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Bushmeat Supply and Consumption in a Tropical Logging Concession in Northern Congo

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Abstract: *Unsustainable hunting of wildlife for food empties tropical forests of many species critical to forest maintenance and livelihoods of forest people. Extractive industries, including logging, can accelerate exploitation of wildlife by opening forests to hunters and creating markets for bushmeat. We monitored human demographics, bushmeat supply in markets, and household bushmeat consumption in five logging towns in the northern Republic of Congo. Over 6 years we recorded 29,570 animals in town markets and collected 48,920 household meal records. Development of industrial logging operations led to a 69% increase in the population of logging towns and a 64% increase in bushmeat supply. The immigration of workers, jobseekers, and their families altered hunting patterns and was associated with increased use of wire snares and increased diversity in the species hunted and consumed. Immigrants hunted 72% of all bushmeat, which suggests the short-term benefits of hunting accrue disproportionately to "outsiders" to the detriment of indigenous peoples who have prior, legitimate claims to wildlife resources. Our results suggest that the greatest threat of logging to biodiversity may be the permanent urbanization of frontier forests. Although enforcement of hunting laws and promotion of alternative sources of protein may help curb the pressure on wildlife, the best strategy for biodiversity conservation may be to keep saw mills and the towns that develop around them out of forests.*

Keywords: biodiversity conservation, bushmeat, Congo, household diet, logging, tropical forest, wildlife

Acopio y Consumo de Carne Silvestre en una Concesión Maderera Tropical en el Norte de Congo

Resumen: *La cacería no sustentable de vida silvestre para alimento vacía los bosques tropicales de muchas especies críticas para el mantenimiento del bosque y las formas de vida de habitantes del bosque. Las industrias extractivas, incluyendo la tala, pueden acelerar la explotación de vida silvestre al abrir los bosques a cazadores y creando mercados para carne silvestre. Monitoreamos la demografía humana, el acopio de carne silvestre en los mercados y el consumo de carne silvestre por familia en cinco pueblos madereros en el norte de la República del Congo. Durante seis años, registramos 29,570 animales en los mercados y colectamos 48,920 registros de alimento familiar. El desarrollo de operaciones madereras industriales condujo a un incremento de 69% en la población de los poblados y un incremento de 60% en el acopio de carne silvestre. La inmigración de trabajadores, buscadores de empleo, y sus familias alteró los patrones de cacería y se asoció con un incremento en el uso de trampas de alambre e incrementó la diversidad de las especies cazadas y consumidas. Los inmigrantes cazaron 72% de toda la carne silvestre, lo que sugiere que los beneficios a corto plazo de la cacería corresponden desproporcionadamente a "fuereños" en detrimento de los pobladores indígenas que tienen derechos legítimos previos sobre los recursos de vida silvestre. Nuestros resultados sugieren que la mayor amenaza de la industria maderera a la biodiversidad puede ser la urbanización permanente de los bosques de frontera. Aunque la aplicación de las leyes cinegéticas y la promoción de fuentes alternativas de proteína pueden ayudar a reducir la presión sobre la vida silvestre, la mejor estrategia para la conservación*

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de la biodiversidad es evitar que los aserraderos y los poblados que se desarrollan alrededor de ellos queden en los bosques.

Palabras Clave: bosque tropical, carne silvestre, Congo, conservación de la biodiversidad, dieta familiar, tala, vida silvestre

Introduction

Overhunting of wildlife for meat across the humid tropics is causing population declines and local extinctions of numerous species (Fa et al. 2001; Cortlett 2007; Peres & Palacios 2007). The statistics are unsettling: 60% of the most common game species in the Congo Basin are hunted unsustainably (Fa et al. 2002), with total harvest of bushmeat in the basin estimated at 1–5 million tons annually (Wilkie & Carpenter 1999; Fa et al. 2002). The loss of animals and species has consequences for ecological processes that drive forest dynamics (e.g., Wright et al. 2007; Terborgh et al. 2008) and for the rural people who depend on wild meat as a source of protein and revenue (Davies 2002; Bowen-Jones et al. 2003). Thus forest regeneration and biodiversity are compromised by overhunting and so are the livelihoods of forest-dwelling peoples.

The drivers of overhunting in the tropics are well known. Expanding road networks fragment the forest, opening it to a growing rural population armed with guns and wire snares (Noss 1998; Robinson et al. 1999; Wilkie et al. 2000). In frontier forests, where people have no history of commercial agriculture or logging, people exploit the most accessible and abundant resource—wildlife. Once roads provide access to markets, bushmeat becomes a market commodity, transforming hunting from a subsistence to a commercial activity. These factors collide and are potentially accelerated by the large-scale operations of extractive industries, including mining, industrial agriculture, and logging. Fueled partially by emerging economies in China and India, the demand for natural resources and the accompanying rise in prices expand the operations of extractive industries and the pressure on wildlife throughout the tropics (Butler & Laurance 2008).

In central Africa selective logging is the most extensive extractive industry, with logging concessions occupying 30–45% of all tropical forests and over 70% of forests in some countries (Global Forest Watch 2002; Laporte et al. 2007). The rate of road construction for logging has increased dramatically in the last decade, potentially opening an additional 29% of central African forests to increased hunting pressure (Laporte et al. 2007). Logging trucks carry bushmeat and hunters, reducing the production costs of the hunter and increasing labor efficiency through the rapid transport of wild meat to markets (Wilkie & Carpenter 1999; Wilkie et al. 2000). Forestry companies pay relatively high wages, thereby growing the local economy and attracting large numbers of people (workers, family members, and traders) into areas that were formerly sparsely populated (Wilkie & Carpenter 1999). Partially because logging typically takes place in remote forests (i.e., away from urban markets, agriculture, and ranching), most companies fail to provide their workers with animal protein, so they survive on bushmeat. Thus logging unites multiple threats to wildlife over large areas, and as timber is extracted from the forest, so is the wildlife.

Despite the realization that logging facilitates hunting, there are few quantitative studies that examine the bushmeat trade within concessions (but see Fimbel et al. 2001). In the face of expansion of industrial logging in the tropics, conservation efforts will benefit from a greater understanding of how forestry affects the use of wildlife and the strength of its impact (Butler & Laurance 2008). We quantified the supply of bushmeat and consumption of animal protein (bushmeat, freshwater fish, and imported meat) over 6 years in five logging towns in the northern Republic of Congo. Specifically we asked: How does industrial logging influence human demographics in frontier forest? To what degree do demographic differences among logging towns affect the supply of bushmeat and patterns of hunting? And what factors determine the consumption of animal protein in logging towns (e.g., season, ethnic origin, principal economic activity, and price)?

Study Site

We conducted our study in three logging concessions (Kabo, Pokola, and Loundoungou/Toukoulaka) in the northern Republic of Congo. The concessions covered 12,000 km^2 of forest adjacent to the Nouabalé-Ndoki National Park (NNNP) and the Sangha trinational network of protected areas. The forests of this region support high diversity of plant and animal species (Harris & Wortley 2008; Clark et al. 2009). Although selective logging has occurred in the area since the 1960s, operations were relatively limited until the end of civil war in 1997, which resulted in a rapid expansion of the sector, opening of concessions, and construction of roads by large commercial operators (Laporte et al. 2007). The Congolaise Industrielle des Bois (CIB) logging company has harvested timber in the three concessions with low-intensity (<2.5

trees/ha), selective, reduced-impact logging techniques (CIB 2006). The Forest Stewardship Council certified the Kabo and Pokola concessions in 2006 and 2008 for having good environmental, social, and logging practices; certification of Loundoungou/Toukoulaka is under way.

The study area historically supported a low human population density (<0.5 km^2) of indigenous Mbendzélé pygmies, who subsisted as semi-nomadic hunter-gatherers, and indigenous Bantu communities, who practiced subsistence fishing and hunting. Over the past 5 decades these communities established several permanent settlements along the Sangha and Motaba rivers. Within the past decade CIB constructed sawmills and offices in two towns, Pokola and Kabo, and established three additional forest towns, Ndoki 1, Ndoki 2, and Loundoungou to house the cutting teams that were transported back and forth from the forest each day: traders, farmers, hunters, and job seekers settled with the workers and their families. In 1999 CIB, the Wildlife Conservation Society, and the Government of Congo formed a partnership, the Buffer Zone Project (BZP; Projet de Gestion des Ecosystèmes Périphériques au Parc National de Nouabalé-Ndoki [PROGEPP] in French) to mitigate the deleterious impacts of logging on wildlife in the CIB logging concessions and in NNNP (Elkan et al. 2006; Poulsen et al. 2007). Through this project several explicit conservation activities were implemented, including enforcement of Congolese wildlife laws, land-use planning for hunting and resource use, conservation education, development of alternative activities to replace hunting, and monitoring of large mammal populations. These activities were developed or ongoing during this research.

Methods

Census of Human Populations and Market Availability of Bushmeat

To assess the relationship between demographic change, hunting patterns, bushmeat supply in towns, and consumption of animal protein, we conducted annual censuses in the logging towns. Between January and March, from 2000 to 2006, BZP research assistants mapped and assigned a unique number to every house in all five towns. The head of each household was interviewed to determine the ethnicity, age, education level, relationship, and occupation of all household residents.

To determine factors that influence the biomass and species composition of bushmeat in each logging town over seasons and time, we monitored bushmeat supply in markets for 10 (Kabo, Ndoki 1, Ndoki 2, and Loundoungou) or 20 (Pokola) randomly selected days each month from 2000 to 2006. Each town had a single bushmeat market, but a portion of the hunted meat was carried directly to households. Therefore research assistants visited markets in the morning when they were most active and before bushmeat had been sold. They observed the principal trails and roads entering each town for 2 h in the evening when hunters tended to return from the forest. On consecutive days of sampling, research assistants avoided double counting bushmeat by asking market women the name of the hunter that supplied them with meat. At each place they recorded the species of animal, condition (fresh or smoked or whole or part), means of capture (gun, cable trap, spear, net, or crossbow), means of transport (canoe, foot, bike, or motor vehicle), sale price, and ethnicity and principal economic activity of the hunter. For a subset of these observations the carcass (or marketed body part of the animal) was weighed. We used average weights to estimate the total biomass (kilograms) arriving in the town. We converted the number of observations to biomass because it allowed us to account for observations of partial animals (e.g., hind quarters of a duiker).

Animal Protein in Household Meals

To understand the factors that influence consumption of animal protein (bushmeat, freshwater fish, and imported meat) in the logging towns, we conducted consumption surveys for 10 (Kabo, Loundoungou, Ndoki 1, and Ndoki 2) or 20 (Pokola) randomly selected households (new households were randomly selected each month without replacement) on 10 randomly selected days each month from 2000 to 2006. Research assistants visited households in the afternoon, recording detailed information about the composition of the principal meal of the day, including the unit price of animal protein, species of bushmeat, principal economic activity of the family, and ethnicity of the head of the household.

For data analysis we classified people from outside Congo as foreigners, people from a different region of Congo as migrants, and people born in northern Congo as indigenous. We use the term *immigrant* to mean both foreigners and migrants combined. Indigenous peoples include several Bantu groups and Mbendzélé pygmies. We discuss some issues particular to the Mbendzélé because their culture and lifestyle often separates them from both immigrant and indigenous Bantu. We also classified bushmeat species into functional groups (see Supporting Information). For analyses, species within functional groups with few observations (i.e., carnivores, large mammals, birds, and small mammals) were categorized as either small- to medium-bodied species (<15 kg) or large-bodied species (>15 kg).

Statistical Analyses

Our analyses focused on factors that would explain the biomass of bushmeat found in logging towns and the presence of animal protein (bushmeat, freshwater fish, or imported meat) in household diets. We examined the effect of time (1–78 months), season (dry season,

short rainy season, and long rainy season), origin of the hunter or head of the household (indigene, migrant, and foreigner), occupation (logging company employee, salaried worker, laborer, and unemployed), and price of the meat. For bushmeat data, with biomass as the response variable, we fitted linear mixed models (LMMs) after examining plots of residuals for the assumptions of normality. For diet data, with the presence or absence of bushmeat, fish, or domestic meat as the response variable, we fitted and evaluated generalized linear mixed models (GLMMs), with a binary error distribution and logit link for each protein type. For both LMMs and GLMMs we used Laplace approximation (lme4 package; Bates and Sakar 2007) for maximum likelihood estimation of the parameters (Bolker et al. 2009). To account for potential correlations between years and months, we treated them as random effects: random factors in mixed models are equivalent to the block structure in analysis of variance. Akaike's information criterion (AIC) was used to compare the goodness of fit of models. We used a difference of four AIC points as the cutoff among models (Burnham & Anderson 2002). The statistical significance of individual fixed effects was tested with t statistics for LMMs and z statistics for GLMMs; however, we emphasize the effect size of model parameters rather than their statistical significance because our large sample sizes may result in statistically significant effects that are biologically unimportant. All statistical analyses and graphing were performed with R Language, (version 2.7.1; R Development Core Team 2008).

Results

Effects of Industrial Logging on Human Demographics

The population of the five logging towns grew by 69.6% (10,122 to 17,164 people) from 2000 to 2006 (Fig. 1). This population boom was largely the result of immigration from other parts of Congo: 69% of new logging town residents were migrants, 18% were foreigners, and 13% were indigenous. In addition to immigration into the concessions, changes in the populations of towns were sometimes the result of logging operations. In 2004 logging operations expanded into the Loundoungou Concession, creating the Loundoungou logging town. In 2005 workers were moved from Ndoki 2 to Kabo, although Ndoki 2 remained occupied by settlers who stayed to farm cassava fields (which demonstrates the lasting effect of logging camps as permanent settlements in previously unsettled forest). The growth of Pokola by 5000 people resulted

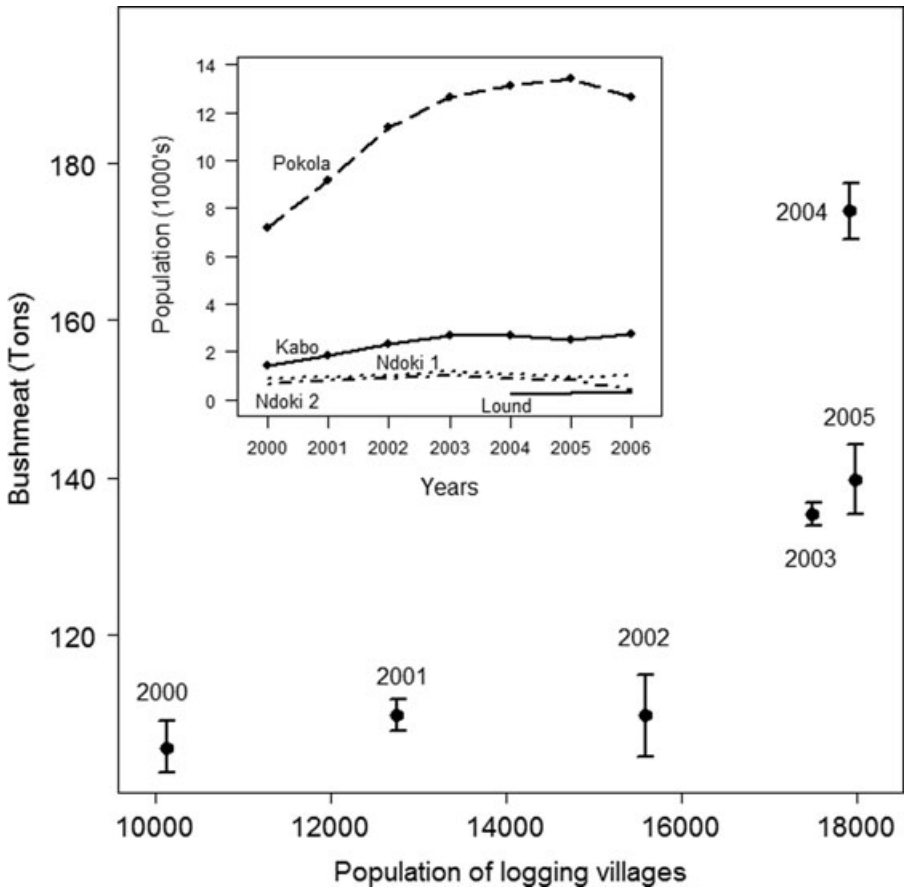

Figure 1. Annual biomass of bushmeat entering logging towns versus the combined populations of the towns. Bars are bootstrapped 95% CIs. Inset graph shows human population by logging town from 2000 to 2006.

Table 1. Bushmeat data (animals observed during the survey of markets and principal roads) and household meal records from five logging towns in northern Republic of Congo.

	Logging towns[b]					
Data categories[a]	*Kabo*	*Loundoungou*	*Ndoki 1*	*Ndoki 2*	*Pokola*	*total*
Bushmeat records						
no. of animals recorded	2,907	1,144	4,439	2,213	18,866	29,570
months of survey	67	24	69	69	71	
guns (%)	94	88	87	91	58	70
other techniques (%)	1	1	3	4	4	3
wire snares (%)	5	11	10	5	39	26
indigenes (%)	20	70	56	91	7	28
migrants (%)	76	27	44	9	57	52
foreigners (%)	4	3	0	0	36	20
fresh carcasses (%)	95	99	96	99	64	78
smoked carcasses (%)	4	1	2	1	35	21
Meal records						
no. of meals	6,268	3,394	9,868	7,313	22,077	48,920
months of survey	66	24	67	66	67	
with animal protein (%)	91	88	94	93	94	93
with fish (%)	60	47	47	47	49	49
with bushmeat (%)	30	47	50	45	41	42
with domestic meat (%)	3	5	2	5	7	5
indigenes (%)	25	31	38	23	40	34
migrants (%)	73	65	61	70	56	62
foreigners (%)	2	4	1	8	4	4
logging employees (%)	48	76	38	68	47	53
hunters (%)	8	9	10	17	3	8
laborers (%)	10	12	49	12	30	25
salaried workers (%)	23	3	2	2	3	4
unemployed (%)	11	0	1	1	17	10

[a]*Bushmeat data are presented as the proportion of all animals killed with different hunting techniques by hunters of different ethnic origins and by condition of the carcass in the market. Household meal data are presented as the proportion of all meals of different types of animal proteins consumed on the basis of ethnic origin and principal household economic activity. Bushmeat in the meal records came from several species groups: duiker (13,792; 28.0%), monkey (1,744; 3.6%), pig (1,686; 3.4%), and reptile (1,221; 2.5%); small- to medium-bodied species (633; 1.3%); insect (534; 1.1%); and large species (188; 0.4%).*

[b]*All towns were sampled from the beginning of 2000 through 2005, except for Loundoungou, which was established in 2004.*

from a combination of expanded sawmill operations and the immigration of people to take advantage of public services provided by the company (e.g., electricity, water, and hospital).

Effects of Demography on Hunting and Bushmeat Supply

We recorded 29,570 animals (approximately 345,119 kg of dressed bushmeat) in markets and along trails into the five logging towns (Table 1). Two species of duikers were the most common species found in markets (*Cephalophus callipygus* and *C. monticola*), and they made up 62.6% of observations of all species. After duikers, monkeys, bushpigs, and reptiles were the most observed species groups (Supporting Information). On average 354 kg of bushmeat arrived in the five towns per day (total of 129 tons [95% CI 124.3–133.6] of bushmeat annually). The total biomass of bushmeat was positively related to populations of the five logging towns (Fig. 1).

The size of towns and number of immigrants affected dynamics of the bushmeat trade. Because foreigners hunted <5% of the bushmeat in all towns except Pokola, we compared immigrants (foreigners and migrants) and indigenes. Immigrants hunted 70% of all bushmeat arriving in all towns; most of the immigrant-hunted meat was observed in Kabo and Pokola (Table 1). Hunting techniques varied by size of town, ethnicity, and principal economic activity (Table 1). Hunters typically shot prey with shotguns (range 87.4–94.0%). In Pokola (93% immigrants), however, only 58.1% of animals were hunted with guns and 39.9% were trapped with snares (range 5.3–11.0% in the other towns). When treated by ethnicity immigrants caught 30.4% of animals with snares and killed 66.2% with guns, whereas indigenous people snared 5.7% of animals and shot 92.1%. Logging company workers hunted with guns 94.7% of the time, whereas hunters (people who identified hunting as their principal economic activity) and noncompany workers used guns 86.5% and 69.1% of the time, respectively. Noncompany workers included refugees from the Democratic Republic of Congo drawn to Pokola for economic opportunities (working as laborers for logging company employees), and they were known to be active snare hunters. In fact 14.5% of the population of Pokola was foreigners, but

they hunted 37.8% of all bushmeat. Finally bushmeat in Pokola was much more likely to be smoked than in other towns (Table 1).

In a comparison of bushmeat arriving in logging towns in 2000 and 2005 the proportion of snared animals increased substantially in all towns (Table 2). The proportion of smoked carcasses increased significantly from 2000 to 2005 in Kabo, Pokola, and Ndoki 1, and the proportion of animals hunted by immigrants increased significantly for Pokola.

Both the total mass of bushmeat and the mass by species group varied with town identity, time, ethnicity, and hunting technique (Fig. 2). For most species the hunting technique had a relatively large effect, which suggests hunting methods used varied among the species groups. Relative to immigrants, indigenous hunters harvested fewer small- to medium-bodied species and more duikers. Substantially higher biomass of total bushmeat and duikers, reptiles, and small- to medium-bodied species arrived in Pokola compared with other towns. This populous town contributed to the intensity of hunting and breadth of species targeted.

Factors Determining Consumption of Animal Protein

Over 6 years we accumulated 48,920 household meal records. The proportion of meals containing animal protein varied by season and town. Meals in the long rainy season were 30% less likely to contain animal protein than in the dry season (GLMM, $Z = 2.78$, $p = 0.005$); Pokola (GLMM, $Z = -7.50$, $p = 6.6 \times 10^{-14}$), Ndoki 1 (GLMM, $Z = -7.52$, $p = 5.6 \times 10^{-14}$), and Ndoki 2 (GLMM, $Z = -2.17$, $p = 0.03$) were more likely to contain animal protein than Kabo and Loundoungou (GLMM, $Z = 4.60$, $p = 4.2 \times 10^{-6}$). The proportion of meals containing animal protein in each town was high, varying between 88% (Loundoungou) and 94% (Pokola and Ndoki 1; Table 1). Of the meals containing animal protein the majority were consumed by migrant and company-employee households (Table 1). Of meals without animal protein 75.3% were in indigenous households, which lacked animal protein in 15% of their meals. Mbendzélé households made up 93.0% of the indigenous meals lacking animal protein, with 38.6% of their meals containing bushmeat, 36.5% containing fish, and 20.6% lacking animal protein.

The proportion of meals containing bushmeat, fish, and domestic meat fluctuated over the year and varied by town (Fig. 3). Pooling all towns, the proportion of fish in meals was negatively correlated with the proportion of bushmeat ($r = -0.730$, CI $= -0.78$ to -0.67, $t = -18.0$, df $= 280$, $p = <2.2e^{-16}$). People consumed less bushmeat during the dry season when fish was readily available. The proportions of fish and bushmeat in household meals were also negatively correlated at the town level; the correlation coefficient fell between –0.47 (Kabo) and –0.91 (Loundoungou). The consumption of domestic meat was negatively correlated with fish ($r = -0.13$, CI $= -0.250$–0.004, $t = -2.0$, df $= 244$, $p = 0.048$), but not bushmeat ($r = -0.09$, CI $= -0.21$–0.039, $t = -1.4$, df $= 243$, $p = 0.174$).

The presence of bushmeat, fish, and domestic meat in meals depended on the ethnic origin and principal economic activity of the head of the household and logging town (Table 3). The presence of bushmeat was about 20% greater in indigenous households than in migrant or foreign households; thus, when meals of indigenous households contained animal protein, it tended to be bushmeat. Likewise, meals of people who claimed hunting was their principal activity contained bushmeat more regularly than meals of people with other occupations. Bushmeat consumption was approximately 20% lower during the dry season, when the proportion of meals containing fish was highest. Foreigners were about 2.5 times more likely to consume domestic meat than migrants who were twice as likely to consume it as indigenous people. Domestic meat was also consumed more frequently by company workers and people with salaried jobs than people with nonsalaried livelihoods.

For all three protein types price and time had a smaller effect on consumption patterns than town, ethnicity, and economic activity (as indicated by the small effect size;

Table 2. Comparisons of bushmeat supply and consumption between 2000 and 2005 in four logging towns.[a]

Logging town	*Hunted animals*[b]						*Bushmeat consumption*[c]			
	snares		*smoked meat*		*migrants*		*migrants*		*logging employees*	
	2000	*2005*	*2000*	*2005*	*2000*	*2005*	*2000*	*2005*	*2000*	*2005*
Kabo	0.07	0.67**[a]	0.04	0.15**	0.81	0.94**	0.72	0.80	0.02	0.48**
Ndoki 1	0.06	0.17**	0.03	0.21**	0.53	NA	0.61	0.70	NA	0.47
Ndoki 2	0.02	0.10**	0.01	0.67	0.16	0.08	0.67	0.86	0.63	0.67*
Pokola	0.02	0.16*	0.09	0.45**	0.88	0.61	0.71	0.66	0.44	0.52

[a] *Data were analyzed as generalized linear mixed models, with month as a random effect and year (2000 or 2005) as a fixed effect. Significance:* **p < 0.01; *p < 0.05; NA, missing data for that village and year.*
[b] *Proportion of animals caught in snares, smoked, and hunted by migrants.*
[c] *Proportion of bushmeat consumed by migrants and logging employees.*

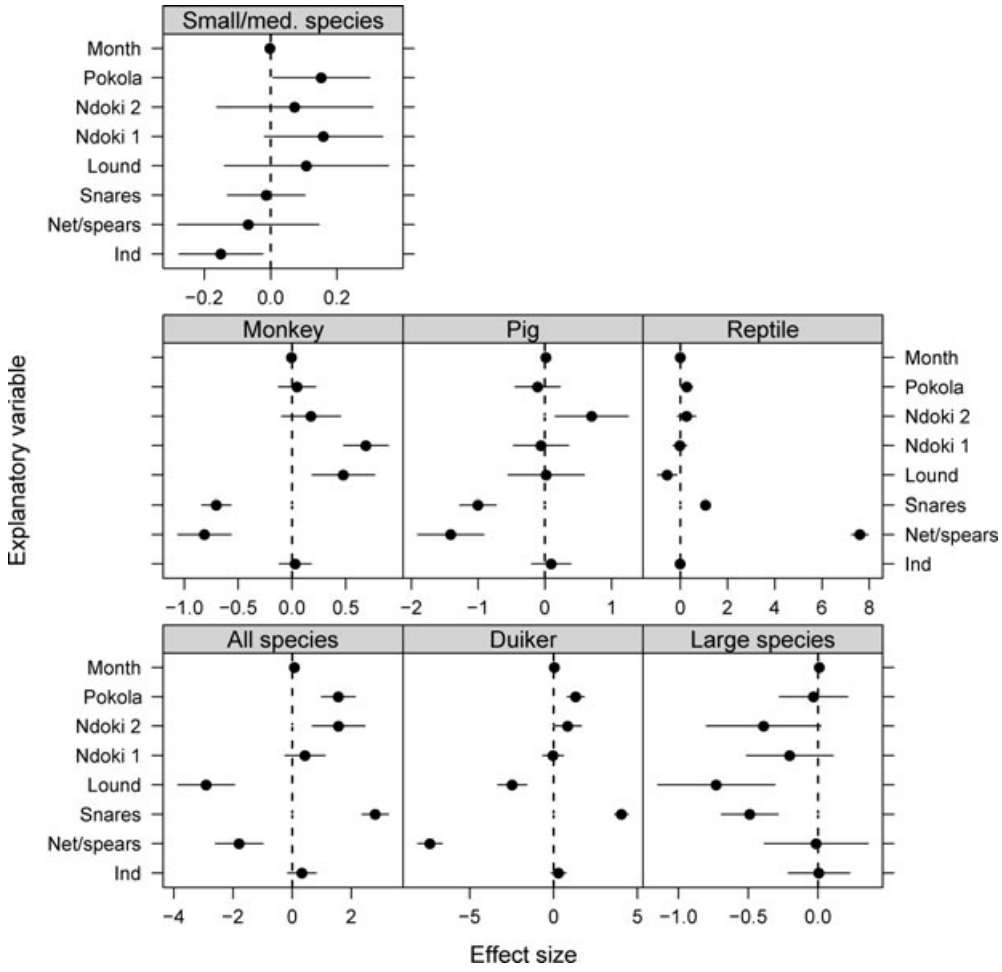

Figure 2. Effects of time (month), town (Pokola, Ndoki 1, Ndoki 2, Loundoungou [Lound], and Kabo), hunting technique, and ethnicity (Ind, indigenes) on the biomass (kilograms) of several species groups of bushmeat (large species, elephant, ape, buffalo, bongo, and sitatunga; small- to medium-bodied, rodent, pangolin, bird, and small carnivore). Effect sizes are results from generalized linear mixed models for each species group, with months as random effects, and are presented with 95% CIs; those that do not overlap the dotted vertical line are statistically different from zero. The variables not shown in the figure are Kabo, guns, and migrants, and they had an estimate of zero and serve as contrasts. Month is an index for time and tests whether the amount of bushmeat of a species group increased or decreased over the 6 years of monitoring. CIs of month are all positive and do not overlap zero for all species, duikers, large species, pigs, and reptiles; however, the effect is very small.

Table 3). Price did not affect the proportion of meals with bushmeat, but lower fish prices led to higher fish consumption. Higher domestic meat prices led to higher consumption of domestic meat. The choice was made to buy a kilogram of meat at the butcher shop rather than buying 0.25–0.50 kg of domestic meat in the open market. Bushmeat and domestic meat consumption increased over the study period, whereas fish consumption decreased, but the effects were small.

The presence of different species groups of bushmeat in household diets varied by ethnic group, season, and town as well as over time (Fig. 3). Notably, meals of indigenous households contained duikers and insects about 1.2 and 4.9 times more frequently than the meals of foreigners and migrants and contained lower amounts of most other species groups. Households in Pokola more frequently ate small- to medium-bodied species, reptiles, and large-bodied species than households in the other towns (with the exception of small- to medium-bodied species in Ndoki 1), but they ate common bushmeat species groups such as duikers and pigs less often. Higher proportions of duikers and insects were consumed during the rainy seasons than in the dry season. Finally consumption of duikers, forest pigs, reptiles, and large species increased over the course of the study; only consumption of monkeys decreased.

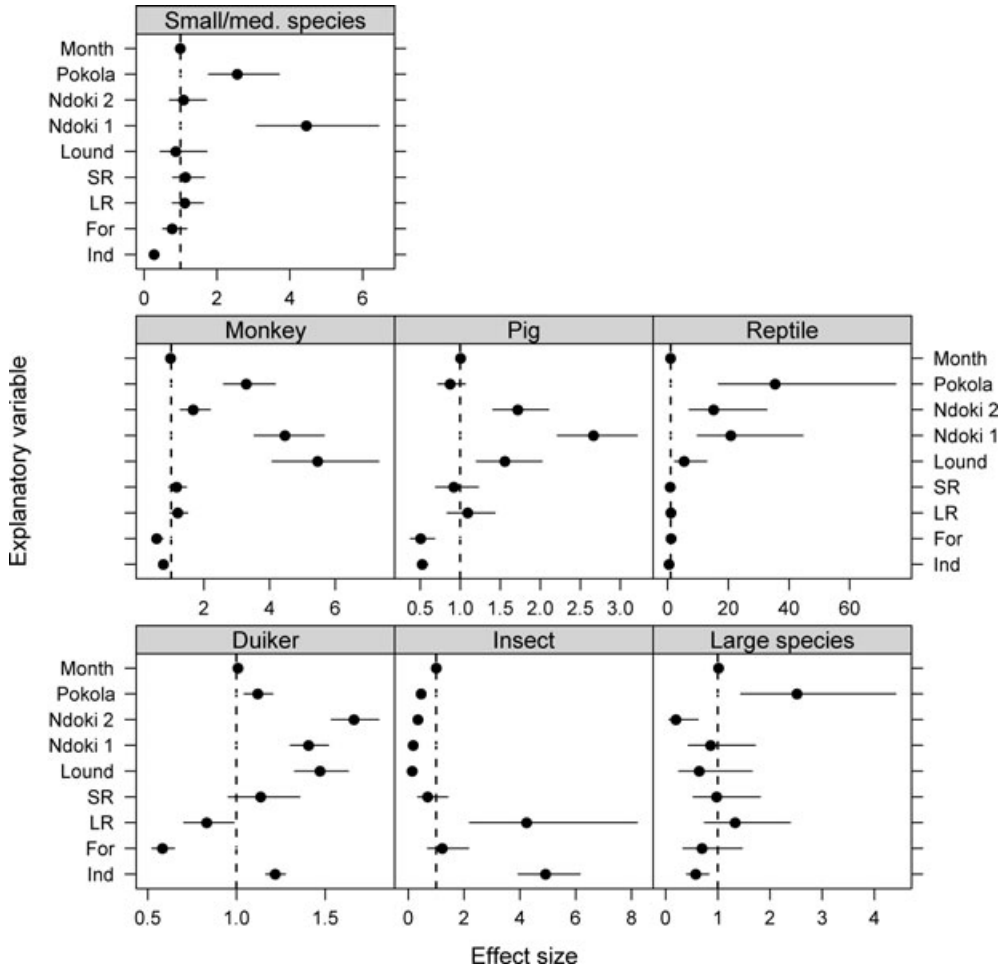

Figure 3. Effects of time (month), town (Pokola, Ndoki 1, Ndoki 2, Loundoungou [Lound], and Kabo), season (SR, short rainy; LR, long rainy), and ethnicity (For, foreign; Ind, indigenes) on the presence of bushmeat in household meals by species groups (large species, elephant, ape, buffalo, bongo, and sitatunga; small- to medium-bodied species, rodents, pangolins, birds, and small carnivores). Effect sizes are results from generalized linear mixed models for each species group, with months as random effects. Effect sizes are odds ratios with 95% CIs; those that do not overlap the dotted vertical line are statistically different from 1. The variables without plotted effect sizes are Kabo, dry season, and migrants, and they have an estimate of 1 and serve as contrasts. Month is an index for time and examines whether the proportional representation of a species group increased or decreased over the 6 years of monitoring. The effect of month is small, but statistically significant and positive for duikers, pigs, reptiles, and large species; only consumption of monkeys declined over time.

Discussion

Local human population growth stimulated by industrial logging activities altered the demographics of rural communities in northern Congo, which influenced patterns of bushmeat supply and consumption. Over 6 years the populations of five logging towns rose by an average of 69%, and the biomass of bushmeat in those towns increased by 64%. The immigration of workers, jobseekers, and their families into logging concessions influenced hunting dynamics, altering who hunted, what they hunted, and how they hunted and transported their prey. Immigrants (migrants and foreigners) harvested 72% of animals recorded in markets and along principal entry routes into logging towns and consumed 66% of all bushmeat.

Impacts of Logging on Bushmeat

In tropical frontier forests, where people depend on forest resources and alternatives to wild meat and fish for protein are often lacking, the positive relationship between population growth and bushmeat is not surprising. Greater numbers of mouths to feed lead to greater levels of hunting. Yet our results demonstrate that urbanization of previously small forest communities, as a result of

Table 3. Results of generalized linear mixed models of household diet data that examined the factors explaining the presence of fish, bushmeat, and domestic meat in meals.

	Meals with fish				*Meals with bushmeat*				*Meals with domestic meat*			
Variables[a]	*est.*	*SE*	Z	p	*est.*	*SE*	Z	p	*est.*	*SE*	Z	p
Intercept	0.051	0.093	0.54	0.588	−0.465	0.093	−4.99	6.0×10^{-7}	−4.44	0.255	−17.4	$<2 \times 10^{-16}$
Ethnicity												
indigenous	−0.152	0.032	−4.71	2.5×10^{-6}	0.195	0.033	5.98	2.20×10^{-9}	−0.797	0.089	−8.98	$<2 \times 10^{-16}$
foreigner	0.215	0.056	3.85	1.2×10^{-4}	−0.489	0.06	−8.15	3.70×10^{-16}	0.912	0.093	9.85	$<2 \times 10^{-16}$
Household economic activity												
logging	0.698	0.069	10.09	$<2 \times 10^{-16}$	−0.566	0.067	−8.5	$<2 \times 10^{-16}$	0.435	0.212	2.05	0.04
emp.	0.957	0.087	11.01	$<2 \times 10^{-16}$	−0.926	0.087	−10.6	$<2 \times 10^{-16}$	0.718	0.235	3.05	0.002
trade	0.992	0.07	14.09	$<2 \times 10^{-16}$	−0.921	0.068	−13.5	$<2 \times 10^{-16}$	0.254	0.214	1.18	0.236
unemp.	0.564	0.07	14.09	2.6×10^{-12}	−0.314	0.079	−3.99	6.5×10^{-5}	0.091	0.236	0.39	0.7
Season												
long rainy	−0.218	0.042	−5.23	1.7×10^{-7}	0.186	0.042	4.42	9.7×10^{-6}	−0.13	0.075	−1.75	0.081
short rainy	−0.064	0.042	−1.52	0.129	0.147	0.043	3.45	6.0×10^{-4}	−0.177	0.076	−2.32	0.02
Town												
Lound.	−0.939	0.094	−10	$<2 \times 10^{-16}$	1.14	0.094	12.19	$<2 \times 10^{-16}$	−1.83	0.474	−3.86	1.1×10^{-4}
Ndoki 1	−0.358	0.062	−5.78	7.3×10^{-9}	0.639	0.064	10.01	$<2 \times 10^{-16}$	−1.81	0.306	−5.92	3.3×10^{-9}
Ndoki 2	−0.555	0.049	−11.4	$<2 \times 10^{-16}$	0.638	0.051	12.45	$<2 \times 10^{-16}$	0.287	0.114	2.52	0.012
Pokola	−0.529	0.048	−11.8	$<2 \times 10^{-16}$	0.544	0.047	11.52	$<2 \times 10^{-16}$	0.854	0.102	8.39	$<2 \times 10^{-16}$
Meat price	-7.85×10^{-5}	2.12×10^{-5}	−3.70	2.1×10^{-4}	-2.38×10^{-5}	2.05×10^{-5}	−1.16	0.247	0.003	3.01×10^{-5}	10.82	$<2 \times 10^{-16}$
Time[b]	-4.00×10^{-3}	9.59×10^{-4}	−4.17	3.0×10^{-5}	3.12×10^{-3}	9.77×10^{-4}	3.19	0.001	0.016	0.002	10.82	3.4×10^{-16}
Months[c]	0.085				0.085				0.085			

[a]*Key: est, estimate; emp, salaried employment; trade, laborer; unemp, unemployed. Effects of categorical variables (ethnicity, town identity, principal economic activity, and season) are contrasts and are compared with the first categorical level (e.g., migrant for ethnicity), with an estimate set at zero.*

[b]*Trend over 6 years.*

[c]*Standard deviation, a measure of variance in monthly consumption.*

employment opportunities and development by logging companies, may present a serious threat to populations of tropical animals.

Of the five logging towns we studied, the center of logging operations, Pokola, was the largest and most developed and was the site of the most worrisome trends for wildlife populations. More bushmeat and a higher proportion of smoked meat arrived in Pokola than other logging towns. The prevalence of smoked bushmeat indicates that Pokola has a widening hunting catchment with increased transport times; thus, hunters preserve meat to get it to the market. The substantial increases from 2000 to 2005 in the proportion of snared animals, animals harvested by immigrants, and smoked meat also suggest hunters are using a larger catchment. The bushmeat in Pokola included a higher proportion of reptiles and small species (e.g., rodents and birds) than most other towns, and residents ate higher proportions of large species, including endangered elephants and apes. The greater diversity of species in Pokola markets and diets is likely due, in part, to the greater use of snares, which are indiscriminate in the species they capture. Hundreds of snares can be set by a single hunter, which suggests commercialization is the intent of the hunt (Noss 1998). The human population pressure in Pokola might be sufficiently great that the current level of hunting is overtaxing wildlife populations such that our monitoring efforts are detecting the early shift in species composition to smaller bodied, more diverse assemblages, which may be an indicator of overharvest (Fa et al. 2002; Jerozolimiski & Peres 2003).

In logging concessions the relatively high salaries of rural workers employed by logging concessionaires provide the means to drive the bushmeat trade (Eves & Ruggiero 2000; Wilkie et al. 2005). In addition to providing a market for bushmeat, company workers have the means to purchase hunting weapons. They often lend their shotguns to indigenous Mbendzélé hunters who lack the cash to buy firearms. In this exchange the gun owner receives the bulk of the meat, giving the intestines or head of the animal to the Mbendzélé hunter (M. Riddell, personal communication). In this way company workers gain cheap meat and benefit from a second source of income by selling a portion of the bushmeat (Wilkie et al. 2001). Without the means to purchase their own weapons, indigenous hunters likely miss an important source of income. It is often the market sale of the meat by the gun owner, and not consumption of wild foods, that can be most important to households living in extreme poverty (De Merode et al. 2004).

In northern Congo the hunter-gatherer Mbendzélé are less likely than other ethnic groups to work for logging companies or have other salaried employment because of their semi-nomadic lifestyles and lack of education. Their principal employment with logging companies is as tree identifiers during preharvest surveys. The high proportion of Mbendzélé meals without animal protein is a demonstration of their poverty compared with other concession residents and suggests that the short-term benefits of hunting are accruing to "outsiders" to the detriment of indigenous peoples who have prior, legitimate claims to bushmeat and other forest resources.

Feeding People in Logging Concessions

Similar to previous studies (Brashares et al. 2004; Wilkie et al. 2005), we found fish consumption was negatively correlated with the consumption of bushmeat and domestic meat, which suggests that both are likely substitutes for fish. We documented a small increase in the consumption of domestic meat over the 6 years of our study. Domestic meat became increasingly available as local traders imported beef and the logging company shipped in frozen meat for sale to concession residents. The increase in the consumption of domestic meat is a promising sign that people are willing to consume alternatives to locally harvested freshwater fish and bushmeat.

Sustainability of Hunting in Logging Concessions

Our method of estimating bushmeat biomass in logging towns greatly underestimated the actual offtake within the logging concessions. Although we surveyed markets and principal entry routes into towns, we missed hunters who returned by other routes from the forest or transported bushmeat directly outside the concessions to other towns. In addition to the five logging towns, there are 28 traditional villages (3098 people) in the concessions that also rely on wild animals for food and revenue.

Although we are uncertain of our estimate of total bushmeat offtake from the concessions, we are confident that the proportional offtake of species and species groups is accurate (with slight underestimations for protected species, including apes and elephants). That both the proportional offtake and the consumption of duikers, pigs, and monkeys remained high and that small species represented a small proportion of all bushmeat suggests wildlife populations might be able to support current offtake levels (Rowcliffe et al. 2003; Fa et al. 2005). Nevertheless, the high diversity of bushmeat species in markets (e.g., Pokola) is alarming because it may indicate the initial phase of wildlife depletion (Fa et al. 2002). Furthermore, a detailed study of hunting and source–sink dynamics of duikers around Kabo found blue duikers are overharvested near Kabo and that hunters increase catchment size to maintain the quantity of duiker meat in the village (Mockrin 2008). The significant increase in the proportion of smoked animals in Pokola, Kabo, and Ndoki 1 similarly suggests that hunters are traveling farther to find prey—a strategy made possible by company vehicles that, despite a ban on transport of hunters and bushmeat, carried 52.5% of all bushmeat to logging

towns. Given these warning signs populations of game animals need to be monitored closely because the decline from healthy faunal populations to faunal depletion can occur suddenly (Albrechtsen et al. 2007).

The Future for Forest Animals

The hunting of bushmeat can be an issue of biodiversity conservation or human livelihood. Most places probably sit somewhere on the continuum between the two extremes (Bennett et al. 2007). In much of West Africa, where populations of large-bodied wildlife species have already declined or been extirpated, the bushmeat problem is one of ensuring that the poor have access to affordable protein sources. In more remote regions of Central Africa, for the time being, the problem is conservation of biodiversity. As we have shown, extractive industries can drive human population growth in frontier forests, intensifying the bushmeat trade and affecting both wildlife populations and human livelihoods. Therefore, where industry is involved, be it industrial logging in Central Africa or agriculture in West Africa, management of bushmeat depends on engaging the private sector so that its actions complement conservation interventions. There is room for optimism that this can happen because industry has been a willing and effective partner in conservation (Elkan et al. 2006; Poulsen et al. 2007; Butler & Laurance 2008).

Industry can promote biodiversity conservation and human livelihoods by moving toward sustainable practices that explicitly consider the direct and indirect effects of their activities on wildlife (Robinson et al. 1999; Milner-Gulland et al. 2003). In our study, we partially attribute the consistency in bushmeat supply over time to conservation measures taken as part of the BZP. Many of these measures apply broadly to extractive industry, not just the forestry sector. First, companies should guarantee the importation or development of protein sources for their workers and their families, keeping prices competitive with bushmeat and fish. Second, companies should contribute to wildlife law enforcement (e.g., salaries of ecoguards who control transport of hunters and bushmeat along logging roads). Third, companies should ensure that their workers hunt legally (with proper licenses and permits) and impose penalties or fire workers who break the law. Fourth, traditional systems of resource management (e.g., hunting territories) should be formalized in land-use planning (e.g., management plans for logging concessions) and access to resources for indigenous people should be prioritized. Fifth, access to forest roads should be restricted to company vehicles, and roads should be closed when not actively used for logging. Finally, urbanization should be avoided in logging concessions. If possible, sawmills and wood-finishing factories should be built and operated in or close to existing cities to avoid the growth of urban centers in the forest. Although the appropriateness of these measures may differ from site to site, active management for wildlife in logging concessions may be the only way to ensure that in tropical forests there are some animals among the trees.

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Supporting Information

The number and identity of bushmeat species observed (Appendix S1) are available as part of the on-line article. The author is responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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