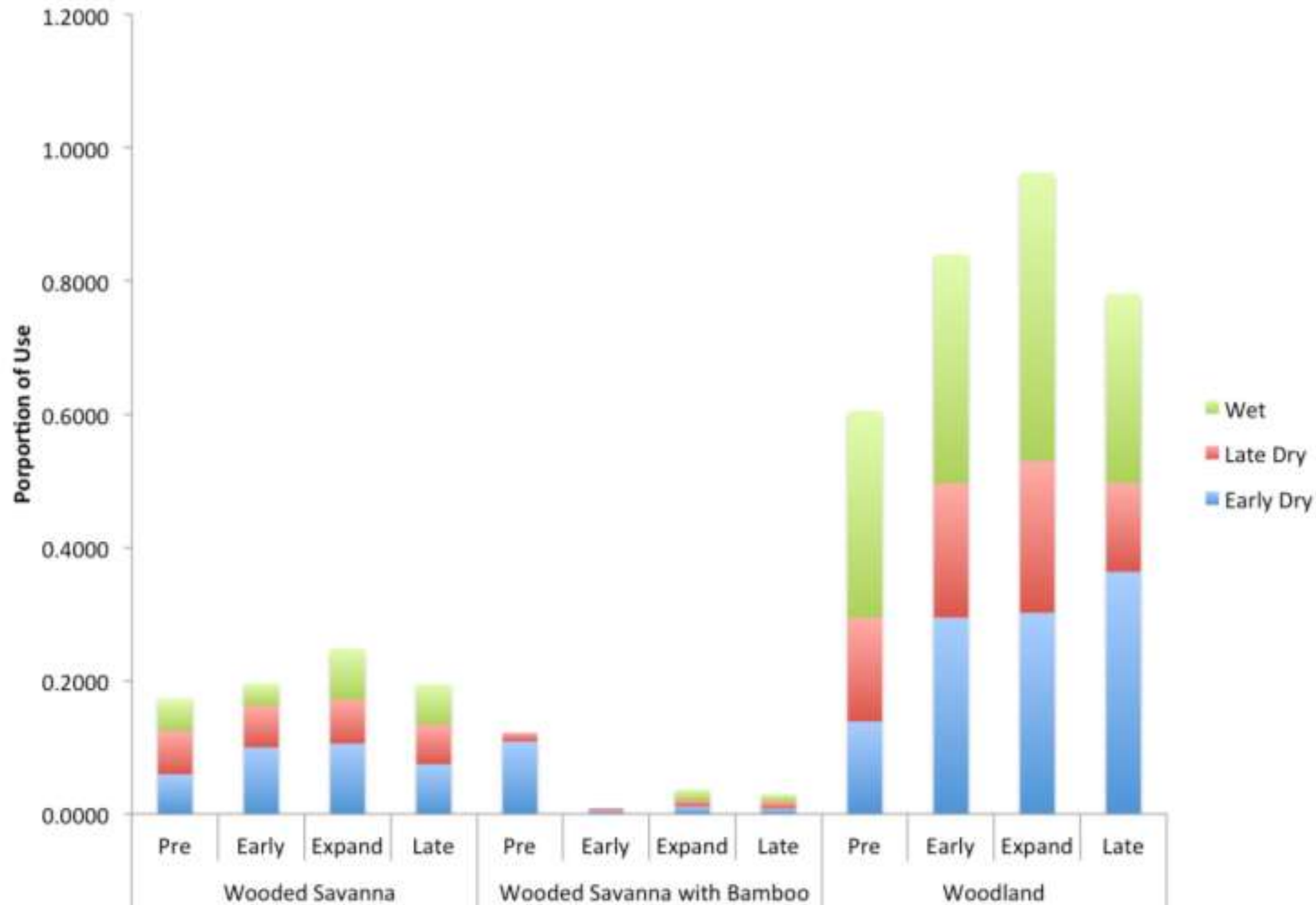

Figure A1.5 Chimpanzee usage of woodland land cover types across mining levels and seasons

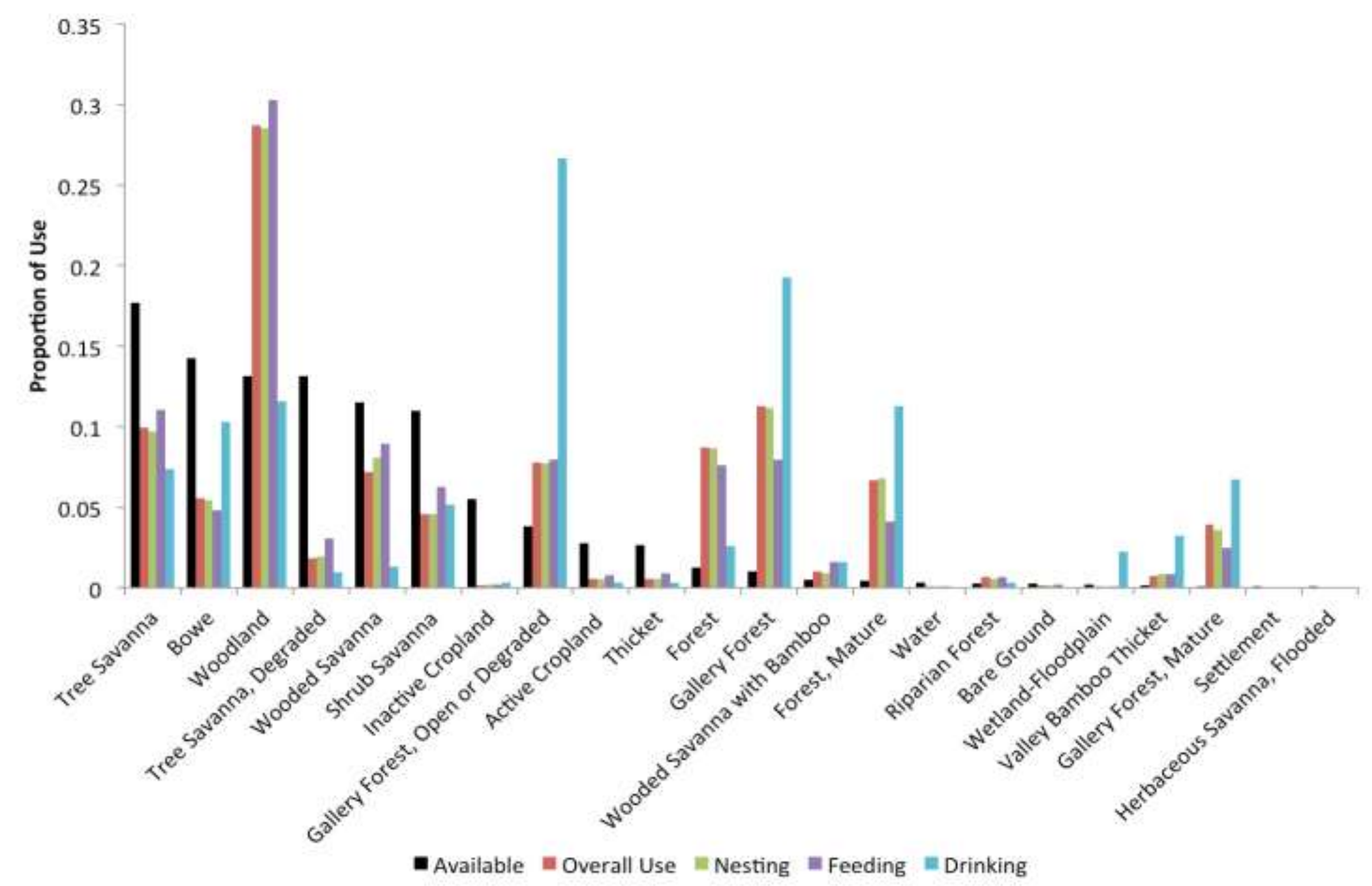

Figure A1.6 Proportion of land cover vegetation types used by the Fongoli chimpanzees compared to available proportions within the community home range for feeding, nesting and drinking behaviors.

CHAPTER VII

CONCLUSIONS

Using an ethnoprimatological approach, this study assesses the impacts of anthropogenic activity associated with artisanal small-scale gold mining (ASGM) on a community of savanna chimpanzees living in a complex and coupled human and natural system. The study quantified ASGM activity over a 10-year period at the Fongoli field site in Senegal and analyzed changes in human-chimpanzee encounters, chimpanzee behavior, and habitat selection. As gold prices rose internationally, mining activity increased at the site from a few seasonal and temporary mining pits to seven intensively mined areas including rudimentary and seasonal mines, permanent placer mines, and mechanized industrial mines managed by ASGM mining companies. The largest and most intensively mined area was the Oundoundou mine.

Summary

In Chapter Four we found that as people's activities shifted from collection of non-timber forest products to gold mining, chimpanzees' visual encounters with people increased, as did human-initiated interactions. Encounters with gold miners spiked in 2011, correlating with the increase in gold prices, and remained elevated in 2012 and 2013, decreasing only in 2014. Although encounters with gold miners, as well as human-initiated interactions, decreased in 2013 and 2014, human-chimpanzee encounters remained elevated. Over the study period, there was a significant change in chimpanzee reactions to people during encounters. The chimpanzees were less likely to flee over the course of the study period, which is likely related to the increasing level of habituation. However, it should also be noted that although there was a general decrease in flee reactions, we saw flee responses increased again in 2013 and 2014. Fleeing was most often associated with people collecting non-timber forest products on foot. Vocalizing reactions increased significantly during the study period. Vocalizations were most often associated with gold miners and vehicles, and vehicles were most used in association with gold mining. Although vigilance did not change significantly over the course of the study, it was most often observed with respect to field workers and also positively associated with other diverse activities that increased during the study period. As human-chimpanzee encounters increased, negative interactions between people and chimpanzees also increased, although they remained rare occurrences overall.

Chapter Five focuses on the impacts of the changing ASGM landscape on the ranging behavior of the chimpanzee community. Relative to the pre-mining period in 2005 to 2007, the furthest extent of the Fongoli chimpanzee's home range (100% minimum convex polygon) decreased in size; however, their home range as estimated using a kernel density estimator method, did not change significantly in size from year to year. Their annual home range shifted westward toward the Oundoundou mine as mining began and remained westward as the mine expanded until 2011. In 2012, the home range began moving away from the continually expanding mine and, by 2014, at the mine's largest size, the home range was at is farthest eastward extent away from the Oundoundou mining area. We found a similar trend in core range movement as well.

Across the home range, we found that habitat use near mining areas increased as the mining began. Two of the mines (Oundoundou and Kerouani) had significant increases of use; however, use of the Oundoundou mining site decreased during the later phases of expansion in 2013 and ceased all together in 2014. For three of the seven mines (Ngari Camp, Niakora, and Djendji) we saw evidence of the chimpanzees going to the mining areas after mining had started, although they did not frequent these areas. These three sites all had large machinery and security guards, but despite the noise, presence of people, and machinery, the chimpanzees did approach the mining sites.

Although ranging activity shifted towards the Oundoundou mine early on, by 2012 we detected a shift to mine avoidance. As the mine expanded in 2012 to 2013 along the tributary to the Fongoli stream it cut off a travel corridor previously used by the chimpanzees to access one of the more densely populated patches of baobabs in the western part of the home range (Lindshield et al., 2017). In 2014, the chimpanzees' travel routes were rerouted to the north, going around the mine, allowing them access again to the feeding patches.

In Chapter Six we assessed changes in habitat selection using resource selection function models. Our results corroborated previous research from Fongoli (Pruetz and Bertolani, 2009), indicating a preference for forested land covers, the importance of water resources and food availability, and the influence of seasonal variation on habitat selection. Despite the relatively small footprint of mining activity (0.04% of the home range), ASGM influenced habitat selection at both the home range scale and the mining site scale. The shifting home range resulted in a decrease in favored woodland and forest habitats, and an increased use of habitats of poorer quality, specifically related to food, water, and shade availability. At the finer scale of habitat selection at the Oundoundou mining area, we found a propensity for chimpanzees to use anthropogenic areas during mining activity from 2009 through 2012. The anthropic areas, however, were only used when miners were not working. Similarly, savanna land cover types were also used more than expected when miners were not present. Forested and woodland areas did not see an increase in activity relative to workers' presence or absence, which is likely do to the cover and security provided by the trees.

In contrast to our predictions that chimpanzees would use the area for traveling and feeding but not for socializing or resting as mining increased, we saw an increase in these stationary activities at both the Kerouani and Oundoundou mining areas. At both mining areas, the chimpanzees began drinking water from mining pits and inspected items that were left behind by the miners.

Synthesis of chapters

By synthesizing the results of this dissertation, we can begin to understand the complexities of the ASGM and chimpanzee behavior. As the international gold prices rose, we saw both the total footprint of mining across the Fongoli home range and the rate of human encounters increase. The greatest impacts of ASGM on the landscape came from the Oundoundou mine, which accounted for 100% of all mining activity between 2008 and 2010, 59% and 56% of all mining in 2011 and 2012, and 49% and 45% in 2013 and 2014, respectively. When gold prices peaked in 2011, mining expanded out of the Oundoundou area and across the home range. Prior to this expansion and peak gold price, the distance of the chimpanzees' core range to the Oundoundou mine decreased, and chimpanzees increased their use of anthropogenic areas of the mine. We also saw an increase in human-chimpanzee encounters and interactions during this time period. After 2012, human-chimpanzee encounters continued to increase, but the apes began to move away from the mined area, using the Oundoundou area less and less. This shift to mine-avoidance behavior suggests that either the mine at Oundoundou reached a threshold level for perceived risk, or that the site was no longer novel or providing benefits to the chimpanzees. As chimpanzee activity began to decrease at the Oundoundou mine, we see activity increase at other mined areas (Kerouani, Djendji, Ngari and Niakora). The overall eastwardly shift of the home range, resulted in a shift in habitat selection. Much of the open and degraded gallery forest land cover is located in the western portion of the home range near the mining areas. This land cover type is particularly important for access to water sources in the late dry season. As chimpanzees shifted their range toward the east, we found an increase use of shrub savannas and thickets, both of which are found in more abundance in the west. Thickets are especially abundant around the village of Djendji.

Disturbance attraction and risk assessment

Contrary to our expected findings, the chimpanzees at Fongoli were attracted to ASGM sites as the mines developed on the landscape. This falls in line with current knowledge of how animals learn about novel predators and risks. In order to assess and understand the risks posed, animals collect information about places or species that may be dangerous to them (Crane and Ferrari, 2013). Much of the research on animal risk assessment has focused on social learning from conspecifics about risks (Laland, 2004; Griffin, 2004; Crane and Ferrari, 2013; Chivers and

Ferrari, 2014), but very little research exists that focuses on how animals learn from first hand encounters with novel predators or risky situations, such as was seen in this study. As environments continue to experience rapid and increasing change from anthropogenic activity, animals are being exposed to novel and risky situations at a greater frequency (Estrada et al., 2017). Learning is required to understand the type and extent of the risk involved, the dangers associated, and the cues to recognize them (Berger, Swenson, & Persson, 2001; Griffin 2004).

In primates, and particularly with great apes, research has documented novel human activity attracting the attention and curiosity of the animals. Tutin and Fernandez (1991) addressed this phenomenon with respect to habituation, suggesting that a primate's reaction to people will be related to previous experiences with them (particularly negative experiences), the novelty of the encounter, and the habitat in which the primate lives. Habituation programs in the Republic of Congo, Cameroon, and Uganda support their hypothesis. In the Goualougo Triangle in the Republic of Congo, naïve chimpanzees were attracted to the researchers' campsite and showed signs curiosity at the sight of people (Morgan and Sanz, 2002). In southeastern Cameroon, 40% of reactions to humans by chimpanzees where characterized as curiosity (Werdenich et al., 2002), whereas gorillas *(Gorilla gorilla gorilla*) in the same study avoided human observers the majority of the time but otherwise showed curiosity towards them. In Uganda, where chimpanzees are familiar with human encounters and were not considered naïve to people, apes show tolerance for humans and not curiosity (McLennan and Hill, 2010).

Taking into consideration the history and social aspects of the chimpanzee-human system at the Fongoli field site, where people and apes have lived alongside one another for centuries and where chimpanzees are not hunted as a general rule, we would expect to also see curiosity to novel human activity. Attraction to novel mining sites despite human presence, active machinery, and vehicles, coupled with observations of chimpanzees investigating mining areas and artifacts left behind by miners, suggests that direct learning by chimpanzees may have been taking place at the ASGM sites. In addition, we can see the results of such learning as the apes were able to change their behavior and habitat selection at the mined areas with respect to the presence and absence of gold miners.

In this case, it seems curiosity regarding the ASGM sites may have been used to acquire information about the riskiness and dangers associated with the mines and miners. Unfortunately, the risks associated with ASGM sites may not be easily recognizable to chimpanzees, potentially resulting in an ecological trap (Robertson and Hutto, 2006). Pollution from lack of sanitation and mercury use can impact chimpanzees that drink from mining water sources without their knowledge of the dangers. Additionally, lack of restoration and reclamation of mined areas results in open and abandoned pits that can become overgrown with vegetation, creating hidden falling and trap hazards. Although the chimpanzees may feel that the areas are safe to use in the absence of people, these unseen risks still loom. The indirect health impacts of ASGM on chimpanzees may be greater in Senegal and other regions of West Africa where chimpanzees are not hunted, which increases the likelihood that chimpanzees will approach mines and investigate novel human disturbances.

At the time of writing, gold prices remain elevated and do not have any indication of dropping below the pre-Global Recession levels. ASGM continues to expand in southeastern Senegal and in countries around the world. West African chimpanzees, recently listed as a Critically Endangered subspecies, are particularly vulnerable to the increasing threat of ASGM disturbance, as gold mining is widespread in the region and habitat fragmentation and depletion continues to grow. The analysis from this study may also be extended to other great apes in central Africa and Asian where resource extraction is also prevalent. This dissertation highlights the need for further research on the health impact of ASGM on great ape population and for increased environmental regulatory standards with respect to ASGM and site reclamation.

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