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Wildlife Sustainability and Human Food Security in Cameroon, Central Africa

By

Karen Zohar Weinbaum

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Committee in charge:

Professor Wayne M. Getz, Chair
Professor Justin S. Brashares
Professor David Zilberman

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ABSTRACT

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Concerns about the sustainability of wildlife hunting, particularly in Central Africa, have dominated the scientific literature on wildlife utilization. Only more recently have researchers began considering the human dependence on wildlife for both nutritional needs as well as sources of livelihoods. I begin with a systematic literature review of the wildlife harvesting literature, examining in detail the type of sustainability indicators predominating in the literature and their strengths and weaknesses. We find that indicator type, continent of study, species body mass, taxonomic group, and socioeconomic status of study site are important predictors of the probability of reported sustainability. Indicators relying on population-specific biological data are most often used in North America and Europe, while cruder estimates are more often used in Africa, Latin America, and Oceania. Our results highlight both the uncertainty and lack of uniformity in sustainability science. This presents a major gap in our ability to monitor wildlife and its use, since the importance of wildlife for human consumption is at its greatest precisely in the places where indicators used are the weakest. We point to future directions in the field.

Subsequent field work was conducted in the humid forest zone of southeastern Cameroon in Central Africa. Cameroon is one of the six Congo Basin countries, and there has traditionally been great concern on the part of environmental conservation organizations over the level of wildlife hunting in the country. The first part of my field work was a pilot study to compare field methodologies for wildlife consumption by rural peoples. For wildlife surveys, I used distance sampling on wildlife transects to determine presence/absence and abundance of wildlife species in four different village sites that represent a gradient of human impact and environmental intactness. To evaluate human use of wildlife relative to economic status, I used household surveys with heads of households to ascertain relative wealth status and other household demographic and economic parameters as they relate to wildlife use and consumption. Finally, I tested methodologies for enumerating hunter activity and catch-per-unit-effort (CPUE) as a potentially useful tool for monitoring the status of hunting sustainability. Results indicate that transect surveys do in fact detect increasing wildlife species in more rural, intact village sites, although sample sizes were too small to enumerate actual wildlife densities. Further, more rural

households tend to both hunt and consume more wildlife; wildlife use in rural areas thus forms a more important source of total livelihood than for more urban households.

Although humans have hunted wildlife for millennia, and it remains an important source of animal protein, there is increasing concern that 'bushmeat' hunting, particularly in central Africa, is unsustainable. We explore the role that wildlife and alternative meat sources play in the food security of human populations in southeastern Cameroon. We conducted a large, cross-sectional study in 24 village and town sites in southeastern Cameroon to evaluate the role of wildlife in human food security in a gradient from urban to rural households. Rural households are significantly more likely to rely on wildlife for animal protein, whereas urban households rely on significantly more domestic meat. Using generalized linear mixed modeling, we found significant associations between bushmeat hunting and consumption and positive effects on food security, highlighting the importance of wildlife to human security in the Congo Basin. We asked interviewees about most consumed and most preferred wildlife species; interestingly, there is a potential synergy between taste preferences and the more resilient species that are hunted.

These results indicate that wildlife consumption plays an important role in human food security in the humid forest zone of southeastern Cameroon. Disappearance of wildlife would negatively impact the food security situation in the region, particularly in the forms of protein-energy malnutrition and iron deficiency. At present, there is little ability to maintain small animal husbandry due to the poor veterinary services throughout the region. I evaluate the cost-effectiveness of a 'Heifer International' model extended to two of the ten provinces in Cameroon that make up the region where wildlife hunting is currently the most important form of animal protein, consisting of the Southern and Eastern provinces ("Regions"), which together have a population of about 1 million people. The Heifer International model would replace the animal protein traditionally taken from wildlife sources with a revolving "micro-loan" of livestock, that must be eventually passed on to neighbors. At a population density of around 8 people/km^2, wildlife hunting is believed to be at least four times above maximum sustainable wildlife hunting rates, and therefore supplementary forms of animal protein need to come from elsewhere. Assuming administrative and training costs are included in the prices of the animals as estimated, a 'Heifer International' model of small animal husbandry would be a cost-effective way to address protein-energy malnutrition and iron deficiency, as well as wildlife conservation concerns in this part of the world.

“Tell me, what is it you plan to do
with your one wild and precious life?”
Mary Oliver

Dedicated to my dear parents, Steve and Zipora,
who have been there for me every step
of the wild and precious way.

TABLE OF CONTENTS

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CHAPTER 1

CHAPTER 1

Searching for sustainability: are assessments of wildlife harvests behind the times?

ABSTRACT

The unsustainable harvest of wildlife is a major threat to global biodiversity and to the millions of people who depend on wildlife for food and income. Past research has called attention to the fact that commonly used methods to evaluate the sustainability of wildlife hunting perform poorly, yet these methods remain in popular use today. Here we conduct a systematic review of empirical sustainability assessments to quantify the use of sustainability indicators in the scientific literature and highlight associations between analytical methods and their outcomes. We find that indicator type, continent of study, species body mass, taxonomic group, and socioeconomic status of study site are important predictors of the probability of reported sustainability. The most common measures of sustainability include population growth models, the Robinson and Redford model (1991), and population trends through time. Indicators relying on population-specific biological data are most often used in North America and Europe while cruder estimates are more often used in Africa, Latin America, and Oceania. Our results highlight both the uncertainty and lack of uniformity in sustainability science. Given our urgent need to conserve both wildlife and the food security of rural peoples around the world, improvements in sustainability indicators is of utmost importance.

INTRODUCTION

The harvest of wildlife for human consumption and use is a major threat to global biodiversity and paradoxically, to the very people who depend on it. Millions of people around the world rely on wildlife as a major source of protein, calories, micronutrients, and in many cases, livelihoods (Brashares et al. 2011; Corlett 2007; Fa et al. 2002; Golden et al. 2011). Although humans have been hunting wildlife for millennia, increasing human populations, improved hunting technologies, expanded market access, and logging roads that bring people deeper into tropical forests all contribute to increased pressure on wildlife populations.

Overexploitation is now one of the major threats to mammals, reptiles, and birds, second only to habitat destruction (Vié 2009). The hunting of wildlife is considered the "single most geographically widespread form of resource extraction" in the tropics (Fa et al. 2002); published accounts of the scale and magnitude of wildlife hunting in the tropics conclude that wildlife hunting for human consumption is largely unsustainable (Fa et al. 2005; Milner-Gulland et al. 2003). This situation has come to be known as the "bushmeat crisis"; bushmeat, a colloquial African term meaning "meat from the bush", and "crisis", the unsustainable levels at which wildlife is being harvested.

Similar to fisheries, wildlife can be viewed as a renewable resource whose regenerative capacity allows some level of harvest while sustaining stock populations at ecologically viable levels. A given level of harvest is considered sustainable if it is at or below the level that permits the resource to regenerate itself in perpetuity. Sustainable use of biological resources has been promoted as a workable solution to averting species extinctions and maintaining acceptable levels of ecosystem health and structure, while at the same time taking into account human needs (Bodmer & Lozano 2001; Ginsberg & Milner-Gulland 1994).

How, then, do we determine if a given hunting level is sustainable or not (and by extension, heading towards a crisis)? Upon closer examination, there is much ambiguity in the scientific literature about how best to measure whether wildlife harvest in a given system is sustainable. In a landmark review, Milner-Gulland and Akçakaya (2001) called attention to the fact that indicators used most commonly to evaluate the sustainability of wildlife hunting "do not perform well under realistic conditions". However, these authors only evaluated a small subset of the most commonly used indicators. While a substantial amount of research has aimed to assess the sustainability of wildlife hunting regimes, particularly across the tropics (e.g., Cowlishaw *et al.* 2005, Fa *et al.* 2005), the methods and results of these efforts remain fragmented. Here we review and synthesize empirical work to date on harvest sustainability, and construct a dataset from the results of these studies to examine the following questions:

(1) What methods are used most frequently in the scientific literature to assess the sustainability of wildlife harvesting?
(2) Does the choice of the sustainability indicator used in a study predict the likelihood that the study will conclude harvests are unsustainable?
(3) Are species' traits, local habitat type, and the socioeconomic context of the countries in which the wildlife harvesting takes place significant predictors of reported sustainability?
(4) Are there geographical biases in where different sustainability assessments are used?

In addressing these questions, we provide a quantitative assessment of the wildlife harvesting literature, discuss theoretical support for the most commonly used sustainability indicators, and provide recommendations for future directions in the field.

When is wildlife hunting sustainable?

In the Convention on Biological Diversity (1993), *sustainable use* is defined as “the use of the components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations” (Article 2, CBD 1993). Theory behind sustainable use of renewable resources emerged in the fisheries literature in the 1950’s to counter the view that such resources were inexhaustible (Rosenberg et al. 1993). Still today, the literature and theory on sustainability is more fully developed for aquatic systems than for terrestrial harvests (Milner-Gulland & Akcakaya 2001).

One of the basic sustainability models applied to harvested biological populations is the surplus production model and Maximum Sustainable Yield (MSY). In the logistic model, the simplest of all continuous-time, density-dependent growth models, a population’s maximum production (recruitment) occurs at a population size of around one-half carrying capacity, which is the point at which total population growth rate is maximized (although in some fisheries cases this occurs at 30% of carrying capacity, see: Clark 1991; Mace 1994; Worm et al. 2009). Though *maximum* yield for many populations may be attained at around one-half carrying capacity, harvest can equal production at any point along the recruitment curve (Clark 2010), although Allee effects might become important at very low population levels (Rowcliffe et al. 2003). Therefore, in its simplest sense, hunting is sustainable when the use or harvest of the resource does not exceed production; but the size of this harvest will also depend on other management goals that may include maximizing production, maximizing economic revenue, minimizing the probability of extinction, or the conservation of a full suite of species in an ecosystem as suggested by the CBD definition (1993).

As many authors have noted, however, sustainability, while conceptually sound, is notoriously difficult to operationalize (Ludwig et al. 1993; Quinn & Collie 2005). A large number of sustainability indicators have appeared in the literature in response to the recognition of declining renewable resources, and the plethora of different indicators is partly a response to the frequent absence of adequate biological data. In this paper, we systematically review commonly used methods for assessing biological sustainability in wildlife harvesting, and consider their major advantages and shortcomings (Table 1).

MATERIAL AND METHODS

Literature search

We conducted a comprehensive literature search using ISI Web of Science updated through 2010, using the following search criterion: (sustain* OR unsustain*) AND (hunt* OR harvest* OR exploit* OR offtake OR yield). This search was refined by the following subject areas: ecology, environmental sciences, environmental studies, zoology, biodiversity conservation, geography, and anthropology. We searched for studies whose stated objectives included assessing the sustainability of wildlife hunting; i.e., studies that used sustainability indicators to determine whether a harvest level was sustainable. We restricted papers to empirical, rather than theoretical work, (comparing indices to actual harvest rates, not purely simulation exercises), and excluded prescriptive papers that estimate future sustainable harvests rather than current harvest sustainability. We eliminated papers in which the objective of the authors was to assess the efficacy of culling or eradication programs rather than the sustainable maintenance of wildlife populations. We restricted reviewed papers to terrestrial species (including birds), as assessment of fisheries sustainability is a separate and currently more developed body of literature. When more than one paper was published from the same study site by the same researcher or research group, the most recent paper was included, unless an earlier paper was more comprehensive (rare). After excluding unrelated papers based on title alone, a subset (20%) was examined for inclusion by two reviewers (K.W. and C.G.) to check for agreement on selection criteria (Pullin & Stewart 2006).

Data extraction

We extracted the following information from each paper: country and continent of study, species and taxon, year of publication, sustainability indicator used, and reported outcome for each sustainability evaluation (dichotomous variable, sustainable/unsustainable). The ecoregion for each study area was determined from information reported in the paper or, if unreported, from WWF’s Terrestrial Ecoregions GIS Database (Olson et al. 2001) using ArcGIS 10. Species body masses were estimated from the following sources: mammals (PanTHERIA Database (Jones et al. 2009)), birds (Dunning 2008; Hoyo et al. 1992; Poole 2005; Snow & Perrins 1998), and reptiles (O'Shea & Halliday 2001). When sustainability assessments were based on multi-species groups instead of individual species, average body weight for all relevant species were used. Finally, we included the Human Development Index (HDI) rank for the country of each study site as an indicator of economic and technical capacity (UNDP 2010). Often, multiple species and/or multiple sustainability indicators were used in a single paper. In such cases, we counted each species, indicator, and outcome as a separate observation, but accounted for non-independence in the analysis using “study” as a random effect in a generalized linear mixed model (GLMM).

Data analysis

We developed a generalized linear mixed model (GLMM) to evaluate whether the choice of the sustainability indicator, species’ taxon and body mass, geographic region of study, ecoregion, HDI rank, or publication year had significant associations with the reported outcome of sustainability assessment. GLMM allows for the testing of non-normally distributed data, and can account for non-independence in the data with random effects terms. Additionally, we tested for multicollinearity among variables using the Variance Inflation Factor (VIF); all VIF values were less than 2, indicating no major collinearity issues (Zuur et al. 2007). We used a logistic link function to model a binary response variable (sustainable/unsustainable), and specified study site as a random effect to account for non-independence of multiple sustainability assessments conducted at the same study site (Bolker et al. 2009; Crawley 2007; Zuur et al. 2009). We compared 20 candidate models using Akaike information criterion corrected for small sample size (AICc), and constructed a 95% confidence set of models using Akaike weights (Burnham & Anderson 2002). The significance of differences among factors of categorical explanatory variables were investigated using Wald's *Z* statistic (Bolker et al. 2009). All analyses were done in R (version 2.12, R Development Core Team 2010), and included the lme4 package for the GLMM analysis (Bates & Maechler 2010).

Finally, for a subset of papers using the model described by Robinson and Redford (1991), which accounts for the single largest number of individual sustainability assessments (for details, see Table 1), we determined sensitivity and specificity of the model relative to other indicators used on the same set of data, relying on comparator indicators that are supported in the literature (population trends through time, and the potential biological removal model (PBR); Table 1). Sensitivity and specificity are measures of the performance of tests with binary outcomes, where sensitivity is the probability that a test correctly classifies the outcome of interest (specified in this case as unsustainability), while specificity is the probability that a test correctly classifies the negative outcome of interest (in this case sustainability).

Table 1. Comprehensive list of indicators used for assessing the sustainability of wildlife hunting in the scientific literature.

Indicator	Model/Parameters	Comparator/Outcome	Advantages	Disadvantages/Critiques	Key reference(s)
Population trends over time					
Population abundance/density	Multiple years of data on population abundance, density, or abundance index	Increase, decrease, or stable	Most direct form of assessing sustainability	Difficult to have adequate power to detect change. Declines may indicate trend towards new equilibrium, not sustainability	Hill *et al.* 2003 Baker *et al.* 2004 Lariviere *et al.* 2000
Catch-per-unit-effort (CPUE)	Catch and effort data	Increase, decrease, or stable	Obtained from hunters; generally easier than monitoring populations	Must be monitored over time. Relation between CPUE and abundance not necessarily straightforward (can have hyperdepletion, hyperstability etc)	Hill *et al.* 2003 Vickers 1994 Kumpel *et al.* 2010
Demographic Models					
Population growth rate (λ)	Demographic model/matrix projection model	If $\lambda \geq 1$, the mortality caused by harvesting is sustainable; if $\lambda < 1$, mortality due to harvesting is considered unsustainable	Mechanistic explanations for population trajectory, given harvesting.	Data intensive Assumes harvesting is the main driver, and assumes all harvesting is accounted for	Lofroth and Ott 2007 Combreau *et al.* 2001
Population viability analysis	Demographic model/matrix projection model	Determine how much human-added mortality is compatible with population persistence, compared with actual harvest	Mechanistic explanations for population trajectory, given hunting. Can take uncertainty into account to provide probabilities of persistence.	Data intensive	Combreau *et al.* 2001
Surplus production models					
Robinson & Redford (1991)	$P = 0.6K(R_{max}-1)F$ K=carrying capacity R_{max} =Intrinsic rate of population increase F =mortality factor	If observed harvest is greater than estimated P, the harvest is considered unsustainable	Widely used in tropical "bushmeat" hunting studies. Relatively few parameters needed; easier to implement than full models in data-	Often K, R_{max} not measured, but taken from other sites/conditions, potentially giving misleading production estimates.	Robinson and Redford 1991 Slade *et al.* 1998 Milner-Gulland & Akcakaya

Indicator	Model/Parameters	Comparator/Outcome	Advantages	Disadvantages/Critiques	Key reference(s)
	(F= 0.2, 0.4 or 0.6 depending on species longevity) Total annual harvests		deficient conditions	May not be precautionary enough. F addresses survival rates, but in a highly simplified way Implicitly assumes one specific form of density dependence	2001
Bodmer Model (1994) *(Unified Harvest Model)*	$P = (0.5D)(Y * g)$ D=population density Y=young/female g=average # gestations/yr	If observed harvest is greater than estimated P, the harvest is considered unsustainable	Used in several "bushmeat" hunting studies. Relatively few parameters needed; easier to implement than full models in data-deficient conditions	Similar to Robinson & Redford model (1991), not precautionary enough; does not include species survival rates. Similar rudimentary natural mortality factor.	Bodmer 1994 Bodmer *et al.* 1994 Robinson and Bodmer 1999
Maximum Sustainable Yield (*MSY*)	$\frac{dN}{dt} = rN\left(1-\frac{N}{K}\right) - H$ $MSY = \frac{rK}{4}$ N=Population abundance K=Carrying capacity r= Intrinsic rate of population growth	If observed harvest is larger than MSY, it is considered unsustainable	Clear reference target, commonly used in fisheries	May have ambiguous results; a harvest less than MSY may indicate overexploitation from a small, overexploited population (Milner-Gulland, 2007)	Milner-Gulland, 2007 Brook and Whitehead 2005 Jensen 2002
US National Marine Fisheries Service algorithm *(Potential Biological Removal)*	$PBR = N_{min} * 0.5R_{max} * F_R$ N_{min} = minimum population estimate R_{max} = maximum per capita rate of population increase F_R = recovery factor	Harvest level exceeding the "potential biological removal level" is considered unsustainable	Clear reference target; Shown by Milner-Gulland & Akcakaya 2001 and others to perform well in simulation tests; Relatively few parameters needed Accounts for uncertainty by using minimum abundance	The intent of the algorithm is to be sufficiently precautionary to allow depleted populations to recover; thus it may not maximize	Milner-Gulland & Akcakaya 2001 Wade 1998 Cowlishaw *et al.* 2005

Indicator	Model/Parameters	Comparator/Outcome	Advantages	Disadvantages/Critiques	Key reference(s)
	between 0.1 and 1		term, and accounts for bias with F_R term.		
Comparison between sites					
Population abundance/density	Comparison of population abundance/density in hunted and unhunted (or lightly hunted) sites	Significant differences (generally hunted sites have lower species abundances) are interpreted as unsustainable	Differences are testable Common index in bushmeat hunting studies	Populations can be harvested "sustainably" at an infinite number of population sizes, as long as offtake does not exceed production rates. Differences in population sizes alone cannot be used to assess sustainability. Sites must be otherwise comparable..	Robinson and Redford 1994 Sutherland 2001 Fitzgibbon 1995
Population age/sex structure	Comparison of population age/sex structure in hunted and unhunted (or lightly hunted) sites	Significant differences are interpreted as unsustainable	Differences are testable Common index in bushmeat hunting studies	Differences in age/sex structure alone cannot be used to assess sustainability	Hurtado-Gonzales and Bodmer 2004 Velasco *et al.* 2003
Market Indices					
Prices of game and alternatives	Market prices	Price trends over time; if prices of wildlife increase, considered an economic signal of diminished supply, and therefore considered unsustainable	Market data often easier to acquire than species demographic data in many tropical settings	Supply and demand can be influenced by multiple factors (e.g. taste preferences, law enforcement, environmental changes), therefore assumptions of sustainability may be misguided.	(Milner-Gulland & Clayton 2002) (Albrechtsen et al. 2007) (Cowlishaw et al. 2005)
Quantity of species sold	Quantity	Quantity of species available over time; Declines signify unsustainability	as above	as above	(Albrechtsen et al. 2007)
Changes in species	Species composition	Changes indicate	as above	as above	(Albrechtsen et

Indicator	Model/Parameters	Comparator/Outcome	Advantages	Disadvantages/Critiques	Key reference(s)
composition	over time	unsustainability (or recovering populations)			al. 2007) Rowcliffe *et al.* 2003 Crookes et al. 2005
Trends in distance of wildlife from source to market	Wildlife source distance information over time	Wildlife source distance; if distance is increasing, hunting is considered unsustainable	as above	Distance to market may be influenced by other factors (e.g. law enforcement, environmental changes)	(Albrechtsen et al. 2007) (Cowlishaw et al. 2005) Crookes et al. 2005
Harvest					
Harvest rates	Harvest data, but no effort data	Temporal trend or comparison with other sites	Obtained from hunters; easier than monitoring populations through time	Ambiguous results, depending on area and effort used for each harvest.	(Hurtado-Gonzales & Bodmer 2004)
Change in distance required for hunting	Distance to hunts	Trends in distance over time or in comparison with other sites	Data relatively easy to obtain	Changes in distance to hunting can have multiple causes, (e.g. changes in supply, demand; local depletion)	(Smith 2008) van Vliet & Nasi 2008
Changes in species composition at village level	Species composition over time	Changes indicate unsustainability (or recovering populations)	Obtained from hunters; generally easier than monitoring populations; multiple prey species evaluated	Need to distinguish between effects of selective vs. non-selective hunting techniques Does not	(Albrechtsen et al. 2007) Rowcliffe *et al.*, 2003
Other Indicators					
Robinson and Bennett's (2000) estimate of sustainable harvest rates at 152 kg/km2	Total harvest rate	Global harvest rate of 152 kg/km^2; calculated for the neotropics only	Simple rule-of-thumb	Does not account for uncertainty or inter-site variation in productivity	Robinson & Bennett 2000 Gavin 2007

Indicator	Model/Parameters	Comparator/Outcome	Advantages	Disadvantages/Critiques	Key reference(s)
Hill and Padwe's (2000) potential sustainable yield	Human population density	Potential sustainable yields when 5 km^2 available per consumer	Simple rule-of-thumb	Does not account for uncertainty or inter-site variation in productivity	Hill and Padwe 2000 Gavin 2007
Robinson and Bennett's(2000) human population density ≤1 person/km^2	Human population density	Sustainable yields with human population densities ≤ 1 person/ km^2	Simple rule-of-thumb	Does not account for uncertainty or inter-site variation in productivity	Robinson and Bennett 2000 Gavin 2007
Compensatory mortality	Quantifying compensatory mortality based on river flooding	Sustainable if harvests less than mortality due to seasonal flooding	Simple counts	Very case-specific	Caputo *et al.* 2005
10% harvest rule	Population sizes	Arbitrary 10% rule applied to several species	Simple rule-of-thumb	Proportion may differ in different species	Caro *et al*. 1998

RESULTS

Our literature search yielded 3,172 studies of harvest sustainability, of which 102 fulfilled all of our *a priori* criteria (see Appendix SA1 in Supporting Information). In these studies, 750 separate evaluations of harvest sustainability were assessed (see Appendix ST1 in Supporting Information), covering 231 unique species (153 mammal species, 60 bird species, and 18 reptile species). 55 of the studies were single-species assessments, and 47 were multi-species assessments. A total of 487 of the 750 (65%) harvests were deemed “sustainable” by the authors, while 263 (35%) were deemed “unsustainable”. Overall, there has been a general increasing trend over time in papers evaluating the sustainability of wildlife hunting since 1993, with a possible leveling off in recent years (Fig. 1). Two models contributed to the 95% confidence set of the GLMM model (cumulative Akaike weights ≥0.95; Table 2). Cumulative Akaike weights can also be used to rank the relative importance of each explanatory variable in predicting the probability of reported sustainability (Burnham & Anderson 2002; Zuur et al. 2009). This provided strong inferential evidence that sustainability indicator, continent, species body mass, taxa, and HDI rank are all important predictors of reported sustainability, whereas ecoregion and publication year were not (Table 3). Because the most explanatory model (lowest AICc) was weighted more than three times the second model (Table 2), we used parameter estimates from the lowest ranked model.

Figure 1. Trend through time of peer-reviewed papers addressing wildlife sustainability

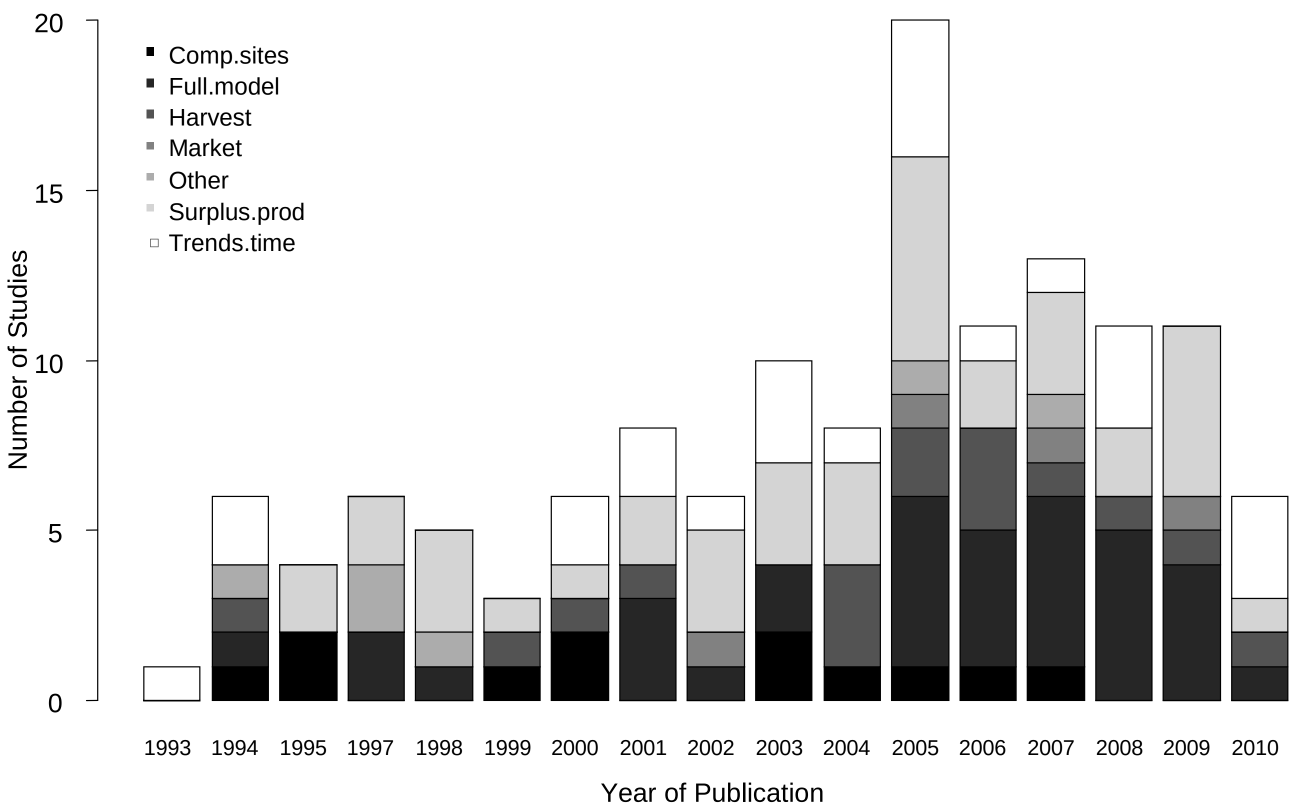


Table 2. 95% confidence set (Models 1 & 2) and 99% confidence set (Models 1-3) of best-ranked generalized linear mixed models (cumulative Akaike weights ≥0.95) from a set of 20 candidate models.

Rank	Model	*K*	AICc	ΔAICc	AIC wt	Deviance
1	I + T + C + BM + H	27	761.82	0	0.77	705.9
2	I + T + C + BM + H + E	32	764.32	2.50	0.22	736.9
3	I + T + C + BM + Y	25	769.26	7.43	0.02	717.5

K=number of parameters; I=Sustainability Indicator; T=Taxa; C=Continent; BM=Body Mass; H=HDI Rank; E=Ecoregion; Y=PubYear

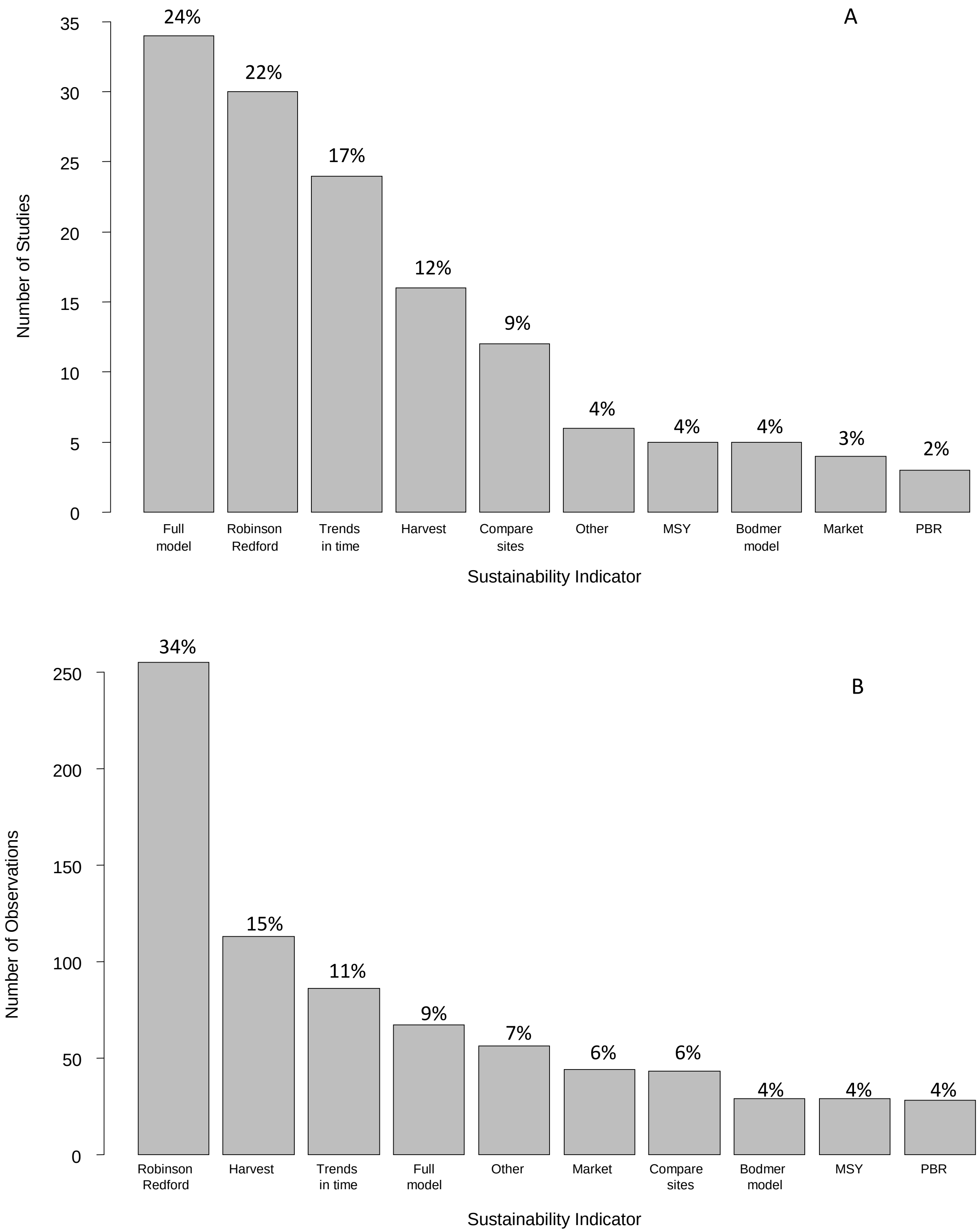
Table 3. Cumulative Akaike weights of explanatory variables used to model the probability of sustainable harvests.

Variable	Relative importance (based on cumulative Akaike weights)
Continent	1
Indicator	1
Species Body Mass (log)	1
Taxa	1
HDI Rank	.98
Ecoregion	.22
Publication year	.02

Sustainability indicators

The probability of reported sustainability was strongly associated with sustainability indictor type (cumulative Akaike weight=1). The top five most commonly used sustainability measures included 1) demographic models of population growth (“Full model”), applied in 24% of the studies, but which made up only 9% of all individual sustainability assessments; 2) the Robinson and Redford model (1991), used in 21% of the studies, but accounted for 34% of all assessments; 3) population trend methods, used in 17% of the studies, and 20% of all assessments; 4) harvest-based indicators (12% of studies and 15% of all assessments), and 5) comparisons of demographic parameters between sites (“Compare sites”), employed in 9% of studies and 6% of assessments (Fig. 2). Relative to the reference group (population trends through time), two assessment methods were significantly different: full models and the “Other” category were negatively associated with the probability of reported sustainability (Wald Z= -2.21, p=0.027; and Wald Z= -2.05, p=0.04, respectively; Table 5, and see Figure S1 in Supporting Information).

Figure 2. Total number of studies (A) and assessments (B) by sustainability indicator type.



Species Traits

The 102 studies yielded 231 unique species examined for harvest sustainability (153 mammal species, 60 bird species, and 18 reptile species). Breaking down the total number of individual assessments, there were 269 assessments of ungulates, 110 assessments of birds, 109 assessments of primates, 91 assessments of rodents, 64 assessments of carnivores, and 107 assessments of other taxonomic groups (Table 4). Species body mass (log) was negatively associated with sustainability (cumulative Akaike weight=1, Table 3; Wald Z= -2.86, p= 0.004; Table 5). Relative to the reference group (rodents), harvests of birds, carnivores, primates, and other mammals were significantly less likely to be deemed sustainable, (Wald Z= -3.29, p= 0.001; Wald Z= -2.82, p= 0.005; Wald Z= -4.37, p< 0.0001; and Wald Z= -2.56, p=0.01 respectively; Table 5 and see Figure S2 in Supporting Information).

Table 4. Characteristics of wildlife harvesting sustainability assessments, 1993-2010.

		Studies		Observations	
		No.	**%**	**No.**	**%**
Continent	Africa	20	19.2%	204	27.2%
	Asia	5	4.8%	12	1.6%
	Europe	9	8.7%	25	3.3%
	North America	31	29.8%	60	8.0%
	Oceania	11	10.6%	25	3.3%
	South America	28	26.9%	424	56.5%
HDI Rank	Low	8	7.5%	32	4.3%
	Medium	25	23.6%	283	37.7%
	High	32	30.2%	352	46.9%
	Very High	41	38.7%	83	11.1%
Indicator	Bodmer model	5	3.6%	29	3.9%
	Compare sites	12	8.6%	43	5.7%
	Full model	34	24.5%	67	8.9%
	Harvest	16	11.5%	113	15.1%
	Market	4	2.9%	44	5.9%
	MSY	5	3.6%	29	3.9%
	Other	6	4.3%	56	7.5%
	PBR	3	2.2%	28	3.7%
	Robinson & Redford 1991	30	21.6%	255	34.0%
	Trends time	24	17.3%	86	11.5%
Taxa	Bird	34	18.6%	110	14.7%
	Carnivore	35	19.1%	64	8.5%
	Edentata	9	4.9%	35	4.7%
	Mammal (other)	12	6.6%	43	5.7%
	Primate	23	12.6%	109	14.5%
	Reptile	11	6.0%	29	3.9%
	Rodent	20	10.9%	91	12.1%
	Ungulate	39	21.3%	269	35.9%
Ecoregion	Desert	6	5.7%	10	1.3%
	Savanna/grassland	15	14.2%	108	14.4%
	Temperate forest	19	17.9%	41	5.5%
	Tropical forest	46	43.4%	552	73.6%
	Tundra/taiga	15	14.2%	20	2.7%
	Various (generalist)	5	4.7%	19	2.5%
Species Body Mass	Range (g)	[16 - 3825000]			
	Mean (g) (±SD)	[49,762 ± 224,778]			

Geographic variables

A majority of sustainability assessments occurred in Africa and South America (204 and 424 assessments respectively, or 84% of total assessments), and the remainder were spread across North America (8%), Europe (3%), Oceania (3%), and Asia (2%), (Table 4). By continent, only Oceania was significantly associated (negatively) with reported sustainability relative to the reference group, Africa (Wald Z= -2.46, p= 0.014; Table 5). 'Medium', 'High', and 'Very High' ranked countries on the Human Development Index (HDI) were positively associated with reported sustainability relative to 'Low' ranked countries (significant associations for 'Medium' HDI Rank, Wald Z= 3.12, p= 0.002, and 'Very High' HDI Rank, Wald Z= 2.36, p= 0.018; Table 5 and see Figure S3 in Supporting Information). The "gold standards" of sustainability indicators, which use direct data on population trends and/or demographic characteristics (e.g. monitoring populations through time, and using full population models to determine population growth rate (λ)), are mainly used in North America, Europe and Asia. Other indicators, which do not necessarily use direct data from the wildlife population being evaluated (e.g. Robinson and Redford (1991) model, Bodmer model (1994), market indices, harvest-based indicators, and others (Table 1)), are used almost exclusively in Africa, South America, and Oceania (see Figure S4 in Supporting Information).

Table 5. Coefficient estimates and significance of parameters in the top candidate model for the probability of sustainable outcome. Parameter coefficient estimates, standard errors, Wald Z test statistics and *p*-values reported.

Variable	**Factor**	**Estimate**	**Std. Error**	**Z value**	**Pr(>|z|)**	
	(Intercept)	2.557	1.318	1.940	0.052	·
Indicator type	Bodmer model	0.242	0.777	0.312	0.755	
	Compare sites	0.071	0.739	0.096	0.924	
	Full model	-1.669	0.757	-2.205	0.027	*
	Harvest	0.791	0.650	1.216	0.224	
	Market	-2.381	1.388	-1.715	0.086	·
	MSY	-0.389	0.930	-0.418	0.676	
	PBR	-1.032	1.242	-0.831	0.406	
	Rob.Red.1991	0.046	0.559	0.082	0.934	
	Other	-1.806	0.879	-2.054	0.040	*
Continent	Asia	-20.860	1068	-0.020	0.984	
	Europe	-1.141	1.478	-0.772	0.440	
	North America	1.044	1.426	0.732	0.464	
	Oceania	-2.615	1.062	-2.463	0.014	*
	South America	0.008	1.044	0.008	0.994	
HDI Rank	Medium	2.983	0.955	3.123	0.002	**
	High	2.031	1.336	1.519	0.129	
	Very High	3.797	1.610	2.358	0.018	*
Body Mass	log(body mass)	-0.305	0.107	-2.855	0.004	**
Taxa	Bird	-1.699	0.517	-3.290	0.001	**
	Carnivore	-1.639	0.581	-2.824	0.005	**
	Edentata	-0.040	0.675	-0.060	0.953	
	Mammal (other)	-1.703	0.664	-2.562	0.010	**
	Primate	-1.991	0.456	-4.369	0.000	***
	Reptile	1.504	1.509	0.997	0.319	
	Ungulate	-0.388	0.466	-0.831	0.406	

Significance of coefficients is denoted as: *** p<0.001, ** p<0.01, * p<0.05, · p<0.10

Comparison of Robinson and Redford (1991) model to other indicators

Generally, studies using the Robinson and Redford model did so in tropical developing regions where biological and population-level data are difficult to acquire. However, we found five papers (Cowlishaw et al. 2005; Hill et al. 2003; Noss et al. 2005; Siren et al. 2004; Zapata-Rios et al. 2009) that used the Robinson and Redford model and that were also able to compare their results with at least one other indicator (trends through time, catch-per-unit-effort, and the potential biological removal model, Table 1). We pooled trends through time, CPUE and PBR indicators and compared these results with the Robinson and Redford model (Table 6). With 86 comparisons, specificity of the Robinson and Redford model (the probability of correctly classifying sustainability) was 92% (95% CI: 82-98%), while sensitivity (the probability of correctly classifying unsustainability) was 42% (95% CI: 25-61%).

DISCUSSION

Sustainability indicators

The global extent of wildlife hunting, the role of wildlife underpinning human food security, and current extinction threats to wildlife highlight the need for appropriate sustainability indicators to monitor conditions and trends of harvested wildlife species. Several authors (e.g., Milner-Gulland & Akcakaya 2001; Robinson & Redford 1994; Sutherland 2001) have called attention to the importance of reliable methods for evaluating the sustainability of wildlife offtake and assessing the status of hunted wildlife populations. They note that theory often does not inform data collection and management planning as it should, which has serious implications for the quality of conservation and livelihood recommendations made from such research. Nowhere is this more urgent than in the places where people rely directly on wildlife meat for protein, calories, micronutrients, and livelihoods (Golden et al. 2011). In such regions, the precautionary principle alone will not be sufficient to balance the needs of wildlife species and the people who depend on them; therefore, efforts to maximize harvests and the persistence of harvested populations must be improved.

Our systematic review of the literature found that the most commonly used sustainability indicators were demographic models of population growth, the Robinson and Redford model, population trends through time, harvest-based indicators, and comparisons of demographic parameters between sites. Although all indicators will have trade-offs in terms of effort required for data collection, scale of coverage, timeliness, accuracy and precision, some of the commonly used indicators have weaker theoretical support and thus may provide only very coarse-scale information whose reliability can be questioned. Static, one-off indicators cannot ultimately predict sustainability; it has been shown that in a sustainable system, half of a random sample of sustainability indicator evaluations would indicate unsustainability due to stochastic processes about an equilibrium (Ling & Milner-Gulland 2006).While we propose the monitoring of harvested populations through time as one of the gold standards in sustainability monitoring, this approach is likely to be more difficult in remote, tropical locations that lack infrastructure for such research. Additionally, without a clear relationship with hunting patterns, wildlife population trends may increase or decrease due to exogenous factors other than hunting, such as habitat or climatic changes, or unmonitored harvests elsewhere in the population (Hill et al.

2003). Demonstrating a decline between two points in time is not enough to diagnose unsustainability. Ideally, population monitoring is an ongoing process and is accompanied by adaptive harvesting strategies (Johnson et al. 2002).

Demographic models in the form of matrix population models ("Full models") are also considered a gold standard (Milner-Gulland & Akcakaya 2001) due to the full use of species' demographic information and the ability to determine optimal offtake by age or stage class (Getz & Haight 1989). However, such models often do not account for density dependence (Dobey et al. 2005; Marboutin et al. 2003), whereas the ability of harvested animals to persist in the presence of sustained exploitation may be evidence for density dependence (Marboutin et al. 2003). Ignoring density-dependence where it occurs could lead to a conservative bias in allowable sustainable offtake, underestimating maximum sustainable yield and possibly explaining the negative bias of full models found in this study relative to monitoring population trends through time (Table 5). This result could also be due to animal dispersal/immigration that is not being properly captured by demographic harvest models (Pople et al. 2007).

The Robinson and Redford model (1991) is relatively easy to implement because it uses Cole's formula (1954) to calculate maximum finite rate of population growth (λ) and thus requires little actual demographic information from local contexts, and involves relatively simple calculations (Robinson & Redford 1994; Slade et al. 1998). While initially intended as a crude indicator able to detect only whether harvests exceeded an estimated maximum possible wildlife production (Robinson & Redford 1994), its simplicity has drawn many users. Robinson and Redford (1994) themselves state that the model "does not allow the conclusion that an actual harvest is sustainable", and that "low harvests might be a consequence of depleted game densities, less than maximum birth rates, higher than minimum mortality rates, etc" (Robinson & Redford 1994). Slade *et al*. (1998) contend that because the Robinson and Redford method uses Cole's formula and ignores mortality of juveniles or adults prior to age at first reproduction, it thus has a tendency to overestimate maximum production and thereby underestimate overharvesting. Despite a mortality factor (F) added to address this (Table 1), it has still been criticized as addressing the issue in a highly simplified way (Milner-Gulland & Akcakaya 2001; van Vliet & Nasi 2008). Our results of sensitivity and specificity support the argument that the Robinson and Redford model poorly classifies unsustainability.

On the other hand, there are some situations where the Robinson and Redford model may be too conservative. In Slade *et al*.'s (1998) analysis, the Robinson and Redford model may have also *underestimated* maximum rates of increase for some species compared to production estimates from complete life tables (in 5 of 19 species examined). A number of authors echo the observation that although deemed unsustainable according to the Robinson and Redford model, some harvested populations showed no signs of depletion (Alvard et al. 1997; Koster 2008; Ohl-Schacherer et al. 2007), or harvest levels in their study sites have been maintained or even increased over time (Alvard et al. 1997; Hill et al. 2003; Novaro et al. 2000; Peres & Nascimento 2006; van Vliet & Nasi 2008). Salas & Kim (2002) and others voice concern over the model's assumption of a closed population, and that in fact localized hunting may be sustainable at larger spatial scales when unhunted populations contribute immigrants to hunted populations, effectively increasing the potential harvestable surplus. They and others (e.g. van Vliet & Nasi 2008) also note that, since density is the most sensitive variable in the Robinson and Redford model, measuring it accurately is perhaps more important than accurately measuring the other parameters in the model, although this is often not done due to difficult monitoring conditions. van Vliet & Nasi (2008) emphasize the number of assumptions required by this model and the uncertainty that is accumulated in these calculations, i.e. in estimates of density, mortality factor *F*, and rate of maximum population increase. In short, it is not possible to predict the net direction of biases in this commonly used model.

Another commonly used sustainability indicator, the comparison of wildlife abundance or other demographic parameters across two or more sites at one point in time (Table 1), cannot actually determine sustainability according to theory relying on logistic, density-dependent population growth (Robinson & Redford 1994), and is sensitive to underlying differences among compared sites. Under this theory, maximum sustainable yield occurs when a population is at one-half of its carrying capacity (although this will vary somewhat by taxa). Methods that demonstrate significant differences between hunted and unhunted sites can effectively demonstrate only local depletion (Hill et al. 2003). Local depletion may reflect sustainable harvest when greater spatial scales are taken into account, where animal dispersal and recolonization can be accounted for (Siren et al. 2004). In some cases, hunting impact studies may not be able to distinguish between evasive prey behavior and actual changes in animal density (Hill et al. 1997; Siren et al. 2004). Additionally, simple comparisons of biomass extraction in different areas can be misleading. Fa and Peres (2002) and others show that mammal biomass is generally higher in Africa than in the Neotropics, and therefore it is to be expected that more biomass per unit area can be extracted from African forests.

Species Traits

Species traits are hypothesized to influence the potential productivity and resilience of a population in the face of harvest (Cardillo et al. 2005). Relative to the reference group (rodents), harvests of birds, carnivores, primates, and other mammals (Marsupialia, Chiroptera, Lagomorpha) were significantly more likely to be characterized as unsustainable (Table 5). These trends match theoretical predictions and empirical observations that taxa with lower intrinsic rates of increase are more susceptible to overharvest (Bodmer et al. 1997; Price & Gittleman 2007). Ungulates (including duikers, brocket deer, and pigs) play an important role in terms of both numbers and biomass consumed; it is notable that they may be relatively tolerant to hunting (Alvard et al. 1997; Bodmer 1995; Hurtado-Gonzales & Bodmer 2004; Reyna-Hurtado & Tanner 2007). In some cases, species may actually show an increase in abundance in more heavily hunted areas, such as the dwarf brocket deer in Argentina, purportedly due to decreased competition with another brocket deer species (Di Bitetti et al. 2008).

Additionally, sustainability will also depend on which age classes of a species are targeted. For example, bird nestlings will be harvested at a maximal rate when all nesting sites are occupied at near carry capacity (Beissinger & Bucher 1992). If there is a proportion of the population that is nonbreeding, hunting is expected to be more compensatory rather than additive (Beissinger & Bucher 1992; Kenward et al. 2007). Although relatively well studied in developed countries, there is still a need for field studies that address hypotheses on forms of density dependent mortality and reproduction, and compensatory vs. additive mortality effects in tropical harvested species.

Geography of Wildlife Hunting Assessments

We found strong geographic trends influencing the probability of reported sustainability, and geographic differences in where sustainability indicators are used. The HDI rank of the country of study plays an important role in predicting reported sustainability, where higher HDI ranked countries are associated with sustainability relative to lower ranked HDI countries (Table 5). The HDI rank is a comparative index of health, education, and economic well-being, and therefore may predict technical and socio-political capacity to manage renewable resources. Oceania was the only region to have significantly lower probability of reported sustainability than Africa (Table 5), which may be explained at least in part by island isolation and lower probability of recolonization of extinct metapopulations. Asia was poorly represented in the number of sustainability studies, which may reflect an endgame of many people and fewer protected areas, and researchers' perceptions that there is no sustainable hunting left in Asia (Bennett 2007). The stark geographical differences in where particular indicators are used may introduce unintended biases into the results of sustainability assessments, particularly since some cruder estimates (characterized by very little local biological and population-level data) are used largely in developing countries, which are the very places where humans have the most direct reliance.

Scale, Source-Sink Theory and Refugia

Many authors note that there is a missing element to most commonly used sustainability analyses: spatial scale. From the metapopulation approach, unhunted and hunted populations can be seen as source and sink populations, respectively, linked to each other to varying degrees by emigration and immigration. Peres (2001) referred to this as the "rescue effect" of overharvested species, where immigrants from surrounding areas can rebuild depleted populations and replenish local game stocks. Siren *et al.* (2004) found different results from the Robinson and Redford model, depending on the extent of the spatial scale they examined. At smaller scales, they found several zones that were overharvested, but when looking at the larger catch basin scale, the harvest appeared sustainable. Novaro *et al*. (2000) compiled results from five separate studies on the sustainability of tapir hunting in South America. Four out of five study results contradicted predictions of extirpation (based on the Robinson and Redford model and Bodmer model), and hunters continued harvesting tapirs over the length of the studies, in some cases up to 20-30 years later.

Studies that assess sustainability at very localized scales may be detecting "depleted" populations, but this hunting may actually be in equilibrium with dispersing animals from unhunted populations outside of the hunted zone. Joshi and Gadgil (1991), McCullough (1996), Ling and Milner-Gulland (2008) and others explore the utility of spatial controls on areas under harvest, as a way to maximize harvest and minimize the risk of overharvest, even in the absence of detailed biological data. This notion of "refugia" in space and time has been shown empirically by Novaro *et al.* (2005), but is still a vastly underappreciated area of research. While some authors emphasize issues of spatial scale, we also stress that temporal scale is a crucial element to assessing longer-term sustainability. Although many sustainability studies are often of limited time frames—whether as part of rapid conservation NGO research or doctoral dissertation research—we advocate a more concerted effort at national and international scales to monitor harvested wildlife populations through time, as part of management efforts (Nichols & Williams 2006). Examples include waterfowl monitoring in the United States (Nichols et al. 1995), kangaroo monitoring in Australia (Pople et al. 2007), and global fisheries and aquaculture monitoring by the Food and Agriculture Organization of the United Nations (FAO 2010).

There are inherent methodological biases both in the field and in the scientific literature that preclude taking interpretations of our analysis too far. Aside from geographical biases of where different sustainability indicators are used, there may also be a selection bias of which populations and study sites are chosen. Conservation biologists may tend to focus on areas or species of particular concern that would be more likely to result in unsustainable harvests. Publication bias might imply that it is more likely that an "unsustainable" harvest be reported, as the "effect" of interest (Gates 2002). The recent leveling off in harvest sustainability papers (Fig. 1), however, might be evidence of a more nuanced understanding of sustainability; and, although researchers continue to use the same indicators, they appear to be more conservative now in the statements they make about sustainability.

FUTURE RESEARCH DIRECTIONS

As argued elsewhere (Milner-Gulland & Rowcliffe 2007), long-term population monitoring programs will be the most informative approach to provide baseline information against which any hunting effects and/or conservation interventions can be monitored; barring this, indicators of sustainability will continue to be used. Milner-Gulland & Akçakaya (2001) simulated harvests using six algorithms in order to assess the trade-offs between maximizing total harvests and minimizing risk of the population going below a population threshold of 2% of carrying capacity. Compared to the Robinson and Redford model, and two related versions of the Bodmer model (Bodmer 1994; Robinson & Bodmer 1999), the full demographic model performed best, with the potential biological removal model (PBR) (Wade 1998) model performing reasonably well. At present, only two empirical terrestrial studies employ the PBR model (Cowlishaw et al. 2005; Dillingham & Fletcher 2008). We suggest that these methods should be the focus of future studies, in favor over the Robinson and Redford model and Bodmer models (Robinson & Bodmer 1999). In addition to prioritizing long-term population monitoring, research should be directed at acquiring basic life-history data for exploited species whose biology is not yet well known, and derived from the population of interest whenever possible. If direct assessments of population abundance or demography remain difficult (e.g. in tropical forest conditions), another avenue for further research is in the utility of catch-per-unit-effort indicators (Rist et al. 2010; Rist et al. 2008), as these are often easier to acquire and can be informed by much of the fisheries modeling, e.g. integrated stock assessments (Maunder & Punt 2004).

More recent emphasis in renewable resource management involves multi-species modeling, and modeling that incorporates uncertainty and takes into account harvester behavior in addition to harvested population dynamics. Wildlife harvesting across much of the tropics involves a multi-species prey base, which may be important to consider simultaneously because of species interactions and the potential for hunting effort to affect different species disproportionately (Rowcliffe et al. 2003). Adaptive harvest management (AHM) is an iterative process of monitoring, assessment and decision making incorporating uncertainties in all of these areas (Johnson et al. 2002), and rests on the premise that harvest sustainability is enhanced with on-the-ground experimentation (Hilborn et al. 1995; Nichols et al. 1995; Walters 2001). The management of harvested waterfowl in North America since 1995 is an example of a successful adaptive management strategy (Nichols et al. 2007). Management Strategy Evaluation (MSE) is a modeling framework that has wide use in fisheries, with great potential for application to terrestrial wildlife management (Bunnefeld et al. 2011; Milner-Gulland 2011). MSEs extend adaptive harvest management to incorporate the underlying social processes that influence harvester behavior. Through probabilistic simulation models, stakeholders can evaluate trade-offs in different management scenarios (e.g. harvest levels), including varying areas and magnitudes of uncertainty.

CONCLUSION

Hundreds of millions of people around the world depend on wildlife for their nutrition and livelihoods. The sustainability of the harvesting of many of these species upon which people depend is at stake. We have shown that some of the most commonly used sustainability indicators rely on very little biological and population-level data from the population of interest, and although they have already received heavy criticism in the scientific literature, they continue to be used. It would be imprudent to continue using “rule-of thumb” indicators in the very regions of the world where people depend most on wildlife as food sources. Resource managers and conservationists should focus on research that seeks to maximize productive use of wildlife while minimizing the probability of species extinction. This will require better knowledge of tropical species’ biology and ecology, more long-term monitoring of wildlife populations, spatial scale and source-sink considerations, and modeling methods that take into account uncertainty.

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CHAPTER 2

CHAPTER 2

Wildlife diversity in cocoa/agricultural mosaics at the Congo Basin forest margin

ABSTRACT

While forest conversion to agriculture is considered one of the most important threats to biodiversity in the tropics, the over harvesting of wildlife is considered to be an even more important threat in the Central African context. The human population gradient on the northern fringe of the Congo Basin represents the future trajectory of change in land use, bushmeat consumption, and biodiversity if human population growth rates continue. In this preliminary study we conducted wildlife transects (n=35 km), hunter-follow surveys (n=14), and socioeconomic interviews (n=42) in four villages across a gradient of human population density (from peri-urban to remote) in southern Cameroon in an agricultural mosaic consisting of cocoa agroforests, food crops, fallow fields, secondary forest and primary forest. Transect results reveal that mammalian diversity increases with village remoteness. Secondary forest had the largest proportion of animal signs of all land uses. Hunter-follows reveal that people invest more time to hunting in more remote areas, and interviews highlight that bushmeat is a more important source of income in more rural areas, and is more often consumed. Fish is consumed more often than bushmeat, however, and is reportedly becoming more scarce locally along with wildlife. The Food and Agriculture Organization has called the unsustainable hunting of bushmeat "one of the most important food security and biodiversity conservation challenges" in Central Africa and requires further research.

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INTRODUCTION

Forest conversion to agriculture is considered one of the most important threats to biodiversity in the tropics. Such land use change modifies forest habitat and facilitates human access to the hunting of wildlife. In Central Africa, deforestation occurs at an estimated rate of 0.1-1.0 % per year (FAO 2005), and in Cameroon, over 85% of this deforestation is attributed to smallholder agriculture, which often ensues after logging roads have been built for the selective extraction of timber. The over harvesting of wildlife for food and income, however, is considered an even more immediate threat to biodiversity than current rates of habitat conversion (Wilkie & Carpenter 1999). The unsustainable harvesting of wildlife in the region therefore poses a major issue to both biodiversity conservation and rural people's food security. Wildlife provides up to 90% of rural forest people's animal protein intake (Fa et al. 2003), and currently >120 mammals in the region are considered threatened with extinction (IUCN Red List 2006).

Although forest conversion to agriculture is often cited as a major threat to tropical biodiversity, some farming systems may incorporate habitat elements that may make them more suitable to integrated conservation strategies. Forest conversion in Cameroon attributed to smallholder agriculture forms a diversified mosaic of agricultural systems which include food crops, cocoa agroforests, and fallow fields (IITA 2000). The potential contribution of mixed agricultural systems to mammalian conservation has largely been overlooked. (Robinson & Bennett 2004) demonstrate that grasslands with rainfall above 500mm can typically support mammalian biomasses of 15,000-20,000 kg/km^2, whereas mammalian biomass in tropical forests can rarely exceed 3,000 kg/km^2. Ungulates make up the bulk of the savanna mammalian biomass, and in the forest ecosystem browse is largely high in the canopy and unavailable to ground-dwelling animals. Mixed agricultural landscapes may contribute to higher rates of mammalian production in otherwise low biomass tropical ecosystems by providing more available browse for ground-dwelling species. To date little work has been done to assess the potential contribution of the mixed agricultural mosaic to mammal conservation and food security in the forest frontier of the Congo Basin (vis-à-vis bushmeat availability).

This project seeks to elucidate the potential contribution of the agricultural mosaic to the conservation of wildlife. We combine biodiversity assessments using transect methods, socio-economic interviews with local residents, and hunter-follows to assess levels of biodiversity and hunting pressure in the mixed agricultural mosaic of the forest margin of Cameroon, Central Africa. We investigate the role of human population pressure on biodiversity and hunting pressure by sampling four villages in a gradient of human population density. Understanding the potential costs and contribution to wildlife at the forest/agricultural interface will be critical to informing both conservation and food security policies.

METHODS

Study Site

This research was conducted in the forest frontier zone of southern Cameroon, in the International Institute of Tropical Agriculture's (IITA) Forest Margins Benchmark Area

(FMBA), established in the early 1990's as part of the global research initiative known as the Alternatives to Slash-and-Burn program (ASB). The benchmark area encompasses 1.4 million hectares, and was chosen for its representative gradient of population pressure (est. 4-100 people/km^2 (IITA 2000)) and resource use intensity. This region also contains representatives of the region's forest margin land use types, including logging concessions, small-holder slash-and-burn agriculture, fallow land, cocoa agroforests, and protected areas.

The Forest Margins Benchmark area is typically divided into three blocks which represent high, moderate, and low human population pressure. Three villages, one in each block, were chosen for this pilot study, with a fourth village included to represent an even more remote site. The northernmost village is Nkometou II in the Yaoundé block, which lies on the national road and is characterized by the high rural population density (72 persons/km^2), good market access, and the most deforestation. The middle block, Mbalmayo block, was represented by the village Awae, which is characterized by moderate population pressure (37 persons/ km^2), relatively poor market access, and moderate deforestation rates. The southernmost village site is Mengomo, which lies on a major national road but has very low population pressure (~4 persons/ km^2), moderate market access, and relatively low deforestation rates. Finally, the village of Akam was chosen which lies on the western border of the Mengamé wildlife reserve, and has both very low human population pressure and poor market access due to its remote access and poorly maintained roads.

Wildlife Census

We estimated wild mammal (>1kg) diversity and relative abundance using traditional line-transect methodology (Muchaal & Ngandjui 1999; Plumptre 2000; White 1994). We established two 5km transects radiating out from each village site (one 5km transect in Akam due to time constraints). Each transect was then walked one time with the help of at least two experienced hunters, and we noted all live animal sightings, dung, footprints, game trails, and nest sites, with perpendicular distance measured for live sightings, dung and nests.

Hunter Follows

In each village site, hunters who hunted on a regular basis (Nkometou, n=2; Awae II, n=5, Mengomo, n=5, Akam, n=1) were identified and accompanied on their next regularly scheduled hunting trip. On each hunter-follow the distance traveled, total time spent hunting per trip, numbers of traps, and any wild meat caught were recorded. These data allow for a common measure of hunting pressure on biological resources known as catch per unit effort (CPUE).

Interviews with Heads of Households

At each of the four village sites we conducted interviews with approximately 10-15 local heads of households per village. Interviews consisted of basic household information, sources of annual revenues, sources of protein, the importance of bushmeat in protein consumption and the economic importance of bushmeat in annual household revenues.

RESULTS

Transects

Increasing remoteness (i.e. increased distance from Yaoundé and more forest area still intact primary forest) predicts higher levels of mammalian diversity. In Nkometou and Awae, the two villages closest to Yaoundé, signs of nine different mammalian species were identified, while in Mengomo, further from Yaoundé and with more forest cover, 16 species were identified. Finally, the most remote village site, Akam, had 20 mammalian species encountered, even though at this site only one 5 km transect was undertaken whereas at the other sites 10 km of transects were conducted (Tables 1 & 2).

Nkometou and Awae had the same common species; these included the giant pouched rat (*Cricetomys emini*), cane rat (*Thryonomys swinderianus*), brush-tailed porcupine (*Atherurus africanus*), tree pangolin (*Phataginus tricuspis*), African civet (*Civettictis civetta*), and blue duiker (*Cephalophus monticola*). Several species of red duiker were evident, but because their footprints are difficult to tell apart we lumped these into a red duiker group category (*Cephalophus spp*). Additional species found in Mengomo included several species of monkey (*Cercopithecus nictitans, Cercopithecus cephus, Miopithecus ogouensis*), the larger Yellow-backed duiker (*Cephalophus silvicultor*), and the African palm civet (*Nandinia binotata*). Finally, in the most remote site, Akam, additional species encountered included the larger primates: mandrills, gorillas and chimpanzees (*Mandrillus sphinx, Gorilla gorilla gorilla, Pan troglodytes*), red river hog, (*Potamochoerus porcus*), and Elephant (*Loxodonta africana cyclotis*) (for full list see Table 2).

Table 1. Village sites and transect summaries.

	Population density (by subdivision, people km^2) *	**Village size**	**Area in primary forest***	**# km**	**# Spp encountered**
Nkometou	72	1600	3.71%	10	9
Awae	37	300	5.30%	10	9
Mengomo	4	700	22.00%	10	16
Akam	<4	100	58.90%	5	20

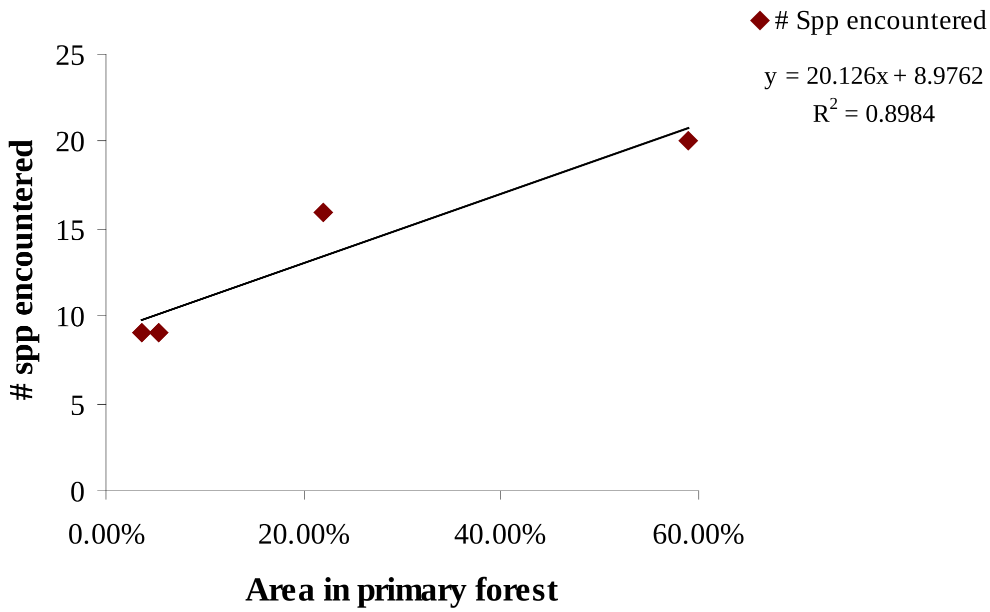

Figure 1. Number of species encountered on transects as a function of percent forest cover in village site block (note: figure based on preliminary results).

Table 2. Species encountered on biodiversity transects in four village sites.

Common Name	Scientific Name	Nkometou	Awae	Mengomo	Akam
Giant pouched rat	Cricetomys emini	*	*	*	*
Cane rat	Thryonomys swinderianus	*	*	*	*
Brush-tailed porcupine	Atherurus africanus	*	*	*	*
Tree pangolin	Phataginus tricuspis	*	*		*
Giant pangolin	Manis gigantea			*	*
Marsh mongoose	Atilax paludinosus	*	*	*	*
African civet	Civettictis civetta	*	*	*	
Blue Duiker	Cephalophus monticola	*	*	*	*
Red Duiker (spp?)	Cephalophus spp	*	*	*	*
Sitatunga	Tragelaphus spekei	*	*	*	*
Yellow-backed duiker	Cephalophus silvicultor			*	*
African palm civet	Nandinia binotata			*	
Putty-nosed monkey	Cercopithecus nictitans			*	*
Moustached monkey	Cercopithecus cephus			*	
Northern talapoin	Miopithecus ogouensis			*	
Gorilla	Gorilla gorilla gorilla			*	*
Chimpanzee	Pan troglodytes				*
Red river hog	Potamochoerus porcus			*	*
Elephant	Loxodonta africana cyclotis				*
Potto	Perodicticus potto				*
Mandrill	Mandrillus sphinx				*
Tree hyrax	Dendrohyrax arboreus				*
Nile monitor	Varanus niloticus				*
Ogilby's duiker/red duiker spp?	Cephalophus ogilbyi ??				*
Squirrel					

Land use

Transects were 5km long straight routes that directed in the landscape at fixed compass bearings. Therefore, an uneven proportion of land uses were sampled. Land use categories included field, fallow, cocoa agroforests, swamp, riparian area, secondary forest, primary forest, and urban area (villages). In order to account for disproportionate representation of different land uses sampled, we compared the proportion of animal signs relative to the proportion of land class represented. In general, wildlife use did not differ significantly between land uses, although secondary forest made a disproportionate contribution to use of land by wildlife (Figure 2).

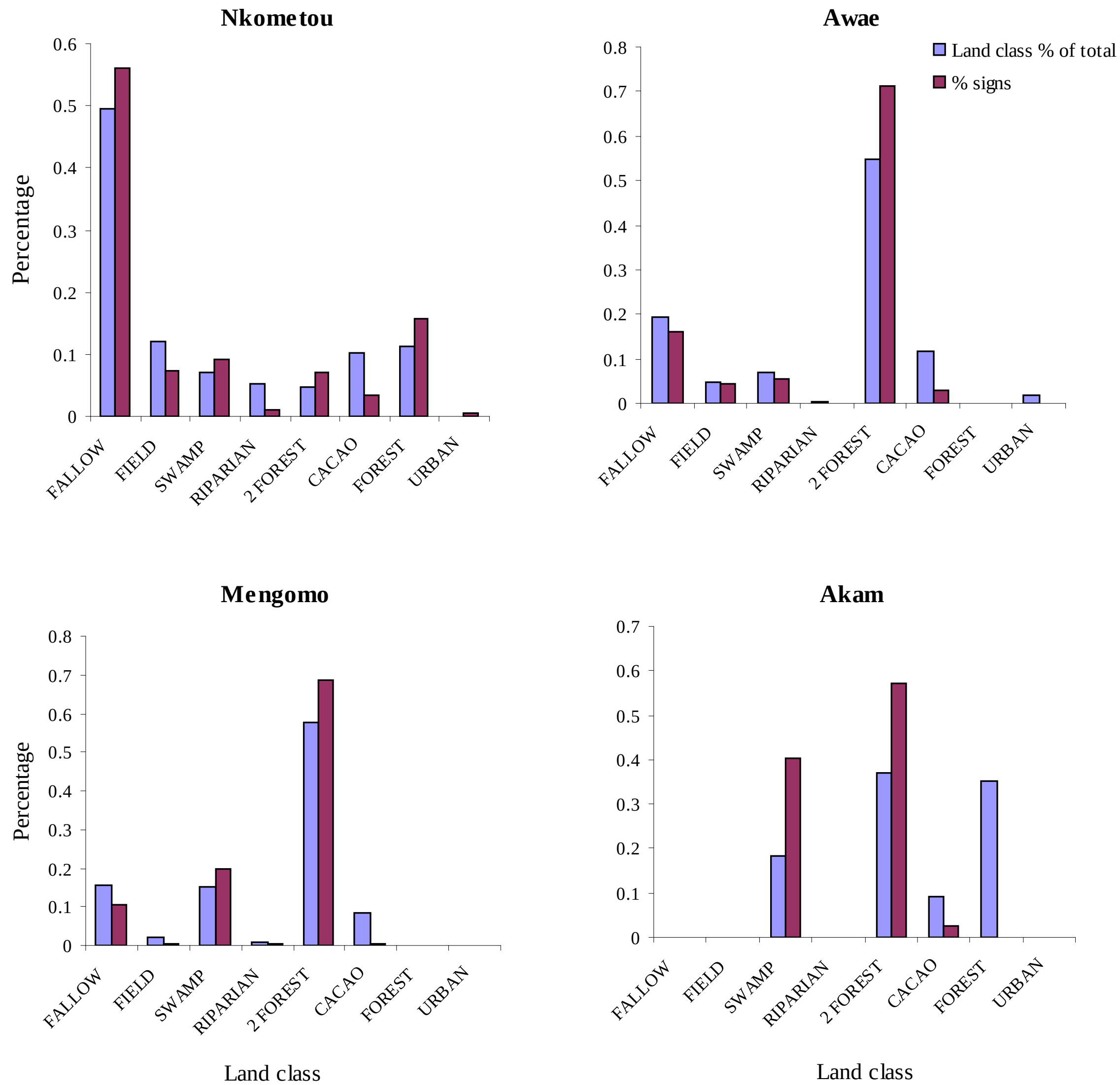

Figure 2. Proportion of animal signs detected per land use.

Socioeconomic Interviews

A total of 42 interviews with heads of households were conducted, but due to various time constraints they were distributed unevenly among the village sites (Nkometou (8), Awae (16), Mengomo (15), Akam (3)). Average age of the head of household interviewed was 48.07 years. Household size tended to be larger nearer Yaoundé, perhaps because it was easier for extended family to move back and forth between the capital and nearby agricultural land (pers. obs.). Farm size tended to increase with increasing rurality. Cocoa and manioc were the most important sources of income at all sites, with tomatoes, plantains, and government posts also important income sources. There was an increasing tendency for hunting to be an important part of a household's annual revenue in more remote locations, but total household income was fairly variable between sites (Table 3).

Table 3. Household demographics for four village sites.

	Nkometou (n=8)	**Awae** (n=16)	**Mengomo** (n=15)	**Akam** (n=3)*
Head of household ave. age (mean ± SE)	46.38 ± 4.34	49.38 ± 3.6	45.53 ± 3.2	51.0 ± 10.54
Household size (mean ± SE)	13.5 ± 2.31	10.5 ± 1.16	8.2 ± 0.81	9.67 ± 4.26
Farm size (mean ha ± SE)	10.15 ± 3.34	12.47 ± 3.17	16.87 ± 3.48	18.83 ± 15.66
Total annual revenue (CFA)	1,467,938 ± 509,247	651,777 ± 99,058	833,556 ± 87,193	592,341 ± 248,898
Most important sources of revenue (proportion of total revenue)	cacao (0.22)	manioc (0.29)	cacao (0.28)	cacao (0.65)
	manioc (0.21)	cacao (0.25)	plantain (0.21)	business/other (0.22)
	tomato (0.19)	government post (0.20)	manioc (0.13)	plantain (0.10)
	mais (0.12)	casual labor (0.07)	**hunting (0.11)**	local wine production (0.03)
	plantain (0.09)	plantain (0.06)	casual labor (0.10)	
	business/other (0.08)	macabo (0.03)	business (0.05)	
	macabo (0.03)	local wine production (0.03)	local wine production (0.05)	
	hunting (0.02)	**hunting (0.03)**	groundnut (0.02)	
	groundnuts (0.02)	mais (0.02)	sugar cane (0.02)	
	potato (0.02)	fishing (0.01)	fishing (0.01)	

* Sample size in Akam is too small for statistical comparison. Also, at the time of survey there were two Ministry of the Environment forest guards stationed in the village which may have limited hunting activity and people's willingness to discuss it.

Part of the purpose of the questionnaire was to assess the relative importance of domestic animals, fish, and bushmeat sources in household's subsistence needs as well income. Domestic animal holdings were relatively insignificant across all village sites. Respondents frequently attributed this to poor veterinary services and frequent diseases sweeping through the village, and also often cited theft of domestic animals as not an uncommon occurrence. Fish was by far the most important source of animal protein, consumed on average 156-253 days a year (Figure 3). Bushmeat was also consumed in each village site, but on 51-143 days a year (Figure 3). There appears to be more reliance on bushmeat in more remote sites, but Nkometou, the village closest to Yaoundé, had an exceptionally high bushmeat consumption rate (albeit with large variance). This anomaly had largely to do with a few individuals hunting heavily with dogs, and catching mainly giant pouched rats.

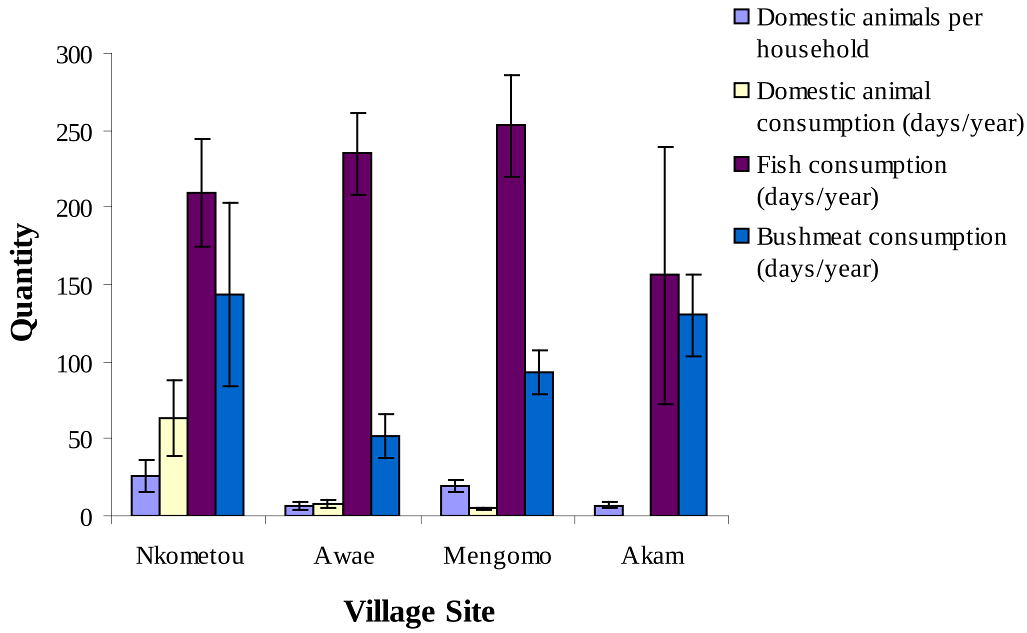

Figure 3. Comparison across village sites of domestic animal holdings per household, and domestic animal, fish and bushmeat consumption in number of days per year. Error bars are plus/minus standard error.

Hunter Follows

In each village site we identified hunters that hunted on a regular basis (Nkometou, n=2; Awae II, n=5; Mengomo, n=5; Akam, n=1), and agreed for us to accompany them on their next hunting trip. (Small sample sizes were due to time constraints, not to small numbers of hunters.) On each hunter-follow the following data were recorded: distance, total time spent hunting per trip, numbers of traps, and any wild meat caught. Hunting trip duration and distance traveled are highly correlated, indicating that they are both reasonable proxies for hunting effort (Figure 4).

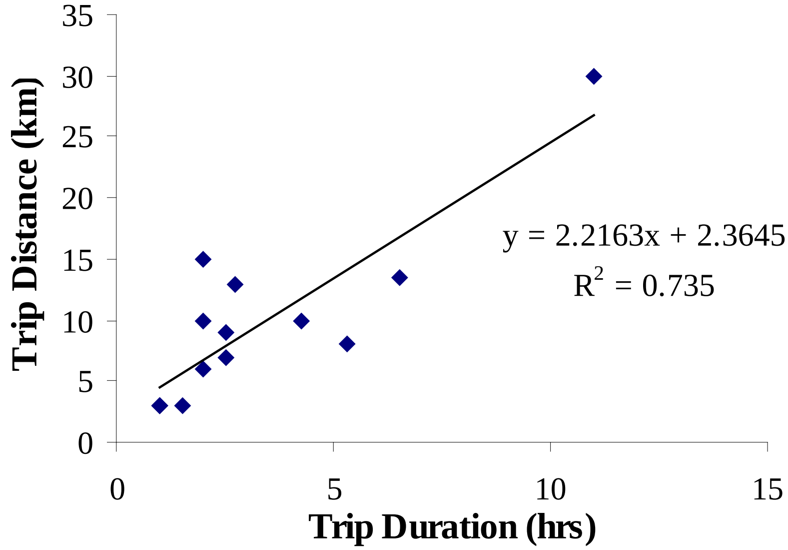

Figure 4. Correlation between trip distance (km) and trip duration (hrs) as proxies for hunting effort.

Table 4. Results of hunter-follows across village sites, including trip duration (hrs), trip distance (km), total number of traps set per hunter, and average # of animals caught in traps per hunter. Values include standard error.

	Nkometou (n=2)	**Awae** (n=6)	**Mengomo** (n=4)	**Akam** (n=1)
Trip Duration (hrs)	2.25 ± 0.25	1.58 ± 0.30	4.44 ± 2.19	6.5
Trip Distance (km)	5 ± 0	4.67 ± 1.09	17.0 ± 4.45	13.5
Total number of traps	59 ± 27	116.67 ± 40.92	166.5 ± 27.74	46
Average # game caught per visit	0.5 ± 0.5	0.5 ± 0.5	0.25 ± 0.25	3

Effort in hunting (i.e. trip duration, distance, and numbers of traps laid) generally tended to increase with increasing remoteness of the site, although the farthest site, Akam, is represented by only one data point and therefore should not be included in the comparison (Figure 5). Catch was very low across all sites (except Akam) so that a much bigger sample size is needed before conclusions can be drawn about tendencies (Figure 6). However, it appears that more effort is put into hunting in more remote sites, but assessing a tendency in catch per unit effort (CPUE) will require more data.

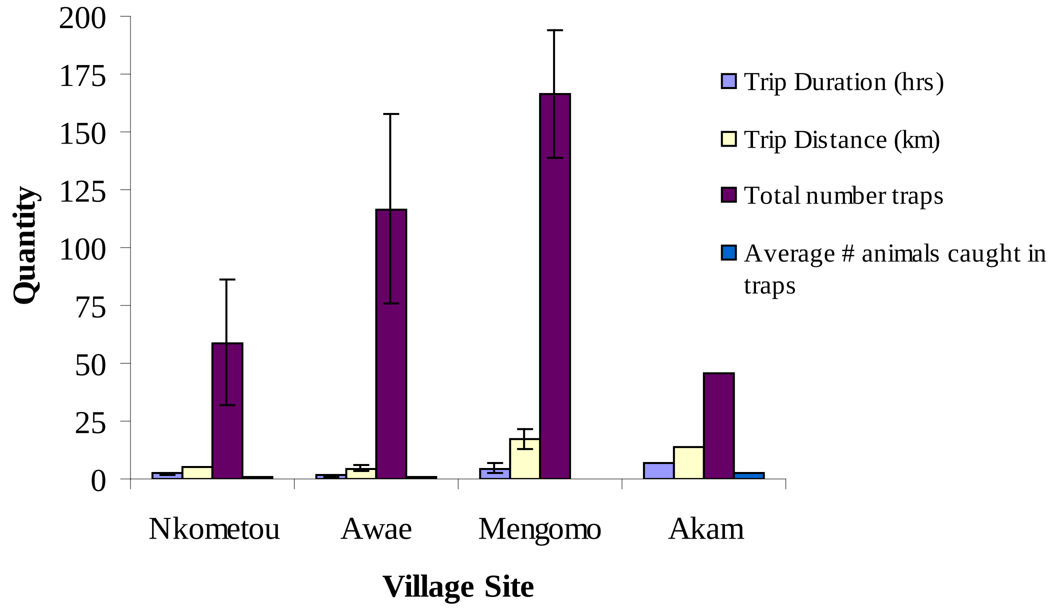

Figure 5. Results of hunter-follows across village sites, including trip duration (hrs), trip distance (km), total number of traps set per hunter, and average # of animals caught in traps per hunter. Error bars represent standard error.

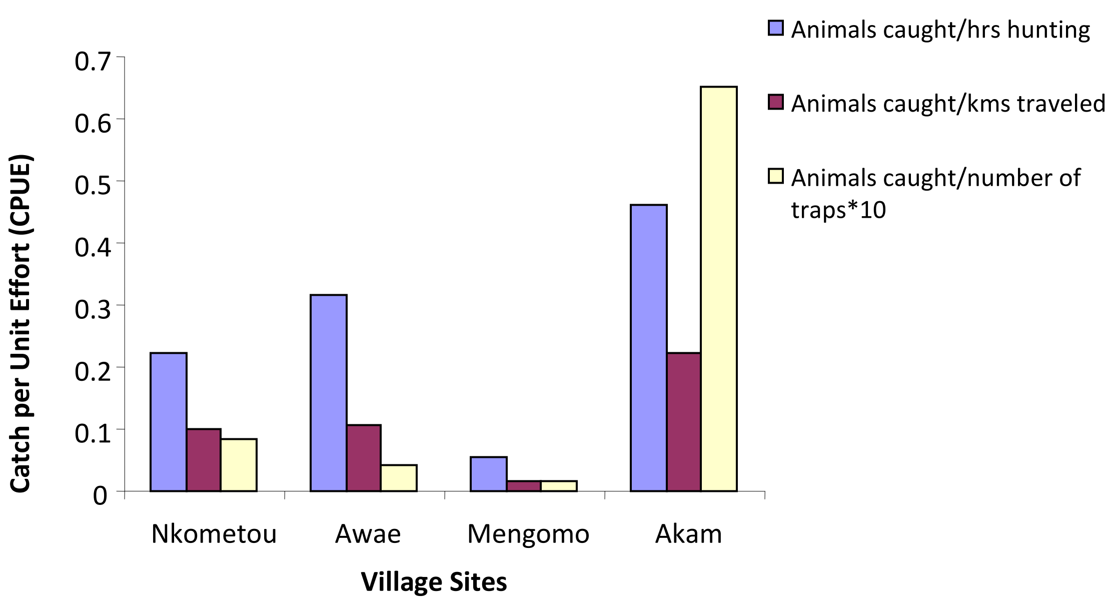

Figure 6. Catch per unit effort (CPUE) compared as catch per hunting trip duration, catch per hunting trip distance, and catch per number of traps per hunter (multiplied by 10 to allow visual comparison on same scale).

DISCUSSION

This pilot study investigated the relationship between human population pressure, land use change and change in wildlife hunting patterns. This study also began to predict which species are most at risk with human expansion and how people in the Forest Margin Benchmark of southern Cameroon respond to declines in bushmeat availability. It was also intended to identify which types of land use associated with the mixed agricultural mosaic common to southern Cameroon may be of conservation benefit.

In the study area, the general pattern of biodiversity response to human population pressure is for increasing mammalian diversity with increasing remoteness (in terms of distance from Yaoundé and primary forest cover left). Therefore, even though all transects were carried out within 5.5 km of each village, the number of species encountered doubled from 9 to 20 between the village site very close to Yaoundé and the farthest site near the border with Gabon. In addition to declines in numbers of species, the species composition changed as well. Greater human population pressure is associated with a loss of the larger-bodied fauna, such as forest elephants, many of the primate species, including gorillas, chimpanzees and mandrills, and the largest of the forest duikers, the yellow-backed duiker. Rodents, small carnivores and many of the forest duiker species, however, seem to persist in areas with heavier human population pressure.

Interviews with heads of households revealed interesting trends in the changing importance of domestic animals, fish, and bushmeat in local protein consumption as well as annual revenue streams. Although results are preliminary, there appears to be an inverse relationship between domestic animal consumption and bushmeat consumption, so that as human population pressure causes bushmeat to become less available, people substitute bushmeat with domestic animal meat either raised at home or purchased. Fish was found to be the most important animal protein source in all sites, contrary to popular belief that bushmeat is the most important source. However, many people in these village sites reported declines in both bushmeat and fish resources, posing a major food security concern and necessitating further investigation.

Cocoa and manioc were the most important sources of income at all sites, with tomatoes, plantains, and government posts (salaried employment) also important income sources. Although total household income was fairly variable between sites, cocoa and hunting are an increasingly important part of a household's annual revenue (in percent contribution of total) in more remote locations. This may be due to the "cash crop" nature of both cocoa and wildlife, for both of which there is an important market and demand. Implicit in this finding is that if cocoa income were to decline due to decreased prices or demand, income would need to be substituted from other sources, with the probable effect of increasing hunting pressure on wildlife.

Hunter follows are one method with which to quantify hunting returns to effort expended. These hunting returns for effort indices, also known as catch per unit effort, are relatively well established for quantifying fishery stocks and harvest, but have been used relatively little to date on terrestrial mammal-harvesting scenarios, particularly in the developing world context (Lancia et al. 1996; Schmidt et al. 2005). This pilot study was an attempt to gauge the feasibility of using the number of animals caught in traps per hunter effort (comparing distance traveled, duration of hunting trip, and numbers of traps as proxies for effort). We anticipated that more rural areas would have higher remaining densities of wildlife and therefore have higher returns to effort. There seems to be an increasing trend in CPUE with more remote sites (Fig. 6), but the dataset is too small at present to draw strong conclusions from and Mengomo posed an anomaly to the expected pattern because although the most effort was expended, the least amount of wildlife was caught. Mengomo was the only village site on a paved highway, which may mean that it has higher than expected hunting pressure perhaps because people from outside the region can access it relatively easily. Also, the road itself might deter wildlife or make them flee farther into the bush. Anecdotally though, one hunter that was followed in the most remote site (Akam) had more and larger game than any of the other hunter-follows conducted in any of the sites.

In general, wildlife use did not differ significantly between land uses, although secondary forest made a disproportionate contribution to use of land by wildlife. Interviewees in the two most remote sites also reported crop raiding by chimpanzees and gorillas (cocoa), and raiding by a small primate (*Miopithecus ogouensis*) of corn fields, implying that these species are benefiting at least to some extent by provisioning in people's fields.

CONCLUSIONS

This pilot study was conducted as a preliminary assessment of various methodologies to look at wildlife abundance and diversity in the mixed agricultural mosaic of southern Cameroon, the importance of wildlife in farmer's annual income and protein intake, and the effects of human population growth rate and land use change on wildlife resources. It is hoped that further study will reveal what supplementary forms and amounts of animal protein would be necessary under different levels of human population pressure to promote a more sustainable harvest of Cameroon's wildlife resources.

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CHAPTER 3

CHAPTER 3

Wildlife and human food security in Cameroon, Central Africa

ABSTRACT

Although humans have hunted wildlife for millennia, and it remains an important source of animal protein, there is increasing concern that ‘bushmeat’ hunting, particularly in central Africa, is unsustainable. We explore the role that wildlife and alternative meat sources play in the food security of human populations in southeastern Cameroon. We conducted a large, cross-sectional study in 24 village and town sites in southeastern Cameroon to evaluate the role of wildlife in human food security in a gradient from urban to rural households. Rural households are significantly more likely to rely on wildlife for animal protein, whereas urban households rely on significantly more domestic meat. Using generalized linear mixed modeling, we found significant associations between bushmeat hunting and consumption and positive effects on food security, highlighting the importance of wildlife to human security in the Congo Basin. We asked interviewees about most consumed and most preferred wildlife species; interestingly, there is a potential synergy between taste preferences and the more resilient species consumed.

INTRODUCTION

Humans have hunted wildlife as a main source of animal protein since pre-historic times. In many parts of sub-Saharan Africa, wildlife continues to provide a significant source of people's animal protein, as well as crucial calories and micronutrients. In many cases, wildlife also makes an important contributions to rural people's livelihoods when sold for petty cash (Brashares et al. 2011; Ntiamoa-Baidu 1998).

Animals in central Africa have evolved under the pressure of animal trypanosomiasis, therefore they are resistant to the devastating effects of animal trypanosomiasis on domesticated livestock. Wildlife is considered to be at least as nutritious, if not more nutritious, than the meat from domesticated livestock. The meat of most wild animal species tends to be low in fat, while equal or better than most livestock in protein content, and much higher in vitamin content (Ntiamoa-Baidu 1998).

In addition to providing people with calories, protein, fat, iron, and other micronutrients, wildlife can also act as a savings and insurance policy, or safety net, serving in the place of a bank for rural forest dwellers. Wildlife has a high "value-to-weight" ratio, meaning that it can fetch a relatively high price for its size, and can thus be transported to market relatively easily.

Although people have relied on wildlife as an important source of animal protein for millennia, human population growth has been exponential, such that it is continuing to place an increasing burden on natural resources, including wildlife. Additionally, logging has increased roads in the tropics, and particularly the Congo Basin, which increases the area that is accessible to hunters and leaves smaller and smaller areas where species are still relatively protected from hunting. Finally, the hunting technology currently in use (e.g. firearms and wire cables for snares) is much more efficient than hunting techniques used historically, which also increases the pressure on wildlife (Wilkie & Carpenter 1999).

Malnutrition in central Africa

Malnutrition in the context of developing countries is used to describe a situation of undernutrition, referring to the inadequate intake of protein, energy and micronutrients (Schroeder 2008). Malnutrition is one of the leading risk factors for disability-adjusted life years (DALY's) in low-income countries (WHO 2004), which is particularly true in sub-Saharan Africa. The World Health Organization's (WHO) Global Burden of Disease database categorizes malnutrition by four categories of nutritional deficiencies: protein-energy malnutrition, iodine deficiency, vitamin A deficiency, and iron-deficiency anemia. Protein-energy malnutrition and iron-deficiency anemia are by far the biggest causes of nutritional DALY's, and both can be caused by a deficiency in animal protein. Protein-energy malnutrition is the underconsumption of calories or protein, and can only be solved by increasing the amount of food intake. Protein-energy malnutrition can lead to kwashiorkor, which is a disease of insufficient protein (presenting as swollen belly, stunted growth, reduced immunity), and marasmus, a disease of insufficient energy, which leads to emaciation. Iron deficiency anemia is one of the most common nutrition disorders worldwide (Ramakrishnan & Semba 2008); more than 40% of people in developing countries are estimated to be suffering from iron deficiency (Leathers &

Foster 2004), and more than half of women and children in sub-Saharan Africa are anemic (Ramakrishnan & Semba 2008).

There is also a synergism between malnutrition and coinfections. Infections tend to increase the severity of malnutrition (Leathers & Foster 2004). People in tropical Africa are also more likely to suffer from comorbidity with a number of infectious diseases, including malaria, diarrhea, and intestinal parasites. Intestinal parasitic infections can exacerbate malnutrition through a number of mechanisms, including anorexia (causing decreased food intake), intestinal inflammation that inhibits nutrient uptake, and diversion of nutrients to the parasites themselves (Leathers & Foster 2004; Stephenson et al. 2000).

Here, we conducted a large, cross-sectional study in 24 village and town sites in southeastern Cameroon to evaluate the role of wildlife in human food security in a gradient from urban to rural households. This is the first study to attempt to evaluate the role of wildlife and other alternative meat sources in human food security using the popular 18-Item household food security scale (Bickel et al. 2000). Other studies have evaluated determinants of consumer demand for bushmeat in Gabon (Wilkie et al. 2005), distribution and use of income from bushmeat in a particular village (Coad et al. 2010), bushmeat consumption in logging concessions in northern Congo (Poulsen et al. 2009), and assessments of wildlife harvest sustainability (Kumpel et al. 2010).

The Case of Southeastern Cameroon

The Republic of Cameroon (hereon Cameroon) is situated in west-central Africa. It is often referred to as “Africa in miniature” because of its geographic diversity, ranging from humid lowland tropical forests in the south, to savannas in the center, to dry Sahelian terrain in the north. It is also known for its cultural diversity, which includes approximately 240 language and ethnic groups. Cameroon’s population numbers at around 19.5 million people. In the latest Global Burden of Disease database available (2008), Cameroon had 5,400 deaths due to nutritional deficiencies, made up largely by protein-energy malnutrition and iron-deficiency anemia (Global Burden of Disease, 2008). In terms of disability-adjusted life years (DALY’s), an estimated 193,000 DALY’s in Cameroon are attributable to nutritional deficiencies (Global Burden of Disease, 2004).

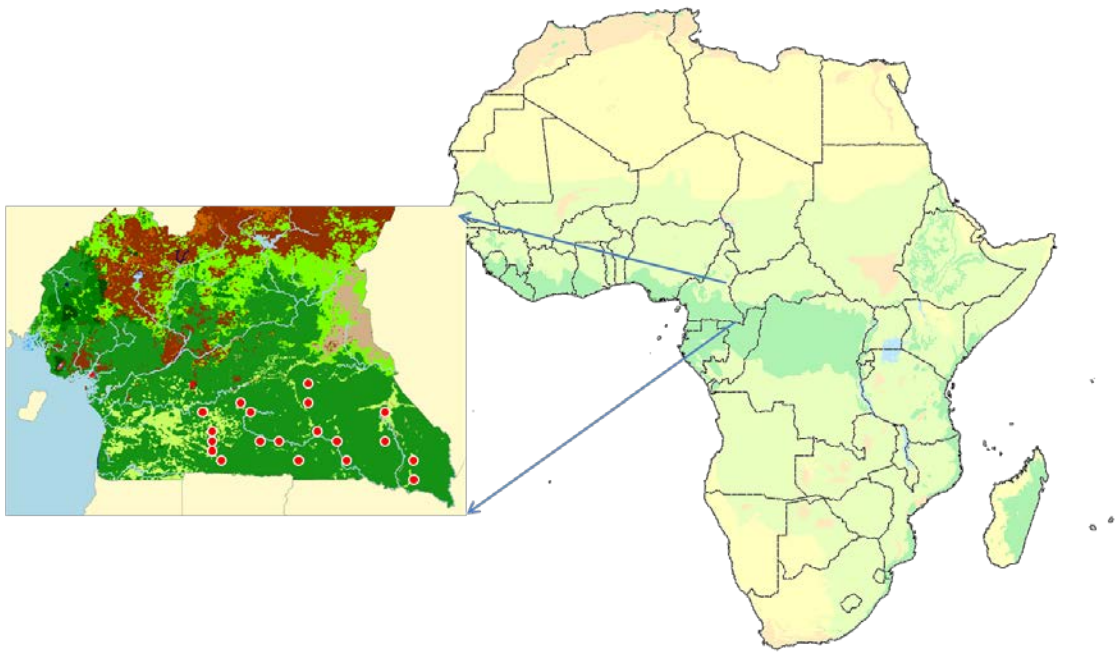

Figure 1. Study sites in southern Cameroon humid tropical forest zone.

METHODS

We conducted a cross-sectional survey of households in southeastern Cameroon using cluster sampling by village (Figure 1). The household survey instrument was designed and piloted by K.Z.W. in 2006, and surveys were conducted by eight Cameroonian postgraduate students in the Center and East Regions of Cameroon in October and November of 2007. Twenty four towns and villages in total were sampled. Towns were chosen at the head of the four major road axes in the region, and villages were chosen randomly for cluster sampling of households using semi-structured survey methods. Survey enumerators first conducted focus group meetings with village chiefs and other villagers to discuss village level information and gain permission for conducting surveys. Household surveys were conducted through systematic random sampling. Approximate village population sizes were ascertained during focus group meetings and used to determine the spacing of household sampling, which led to 16 household surveys per village and 50 household surveys per town.

At the village level, we inquired about village size, predominant ethnic groups, and presence of electricity, phone networks, schools and hospitals. We took Global Positioning System (GPS) coordinates of all village locations, and road distances to urban centers and nearest paved roads were calculated using ArcGIS 9.1. At the household level, we estimated household wealth was using a “basket of goods” technique to estimate household assets (Foerster et al. 2012). Annual wildlife consumption was measured through annual recalls of hunting and/or purchase by weekly, monthly, or seasonal frequency. Biomass was obtained by multiplying estimated annual consumption by the average adult body mass of each species or species group using weights from the PanTHERIA database (Jones et al. 2009). Access to wildlife was reported by respondents as the maximum distance traveled from village to hunting activities.

Measurement of food security

According to the WHO, food security is the condition "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life". Food security is built on "three pillars" (WHO)(Sarlio-Lahteenkorva & Lahelma 2001):

1) Food availability: sufficient quantities of food available on a consistent basis.
2) Food access: having sufficient resources to obtain appropriate foods for a nutritious diet.
3) Food use: appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation.

We used an 18-Item household food security scale used by USAID, World Food Program, and the Food and Agricultural Organization of the United Nations (FAO) to develop an indicator of food insecurity at the household level (Bickel et al. 2000; Frongillo 1999; Perez-Escamilla et al. 2004). This indicator takes into account anxiety or perception that the household food budget or food supply was inadequate; perceptions that the food eaten by adults or children was inadequate in quality; and reported instances of reduced food intake, or consequences of reduced intake, for household members. There are several subcategories within these general categories that represent degrees of severity for each of these.

Statistical analysis

We compiled descriptive demographic statistics for the populations surveyed by the household surveys, and compared urban and rural populations in demographic parameters, wild resource utilization, and food insecurity. A generalized linear mixed model was used to test associations between wildlife consumption, fish consumption, livestock meat consumption, hunting activities, food security, and other factors. Outcome variables included total wildlife consumption, per capita wildlife consumption, wildlife hunted, and food insecurity. Explanatory variables included a measure of wealth based on a "basket of goods" (Foerster et al. 2012; Wilkie et al. 2005), household size, distance to paved road, urban town/rural village dichotomous variable, whether the household had a member who hunted, whether the household had a member who fished, the total quantity of wildlife/fish consumed as well as per capita consumption, and any small livestock holdings (# of animals). All analyses were done in R version 2.12, (R Development Core Team 2010), and included the lme4 package for the GLMM analysis (Bates & Maechler 2010).

RESULTS

The four teams of two interviewers surveyed a total of 24 towns and villages, and conducted 527 household interviews. 201 urban households, and 326 rural households were surveyed. Average distance of village sampled to the nearest paved road was 195 ± 155 (*SD*). Although interviewers were generally with heads of household, a total of 3,956 people were included in the 527 interviewed households, for an average household size of 7.5 ± 3.4 (*SD*) members. The 18-item food insecurity scale ranges from 0-27, with 0 being completely food secure and 27 being extremely food insecure. Among households interviewed, food insecurity was at an average of 8.5 ± 6.7 (*SD*).

There were significant differences between urban and rural meat acquisition and consumption patterns. 202 of 527 households (38%) participated in fishing activities, with 439 of 527 households (83%) reporting fish consumption (this includes both personally acquired through fishing activities and purchased fish). 220 of 527 households (42%) reported hunting wildlife, with 376 of 527 households (71%) reporting wildlife consumption (this includes personally acquired through hunting and purchased wild meat). Households kept an average of 7 ± 26 (*SD*) domesticated animals/household. There was a significant difference in urban vs. rural wildlife hunting behavior: only 9% urban households hunt wildlife, while 62% of rural households hunt wildlife (χ^2=143.66, p<0.0001).

The frequency of wildlife, fish and livestock meat differed significantly between urban and rural villages. Bushmeat in rural areas was consumed over 2.5x the amount consumed in urban villages (Table 1 &Figure 2; χ^2= 35.05, p<0.0001). Fish and livestock meat were both consumed significantly more in urban areas (χ^2= 35.05, p<0.0001, χ^2= 65.60, p<0.0001, respectively). The same relationships hold true for percentage of households reporting that they ate bushmeat, fish or livestock meat in the last 7 days (Table 1).

Table 1. Summary statistics of interviewed households, including hunting, fishing, and domestic meat utilization. A total of 527 households were interviewed in 24 rural villages and towns. All figures reported from total households, unless otherwise noted due to incomplete survey data. All summary statistics were based on full dataset (527 households) unless otherwise noted.

	All	**Rural (Villages)**	**Urban (Towns)**
Villages/Towns	24	20	4
Households	527	326	201
Total # of people	3956	2419	1537
Average household size	7.51 ± 3.38	7.42 ± 3.43	7.65 ± 3.30
Food security scale	8.46 ± 6.58	8.61 ± 6.30	8.23 ± 7.01
Wealth ('basket of goods' index, *FCFA*)	396,785 ± 588,140	325,658 ± 485,883	512,146 ± 710,271
No. households hunt (%)	220 (41.7%)	202 (62.0%)	18 (9.0%)
No. households fish (%)	202 (38.3%)	175 (53.7%)	27 (13.4%)
No. households with livestock (≥1 animal) (%)	280 (53.1%)	213 (65.3%)	67 (33.3%)
Distance hunters travel to hunt	8.63 ± 9.05	8.88 ± 9.04	6.59 ± 9.05
No. of hunters who use guns	64 (29.1%)	57 (28.2%)	7 (38.9%)
No. of snares used per hunter	72.0 ± 113.8	73.9 ± 117.1	43.8 ± 31.9
No. households that own at least 1 gun (%)	47 (8.9%)	41 (12.6%)	6 (3.0%)
% Households reporting eating bushmeat in the last 7 days	315 (59.8%)	233 (71.5%)	82 (40.8%)
Frequency of eating bushmeat in the last 7 days	2.32 ± 2.22	2.97 ± 2.27	1.13 ± 1.54
% Households reporting eating fish in the last 7 days	446 (84.6%)	255 (78.2%)	191 (95.0%)
Frequency of eating fish in the last 7 days	3.52 ± 2.30	3.12 ± 2.40	4.13 ± 2.01
% Reporting eating domestic meat in the last 7 days	112 (21.25%)	31 (9.5%)	81 (40.3%)
Frequency of eating domestic meat in the last 7 days	0.66 ± 1.22	0.31 ± 0.79	1.11 ± 1.50

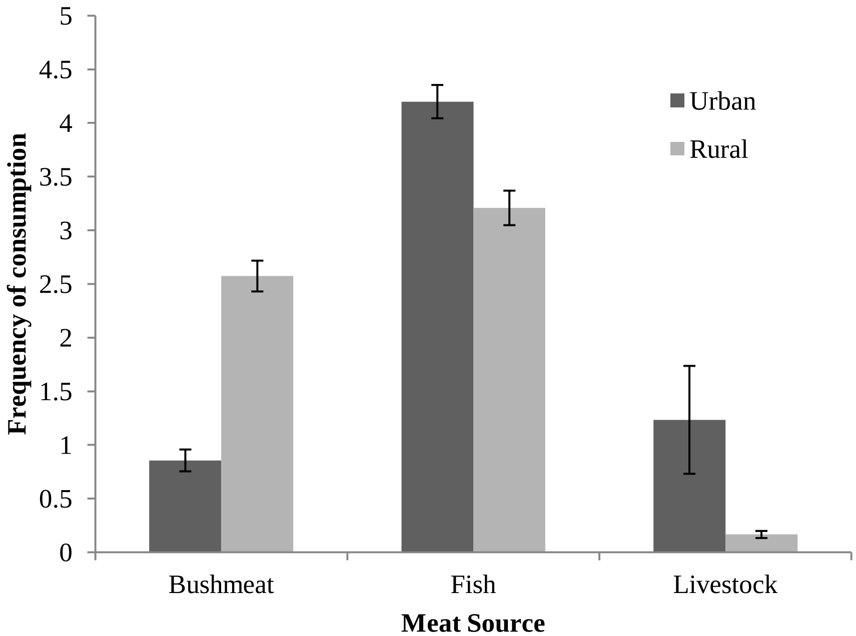

Figure 2. Mean frequency of consumption, reported as the number of times bushmeat, fish and livestock were consumed in the 7 days leading up to the survey. Consumption of bushmeat, fish and livestock were significantly different between urban and households (χ^2= 57.75, p<0.0001, χ^2= 35.05, p<0.0001, χ^2= 65.60, p<0.0001, respectively).

Four different generalized linear mixed models were tested. Two tested the outcome variables of total bushmeat consumed and per capita bushmeat consumption, both through hunting activities as well as purchased. In both cases, significant positive predictors included whether someone in the household hunted, whether someone in the household fished, total fish consumed by the household, and was negatively associated with food insecurity (Table 2). The third model tested predictors solely of the amount of bushmeat hunted (focusing on hunting activity, not purchasing power). Significant outcomes were whether someone in the household hunted, whether someone in the household fished, and overall fish consumption. There was a moderately significant negative association with food insecurity. Finally, we tested correlates of food insecurity: wealth, bushmeat consumption, and domestic meat consumption were significant negative predictors of food insecurity status, whereas household size and fishing activity were positive predictors of food insecurity (Table 2).

Table 2. Results of four generalized linear mixed models, modeling the response variables total bushmeat consumed, per capita bushmeat consumed, total bushmeat hunted, and household food insecurity, respectively. Coefficient estimates, standard error, and *p*-values based on the likelihood ratio test are reported (n=448).

Response Variable	Explanatory variables	Estimate	SE	*p*-value
Total bushmeat consumed	food insecurity	-0.0179	0.0063	0.0050**
	wealth	0.0166	0.0351	0.6770
	urban	0.5878	0.8026	0.4640
	hhsize	0.0235	0.0118	0.0430*
	hunt	1.2536	0.1004	0.0000***
	livestock	0.0018	0.0014	0.2100
	fish	0.2106	0.1070	0.0460*
	fish consumption	0.2896	0.0601	0.0000***
	domestic meat consumption	0.0563	0.0569	0.3030
	wealth:urban	-0.0724	0.0623	0.2460
Per capita bushmeat consumed	food insecurity	-0.0143	0.0047	0.0030**
	wealth	0.0232	0.0262	0.4000
	urban	0.2171	0.6047	0.7240
	hhsize	-0.0147	0.0094	0.1370
	hunt	1.0153	0.0746	0.0000***
	livestock	0.0006	0.0011	0.5490
	fish	0.1898	0.0815	0.0190*
	fish consumption	0.2743	0.0558	0.0000***
	domestic meat consumption	0.0662	0.0586	0.2470
	wealth:urban	-0.0377	0.0464	0.4200
Bushmeat hunted	food security	-0.0081	0.0043	0.0640·
	wealth	-0.0063	0.0244	0.7800
	urban	-0.1496	0.5600	0.7810
	hhsize	0.0053	0.0082	0.5010
	hunt	2.7495	0.0695	0.0000***
	livestock	-0.0009	0.0010	0.3670
	fish	0.2412	0.0741	0.0010***
	fish consumption	0.0957	0.0416	0.0200*
	domestic meat consumption	-0.0314	0.0394	0.4270
	wealth:urban	0.0122	0.0431	0.7690
Household food insecurity	wealth	-0.9941	0.2615	0.0000***
	urban	0.4913	6.0748	0.9440
	hhsize	0.2219	0.0894	0.0120*
	hunt	-0.3041	0.8847	0.7080
	livestock	-0.0016	0.0110	0.8800
	fish	1.8206	0.8081	0.0250*
	tot. bushmeat consumption	-1.0225	0.3585	0.0050**
	tot fish consumption	0.2266	0.4666	0.6230
	tot domestic meat consumption	-1.4729	0.4250	0.0010**
	wealth:urban	0.0360	0.4719	0.9290

Significance of coefficients is denoted as: *** $p<0.001$, ** $p<0.01$, * $p<0.05$, · $p<0.10$

DISCUSSION

This study examined urban/rural differences in wildlife, fish and domestic meat consumption in the forest zone of southeastern Cameroon, and their role in human food security. There are a number of indications of the important role wildlife plays in human food security in the region. First is the absolute number of households that report hunting (42%) and consuming wildlife (71%). This figure is even more important when comparing more rural vs. more urban households, where rural villagers are more than 2.5 times as likely to have consumed wildlife in the previous 7 days, and among those who consume wildlife, rural villager households consume it 2.5 times as often as more urban households (Table 1). Rural households are much more likely to hunt wildlife, which is logical given their lack of access to refrigeration, and lower access to markets and alternative domestic meat sources.

Total bushmeat consumption and per capita bushmeat consumption both correlate with having a hunter in the household, and with fish consumption and having someone who fishes in the household. There are clear connections as to why a hunter in the household could contribute to increased bushmeat consumption, but one explanation for the positive correlation with fishing and fish consumption may have to do with particular households having increased access to wild resources in general. Another explanation may be that households that are able to afford a lot of bushmeat consumption can also afford a lot of fish consumption, however, the wealth variable was not significant in this analysis. Modeling the explanatory variables of bushmeat hunted focuses on explaining wildlife hunting activity rather than purchased wildlife. Significant explanatory variables of bushmeat hunted again included having a hunter in the household, fishing activity and fish consumption. It was also marginally negatively correlated with food insecurity, which in other words means that bushmeat hunting is positively correlated with food security (β= -0.008, p=0.064; Table 2).

Finally, we also modeled the predictors of food insecurity in southeastern Cameroon related to meat sources. Wealth was a highly significant (negative) predictor of household food insecurity (e.g. the wealthier the household the more food secure (β= -1.043, p<0.001; Table 2)). Larger household size was associated with food insecurity (β= 0.209, p=0.019; Table 2), such that the more mouths to feed, the more difficult it is to do so. Interestingly, households that hunt correlated negatively with food insecurity, whereas households that fish are positively correlated with food insecurity. Barriers to entry into wildlife hunting may be higher than for fishing, and perhaps returns from bushmeat are also higher. Total domestic meat consumption was negatively correlated with food insecurity, and domestic meat consumption is generally associated with wealthier households.

When asked about most frequently consumed wildlife, the top most frequently cited species included rodents (rats, african brush-tailed porcupine, cane rats) and the Blue duiker *(Philantomba monticola)* (Table 3). Interestingly, when asked about most preferred species, the list was similar but included the Pangolin *(Manis tricuspis)* as a favored species, which along with rodents and blue duikers, is a species of lesser concern. Assuming responders reported honestly, this is encouraging for the future of managing wildlife harvests sustainably, given that resilient species align with the taste preferences on people in the region.

Table 3. Most frequently consumed and most preferred species, as reported by households interviewed.

Most frequently consumed	Most preferred
Rats *(esp. Cricetomys emini)*	African Brush-Tailed Porcupine *(Atherurus africanus)*
Blue duiker *(Philantomba monticola)*	Pangolin *(Manis tricuspis)*
African Brush-Tailed Porcupine *(Atherurus africanus)*	Blue duiker *(Philantomba monticola)*
Cane rat *(Thryonomys swinderianus)*	Cane rat *(Thryonomys swinderianus)*

These results indicate the wildlife consumption plays an important role in human food security in the humid forest zone of southeastern Cameroon. Disappearance of wildlife would negatively impact the food security situation in the region, particularly in the forms of protein-energy malnutrition and iron deficiency. At present, there is little ability to maintain small animal husbandry due to the poor veterinary services throughout the region. Possible policy interventions include (1) increasing veterinary services; (2) nutrient supplementation; (3) domestication of local species; and (4) a micro-loan program for small livestock distribution, modeled after Hiefer International but directed to this region in southeastern Cameroon. Increasing veterinary services, unfortunately, can only be accomplished through government initiative, and therefore it would be extremely difficult for outside intervention to tackle. Nutrient supplementation, and particularly iron, is a relatively cheap, cost-effective intervention. However, it only addresses iron deficiency, but cannot do anything for the protein-energy malnutrition likely to result. This deficiency can only be addressed with increased food intake. An alternative to these would be the scaling up and rolling out of domestication projects of local wild species, including cane rats, porcupines, and even giant African snails. These have the advantage of being already culturally acceptable as a food source (and people report these to be highly desirable meats). These species are also already adapted to local conditions and diseases, and therefore can be expected to have reduced veterinary costs associated with vaccinations. Domestication of local wild species would be a wise investment, ecologically and economically speaking, because these species are already adapted to local conditions, food options, and are effectively trypanosomiasis-resistant. There have been small pilot projects with the cane rat and porcupine (Jori et al. 2005), but these projects do not appear to have caught on, and perhaps entrepreneurial or marketing research and support would be beneficial.

CONCLUSIONS

Malnutrition is a significant problem in sub-Saharan Africa. People have traditionally relied on wildlife as a major source of protein, calories and micronutrients, and it continues to play a significant role in food security in southeastern Cameroon today. Although increasing human population pressure in the region has resulted in a situation where wildlife hunting is no longer considered sustainable, results of this study underline the importance of wildlife for human food security, and the possible synergies between people’s taste preferences and the species that are most resilient to harvest.

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CHAPTER 4

CHAPTER 4

The 'Heifer International' model as an alternative to unsustainable wildlife hunting for food

INTRODUCTION

Malnutrition is one of the leading risk factors for disability-adjusted life years (DALY's) in low-income countries (WHO 2004). This is particularly true in sub-Saharan Africa. The World Health Organization's (WHO) Global Burden of Disease database categorizes malnutrition by four categories of nutritional deficiencies: protein-energy malnutrition, iodine deficiency, vitamin A deficiency, and iron-deficiency anemia. Protein-energy malnutrition and iron-deficiency anemia are by far the biggest causes of nutritional DALY's, and both are also addressed by animal meat sources; therefore, they form the focus of the research and proposed intervention in this paper.

Humans have hunted wildlife for millennia. However, it is currently believed to be at unsustainable rates because human populations have increased exponentially, logging roads have opened up previously inaccessible forests to hunting, and hunting technology has gotten much more efficient (e.g., firearms and wire cable snares) (Wilkie & Carpenter 1999). Therefore, there is an increasing concern that forest people's food security will be more at stake as they begin to deplete the wildlife resources they have hitherto relied on for animal protein (and in some cases livelihoods) (Fa et al. 2003). In this paper, I propose an intervention modeled after Heifer International—a model that introduces domestic livestock to households as a form of "micro-loan"; these must then be repaid by passing on the loan to a neighbor with the offspring of the original animal given.

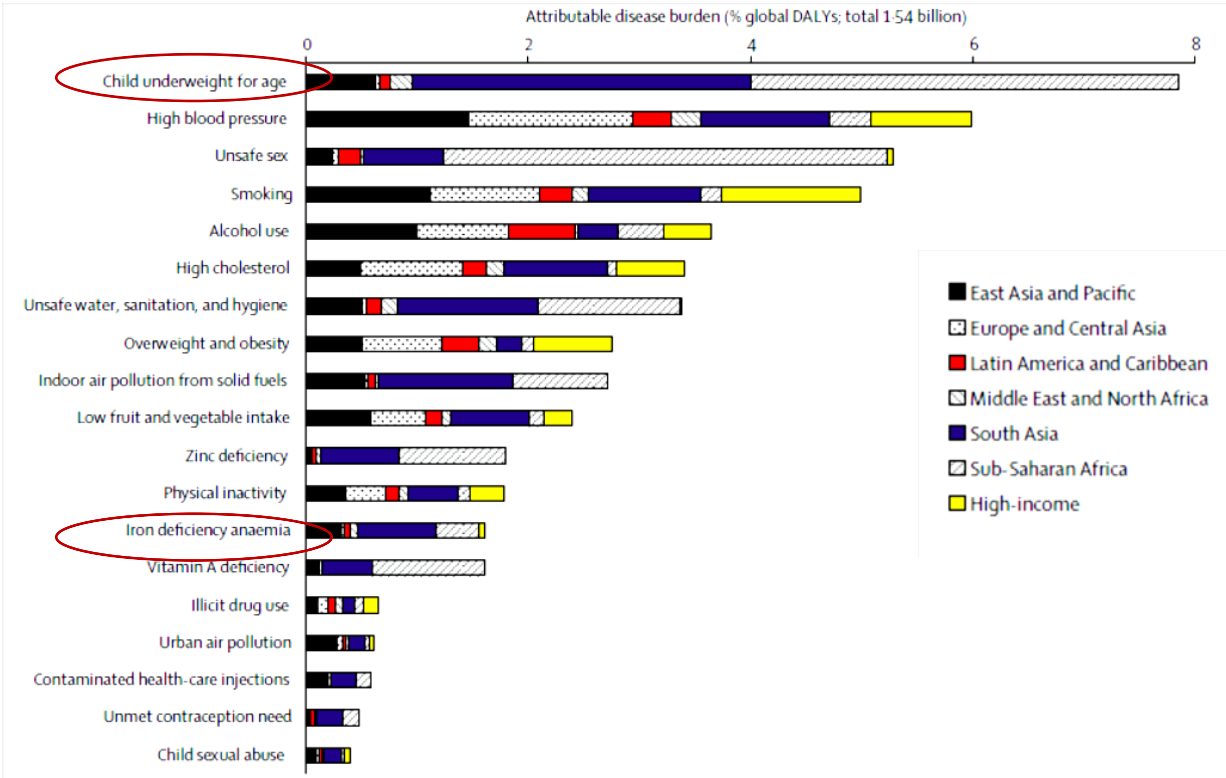

Figure 1. Percentage of global DALY's, attributed to nutritional deficiencies. Source: Lopez AD, Mathers CD, Ezzati M, Jamison DT, Murray CJL. 2006. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. Lancet 367(9524): 1747-1757.

Malnutrition

Malnutrition in the context of developing countries is used to describe a situation of undernutrition, referring to the inadequate intake of protein, energy and micronutrients (Schroeder 2008). Most people who are malnourished have mild or moderate, rather than severe forms of malnutrition. Malnutrition is caused directly by poor dietary intake and illness, although at least one study that tried to estimate the relative importance of the two and found that energy intake at recommended WHO levels would have had a significantly greater effect on weight gain than treatment of diarrhea and fever (Becker et al. 1991). Malnutrition can be further broken down into (Leathers & Foster 2004):

(1) Protein-energy malnutrition: underconsumption of calories or protein, and can only be solved by increasing the amount of food intake. Protein-energy malnutrition can lead to kwashiorkor, is a disease of insufficient protein (presenting as swollen belly, stunted growth, reduced immunity), and marasmus, generally occurring areas of high poverty where there is simply insufficient food. A child with marasmus will have many of the same symptoms as a child with kwashiorkor, and will also be extremely weak and have wasted muscles (Leathers & Foster 2004).
(2) Micronutrient malnutrition: A diet lacking sufficient amounts of one or more essential micronutrients. These are most often Vitamin A, iodine, and iron. In particular, iron

deficiency anemia is one of the most common nutrition disorders worldwide (Ramakrishnan & Semba 2008). It causes reduced capacity to work, diminished ability to learn, and increases susceptibility to infections. More than 40% of people in developing countries are estimated to be suffering from iron deficiency (Leathers & Foster 2004), and more than half of women and children in sub-Saharan Africa are anemic, (Table 1) (Ramakrishnan & Semba 2008).

Table 1. Prevalence of anemia in developing and industrialized countries. Source: Ramakrishnan U, Semba RD. 2008. Ch 16: Iron Deficiency and Anemia. In: Nutrition and Health in Developing Countries, (Semba RD, Bloem MW, eds). Totowa, NJ:Humana Press.

Prevalence of anemia in developing and industrialized countries and in World Health Organization (WHO)-classified regions [23]

	Pregnant women (%)	*Nonpregnant women (%)*	*School-aged children (%)*
Industrialized countries	18	12	9
Developing countries	56	44	53
WHO regions			
Africa	51		52[a]
Americas	35		23[a]
South-East Asia	75		63[a]
Europe	25		22[a]
Eastern Mediterranean	55		45[a]
Western Pacific	43		21[a]

[a]Five- to 14-year-olds.

Health Impacts of Malnutrition

Malnutrition impairs physical activity, work capacity, and can have cognitive and behavioral impacts (Schroeder 2008). Malnutrition during pregnancy and early childhood can cause delayed physical growth and motor development; impaired cognitive development and lower IQ's; and behavioral problems including decreased attention and impaired learning (Schroeder 2008). The effects of malnutrition in the early years of life are also largely irreversible, leading to long-term consequences in economic earning capacity, educational achievement, and overall health and well-being.

Table 2. Top sources of DALY's for sub-Saharan Africa. Source: WHO 2001.

Sub-Saharan Africa	Percentage of total DALYs(3,0)
1 HIV/AIDS	16.5
2 Malaria	10.3
3 Lower respiratory infections	8.8
4 Diarrheal diseases	6.4
5 Perinatal conditions	5.8
6 Measles	3.9
7 Tuberculosis	2.3
8 Road traffic accidents	1.8
9 Pertussis	1.8
10 Protein-energy malnutrition	1.5

Vulnerable Populations

There is an increased requirement for iron particularly during periods of rapid growth, including infancy, childhood and adolescence, as well as during pregnancy (where iron is transferred to the fetus), and during monthly menstrual blood loss (Ramakrishnan & Semba 2008). Additionally, people in rural Africa are more likely to participate in heavy manual labor, requiring increased protein, energy and micronutrients.

There is also a synergism between malnutrition and coinfections. Infections tend to increase the severity of malnutrition (Leathers & Foster 2004). People in tropical Africa are also more likely to suffer from comorbidity with a number of infectious diseases, including malaria, diarrhea, and intestinal parasites. Intestinal parasitic infections can exacerbate malnutrition through a number of mechanisms, including anorexia (causing decreased food intake), intestinal inflammation that inhibits nutrient uptake, and diversion of nutrients to the parasites themselves (Leathers & Foster 2004; Stephenson et al. 2000).

Prevention of Malnutrition

Animal products, such as eggs, milk and meat, may be a key strategy for improving dietary quality and nutrition outcomes (Leathers & Foster 2004; Schroeder 2008). All essential amino acids can be found in animal proteins, whereas vegetable sources are usually deficient in one or more of these essential amino acids (Leathers & Foster 2004). The dietary source of iron also matters; meat is a good source of iron because it is a 'heme iron', and therefore has an absorption efficiency that is at least 2-3 times greater than 'non-heme iron' found in plant foods and fortified food products (Ramakrishnan & Semba 2008).

Importance of Wildlife in the Human Diet

Humans have hunted wildlife as a main source of food since pre-historic times. In many parts of sub-Saharan Africa, wildlife continues to contribute significantly to people's animal protein supply, as well as making important contributions to rural people's livelihoods when sold for petty cash (Brashares et al. 2011; Ntiamoa-Baidu 1998). Animals in central Africa have evolved under the pressure of animal trypanosomiasis, therefore they are resistant to the devastating effects of animal trypanosomiasis on domesticated livestock. Wildlife is also seen to be at least as nutritious, if not more nutritious, than the meat from domesticated livestock. The meat of most wild animal species tends to be low in fat, while equal or better than most livestock in protein content, and much higher in vitamin content (Ntiamoa-Baidu 1998).

Although people have relied on wildlife as an important source of animal protein for millennia, human population growth has been exponential, such that it is continuing to place an increasing burden on natural resources, including wildlife. Further, logging roads in the tropics, and particularly the Congo Basin, have increased the area that is accessible to hunters, leaving smaller and smaller areas where species are still relatively protected and can continue to reproduce faster than they are hunted. Finally, the hunting technology currently in use (e.g. firearms and wire cables for snares) is much more efficient than historically, which also increases the pressure on wildlife (Wilkie & Carpenter 1999).

In addition to providing people with calories, protein, fat, iron, and other micronutrients, wildlife can also act as a savings and insurance policy or safety net, serving in the place of a bank for rural forest dwellers. Wildlife has a high “value-to-weight” ratio, meaning that it can fetch a relatively high price for its size, and can thus be transported to market relatively easily, and is also worth quite a bit when it gets there.

The Case of Southeastern Cameroon

The Republic of Cameroon (hereon Cameroon) is situated in west Central Africa. It has been referred to as “Africa in miniature” because of its geographic diversity, ranging from humid lowland tropical forests in the south, to savannas in the center, to dry Sahelian terrain in the north. It is also known for its cultural diversity, which includes approximately 240 language and ethnic groups. Cameroon’s population numbers at around 19.5 million people. In the latest Global Burden of Disease database available (2008), Cameroon had 5,400 deaths due to nutritional deficiencies, made up largely by protein-energy malnutrition and iron-deficiency anemia (Global Burden of Disease, 2008). In terms of disability-adjusted life years (DALY’s), an estimated 193,000 DALY’s in Cameroon are attributable to nutritional deficiencies (Global Burden of Disease, 2004).

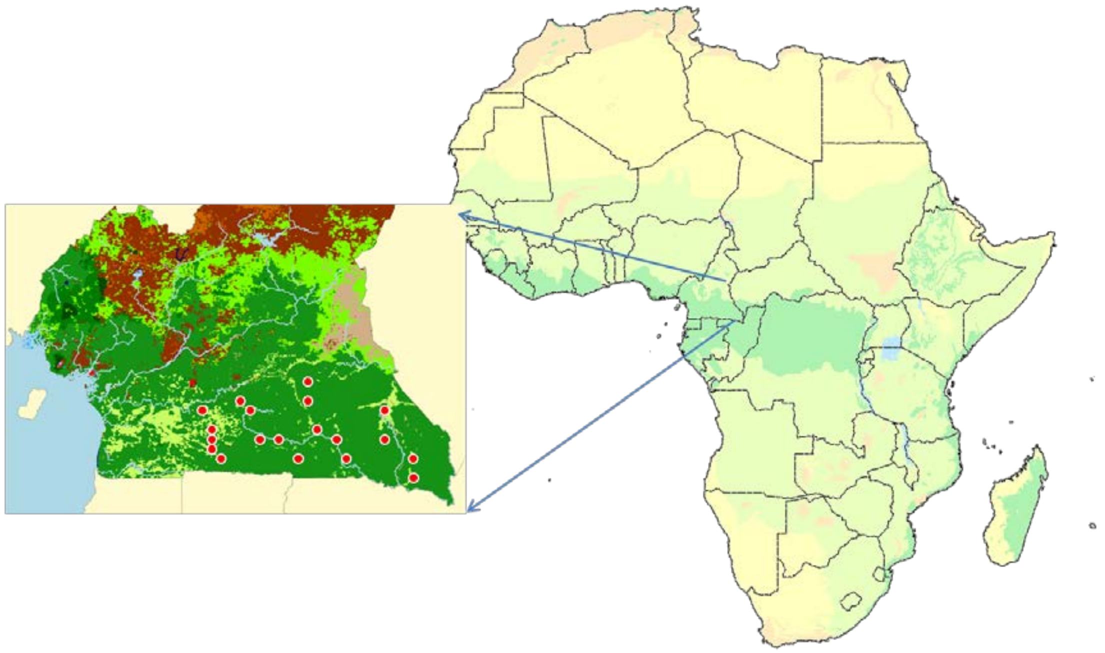

Figure 2. Study sites in southern Cameroon humid tropical forest zone.

METHODS

We conducted a cross-sectional survey of households in southeastern Cameroon using cluster sampling by village (see Figure 2). Household survey instruments were designed and piloted by K.Z.W. in 2006, and surveys were conducted by eight Cameroonian postgraduate students in the Center and East Regions of Cameroon in October and November of 2007. 20 towns and villages in total were sampled. Towns were chosen at the head of the four major road axes in the region, and villages were chosen randomly for cluster sampling of households using semi-structured survey methods. Survey enumerators first conducted focus group meetings with village chiefs and other villagers to discuss village level information and gain permission for conducting surveys. Household surveys were conducted through systematic random sampling. Approximate village population sizes were ascertained during focus group meetings and used to determine the spacing of household sampling, which led to 16 household surveys per village and 50 household surveys per town.

At the village level, we inquired about village size, predominant ethnic groups, and presence of electricity, phone networks, schools and hospitals. We took Global Positioning System (GPS) coordinates of all village locations, and road distances to urban centers and nearest paved roads were calculated using ArcGIS 9.1. At the household level, we estimated household wealth was using a “basket of goods” technique to estimate household assets (Foerster et al. 2012). Annual wildlife consumption was measured through annual recalls of hunting and/or purchase by weekly, monthly, or seasonal frequency. Biomass was obtained by multiplying estimated annual consumption by the average adult body mass of each species or species group using weights from the PanTHERIA database (Jones et al. 2009). Access to wildlife was reported by respondents as the maximum distance traveled from village to hunting activities.

Measurement of food security

According to the WHO, food security is the condition "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life". Food security is built on "three pillars" (Sarlio-Lahteenkorva & Lahelma 2001):

1) Food availability: sufficient quantities of food available on a consistent basis.
2) Food access: having sufficient resources to obtain appropriate foods for a nutritious diet.
3) Food use: appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation.

I used an 18-Item household food security scale used by USAID, World Food Program, and the Food and Agricultural Organization of the United Nations (FAO) to develop an indicator of food insecurity at the household level (Bickel et al. 2000; Frongillo 1999; Perez-Escamilla et al. 2004). This indicator takes into account anxiety or perception that the household food budget or food supply was inadequate; perceptions that the food eaten by adults or children was inadequate in quality; and reported instances of reduced food intake, or consequences of reduced intake, for household members. There are then several degrees of severity for each of these.

Statistical analysis

Descriptive statistics were generated from the household surveys. A generalized linear model was used to test associations between wildlife consumption, food security, and other factors. Outcome variables included total wildlife consumption, and food insecurity measurement. Explanatory variables included wealth (based on "basket of goods" assets), household size, distance to paved road, whether the household had a member who hunted, whether the household had a member who fished, the quantity of wildlife/fish consumed, and any small livestock holdings (# of animals).

RESULTS

The four teams of two interviewers surveyed a total of 20 towns and villages, and conducted 527 household interviews. 201 urban households, and 326 rural households were surveyed. Average distance of village sampled to the nearest paved road was 195 ± 155 (*SD*). Average household size was 7.5 ± 3.4 (*SD*) members. Food insecurity scale ranges from 0-27, with 0 being completely food secure and 27 being extremely food insecure. The average insecurity ratings in the study site were an average of 8.5 ± 6.7 (*SD*).

Regarding access to meat consumption, 202/527 households (38%) participated in fishing activities, with 439/527 households (83%) reporting fish consumption (this includes personally acquired through fishing and purchased fish). 220/527 households (42%) reported hunting wildlife, with 376/527 households (71%) reporting wildlife consumption (this includes personally acquired through hunting and purchased wild meat). Households kept an average of

7 ± 26 (*SD*) domesticated animals/household. There was a significant difference in urban vs. rural wildlife hunting behavior: only 9% urban households hunt wildlife, while 62% of rural households hunt wildlife (χ^2=143.66, p<0.0001).

Significant correlates of wildlife consumption (log) in the generalized linear mixed model are household size, whether someone in the household hunts, food secure, and an interaction term between distance to paved road and level of food insecurity (Table 3). Significant correlates of food security in the generalized linear mixed model are wealth, household size (inversely), whether someone in the household hunts, and whether someone in the household fishes (Table 4).

Table 3. Results of a generalized linear model, with outcome variable as wildlife consumption (log).

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	8.35E-01	1.39E-01	6.008	3.90E-09	***
Wealth	-4.41E-09	7.85E-08	-0.056	0.95529	
Household size	**3.20E-02**	**1.26E-02**	**2.543**	**0.01133**	*
Dist to paved road	4.83E-04	4.51E-04	1.07	0.28513	
Hunt	**1.44E+00**	**1.01E-01**	**14.247**	**< 2e-16**	***
Animal husbandry (yes/no)	6.27E-03	3.61E-03	1.735	0.08344	.
Fish	2.01E-01	1.05E-01	1.907	0.05711	.
Fish consumption	5.46E-05	3.14E-05	1.736	0.08323	.
Food Insecurity	**-2.08E-02**	**6.99E-03**	**-2.977**	**0.003045**	**
Dist to paved road : food insecurity	**1.48E-04**	**4.66E-05**	**3.166**	**0.00165**	**

Table 4. Results of a generalized linear model, with outcome variable as food insecurity scale.

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	7.60E+00	8.34E-01	9.111	< 2e-16	***
Wealth	**-2.95E-06**	**5.53E-07**	**-5.329**	**1.57E-07**	***
Household size	**2.73E-01**	**9.05E-02**	**3.012**	**0.00275**	**
Dist to paved road	2.64E-03	2.02E-03	1.311	0.19046	
Wildlife consumption	2.52E-04	1.56E-04	1.614	0.10728	
Hunt	**-1.76E+00**	**7.29E-01**	**-2.42**	**0.01594**	*
Animal husbandry (yes/no)	-2.81E-02	2.62E-02	-1.074	0.28357	
Fish	**1.53E+00**	**7.60E-01**	**2.01**	**0.04507**	*
Fish consumption	-2.02E-04	2.28E-04	-0.886	0.37591	
Dist to paved road : food insecurity	-8.43E-07	5.19E-07	-1.625	0.10496	

DISCUSSION

There are a number of indications of the important role wildlife plays in human food security in the forest zone of southeastern Cameroon. First is the absolute number of households which report hunting (42%) and consuming wildlife (71%). This figure is even more important when comparing more rural vs. more urban households. Rural households are much more likely to hunt wildlife, which is logical given their lack of access to refrigeration, and lower access to markets and domestic meat sources.

Correlates of wildlife consumption indicate that household size is positively correlated with wildlife consumption. An important result from this model is that the food insecurity scale is negatively correlated with wildlife consumption. In other words, households that are most food secure are consuming more wildlife. This association gives evidence for the role that wildlife is playing in household food security. Finally, there is also an interaction taking place between distance to paved road (a proxy for rurality), and food insecurity, such that they mediate one another in their association with wildlife consumption.

Correlates of food insecurity indicate that wealth is negatively correlated with food insecurity; that household size is positively correlated with food insecurity; that households who hunt are negatively correlated with food insecurity, and that households that fish are positively correlated with food security. Hunting, but not wildlife consumption, per se, is correlated with improved food security. Thus, both regression analyses suggest that wildlife hunting plays a significant role in people's food security in this region.

RECOMMENDATIONS

These results indicate the wildlife consumption plays an important role in human food security in the humid forest zone of southeastern Cameroon. Disappearance of wildlife would negatively impact the food security situation in the region, particularly in the forms of protein-energy malnutrition and iron deficiency. At present, there is little ability to maintain small animal husbandry due to the poor veterinary services throughout the region. Proposed policy interventions include (1) increasing veterinary services; (2) nutrient supplementation; (3) domestication of local species; and (4) a micro-loan program for small livestock distribution, modeled after Hiefer International but directed to this region in southeastern Cameroon.

Increasing veterinary services, unfortunately, can only be accomplished through government initiative, and therefore it would be extremely difficult for outside intervention to help on that score. Nutrient supplementation, and particularly iron, is a relatively cheap, cost-effective intervention. However, it only addresses iron deficiency, but cannot do anything for the protein-energy malnutrition likely to result. This can only be addressed with increased food intake. Domestication of local wild species would be a wise investment, ecologically and economically speaking, because these species are already adapted to local conditions, food options, and are effectively trypanosomiasis-resistant. There have been small pilot projects with the cane rat and porcupine (Jori et al. 2005), but these projects have not appeared to have caught on. There may be an opportunity here for entrepreneurs to get involved. The final intervention investigated follows the Heifer International model, which will be explored further here.

The Heifer International model

Heifer International is an international non-profit organization with the goal of ending hunger and poverty in a long-term sustainable way through what are essentially micro-credit loans in the form of regionally appropriate livestock. These loans are accompanied by training and extension work, as well as organizational development skills. Each family or community that receives assistance promises to “repay” their loan by donating one or more of their animal’s offspring to another family (Heifer International, 2012).

Heifer International (HI) has been in operation since 1944. It has reportedly helped out over 4.5 million families in more than 125 countries (Bryant 2003). The Better Business Bureau reports that Heifer International meets all of its standards for charity accountability. An independent evaluation conducted by The Evaluation Center of Western Michigan University in 2005 of 8 HI projects in the U.S. and 5 sites in Peru concluded that HI projects were cost effective and sustainable (Jori et al. 2005).

For this project, I will be focusing on extending the Heifer International model to two of the ten provinces in Cameroon that make up the region where wildlife hunting is currently the most important form of animal protein. These consist of the Southern and Eastern provinces (“Regions”), which together have a population of about 1 million people. At a population density of around 8 people/km^2, wildlife hunting is believed to be at least four times above maximum sustainable wildlife hunting rates, and therefore supplementary forms of animal protein need to come from elsewhere.

2012 prices for Heifer International livestock, by animal type.

Livestock Item	**Average Cost/Unit**
Flock of chicks, ducks, or geese	$20
Goat, sheep, or pigs	$120
Fish fingerlings	$300
Cows	$500

There is an estimated 1 million people in the region of interest, and household size is approximately 7.5 people/household. Therefore, there are about 133,333 households. If 20% are chosen to be given an animal loan over the course of 10 years, that would involve making loans to 26,667 households. Households could choose from a flock of chicks, ducks, geese, or goats, sheep, pigs, a fish starter kit, or a cow (current prices shown in table above). Assuming an even distribution of the above types of animals, the total cost for the animals would be approximately US$ 6.3 million. The share of DALY’s due to nutritional deficiencies that would be averted in these two provinces amount to ~10,722, giving a cost per DALY of $585. This, however, could be significantly reduced if cows (the most expensive form of livestock) were not included, and instead the animal gifts were made up of equal amounts of birds, goats/sheep/pigs, and fish. In this latter case, total costs would amount to US$ 3.9 million, for a cost per DALY of $361. There would be additional administrative costs associated with the project, not the least of which would be the costs of repeated vaccinations against animal trypanosomiasis, which at currently available technology would require repeating animal vaccinations every 3-6 months! Presumably, however, these costs are reflected in the purchase costs of these animals.

Budget and cost per DALY for the livestock component of the project:

	Costs including cows	Costs excluding cows
Population Total	1000000	1000000
Household size	8	8
No. of households	133333	133333
20% to receive loan	26667	26667
Flock of chicks/ducks	133333	176000
Goat, sheep, pigs	800000	1056000
Fish	2000000	2640000
Cows	3333333	
TOTAL for animal costs	**6266667**	**3872000**
DALYs in Cameroon due to nutritional deficiencies	193000	193000
DALY's in case study region	10722	10722
Cost/DALY	**584**	**361**

An alternative to this would be scaling up and rolling out domestication of local wild species, including cane rats, porcupines, and even giant African snails. These have the advantage of being already culturally acceptable as a food source (and people report these to be highly desirable meats). These species are also already adapted to local conditions and diseases, and therefore can be expected to have reduced veterinary costs associated with vaccinations. Therefore, if the Heifer International model could be expanded to domesticated local species, costs could be even further reduced, and it would be a culturally appropriate solution. This latter solution has been piloted for decades (Jori et al. 2005)—the question remains why it has never taken off commercially.

CONCLUSIONS

Malnutrition is a significant problem in sub-Saharan Africa. People have traditionally relied on wildlife as a major source of protein, calories and micronutrients, and it continues to play a significant role in food security in southeastern Cameroon today. However, increasing human population pressure in the region has resulted in a situation where wildlife hunting is no longer considered sustainable. The intervention proposed in this paper follows the model of Heifer International, in order to replace the animal protein traditionally taken from wildlife sources with a revolving “micro-loan” of livestock, that must be eventually passed on to neighbors. Assuming administrative and training costs are included in the prices of the animals as listed above, small livestock would be a cost-effective way to address protein-energy malnutrition and iron deficiency in this part of the world.

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APPENDICES

Figure S1. Predicted probability of sustainability as a function of species body mass, by indictor method (only those significantly different from reference level (Population trends through time) shown).

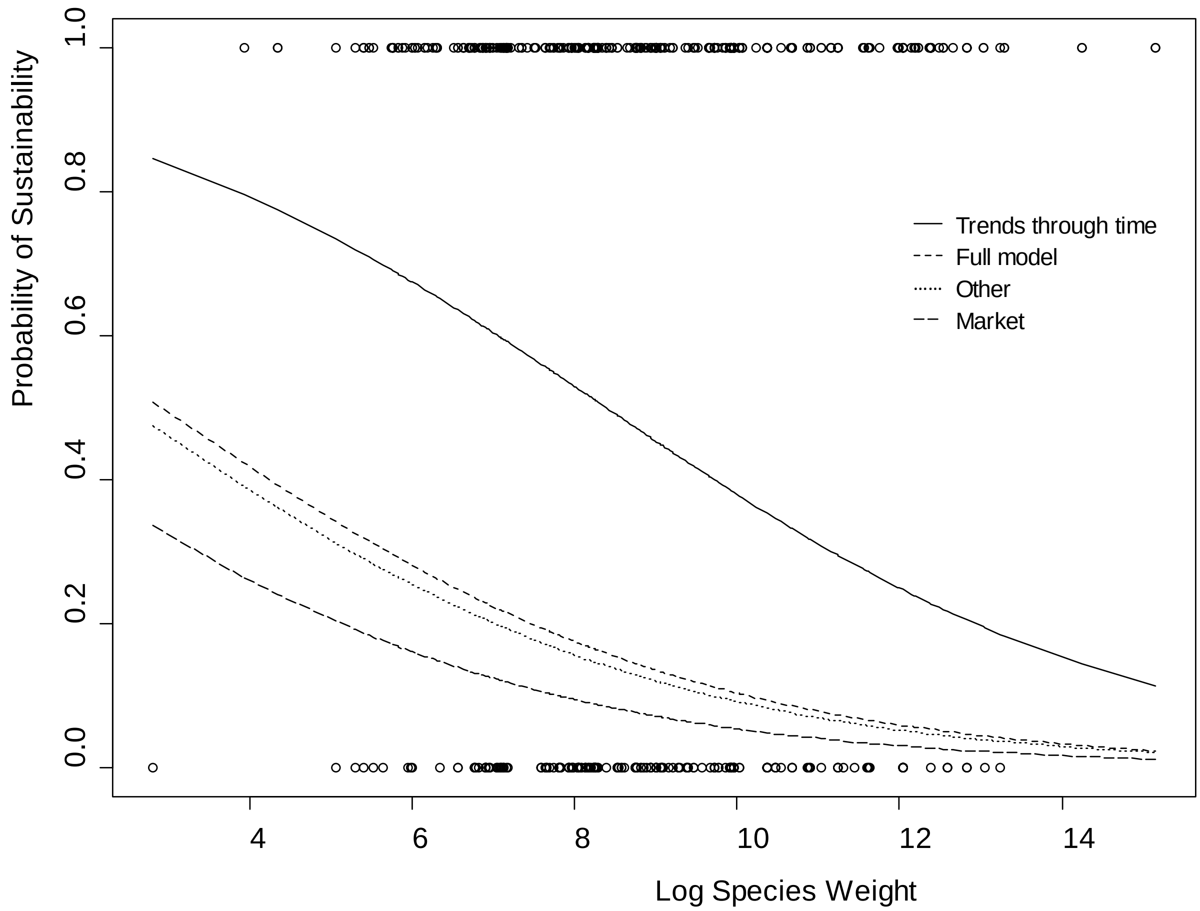


Figure S2. Predicted probability of sustainability as a function of species body mass, by taxonomic groups (only those significantly different from reference level (rodents) shown).

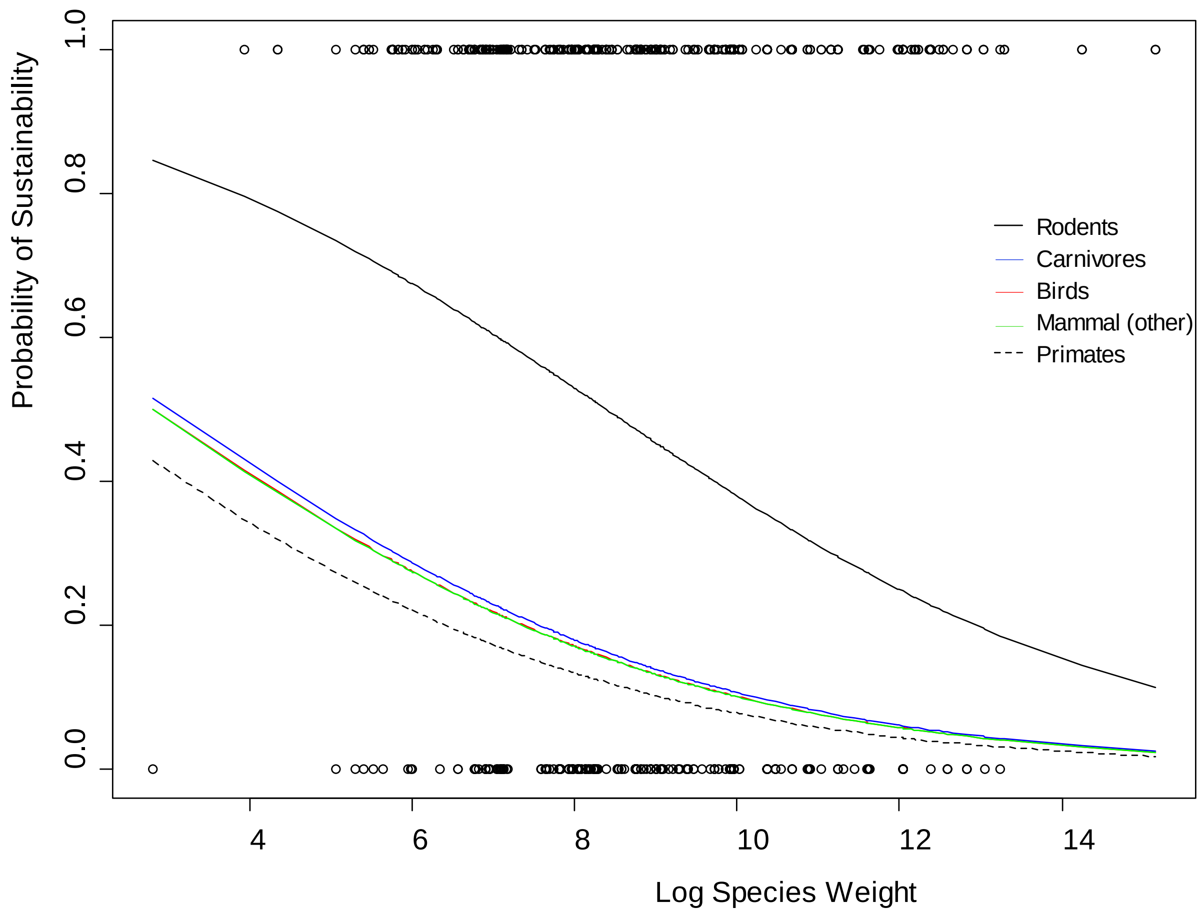


Figure S3. Predicted probability of sustainability as a function of species body mass, by HDI ranking.

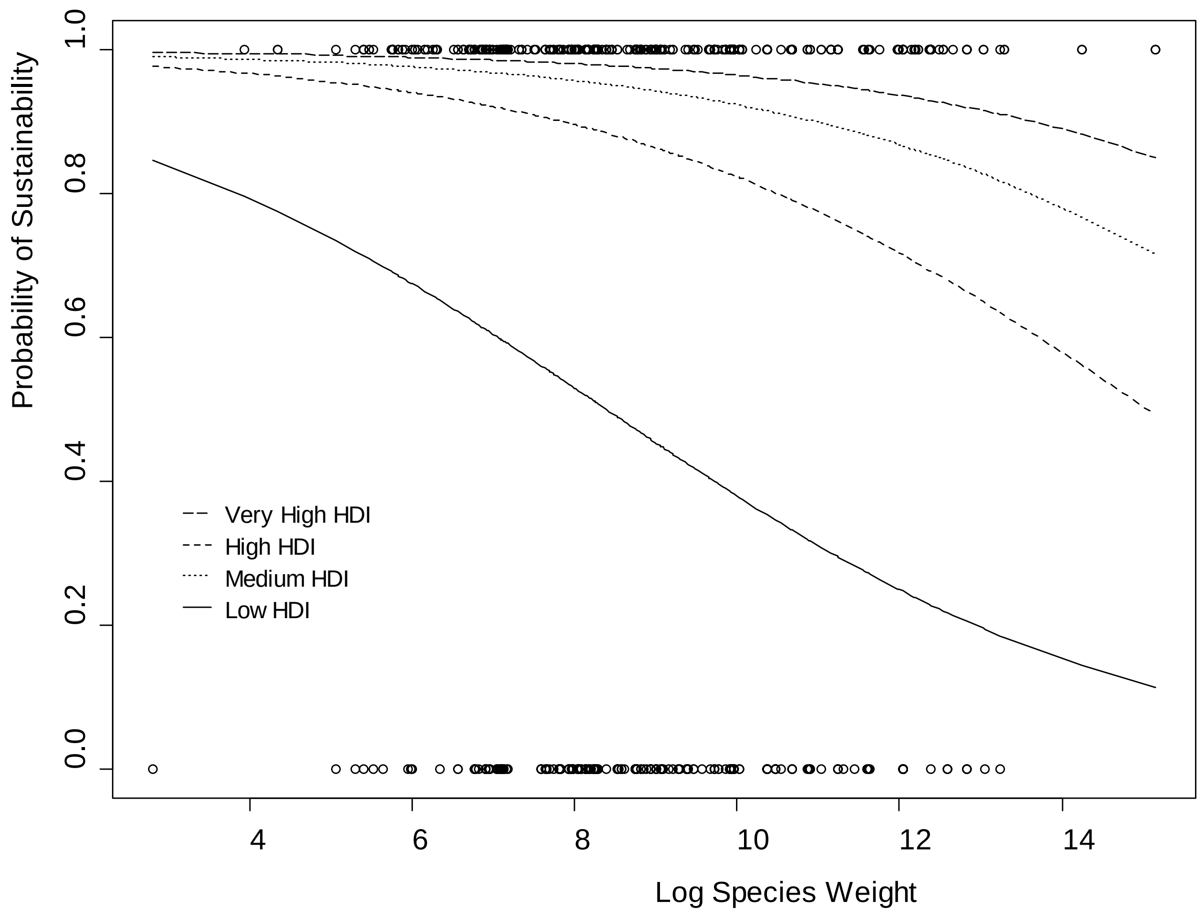
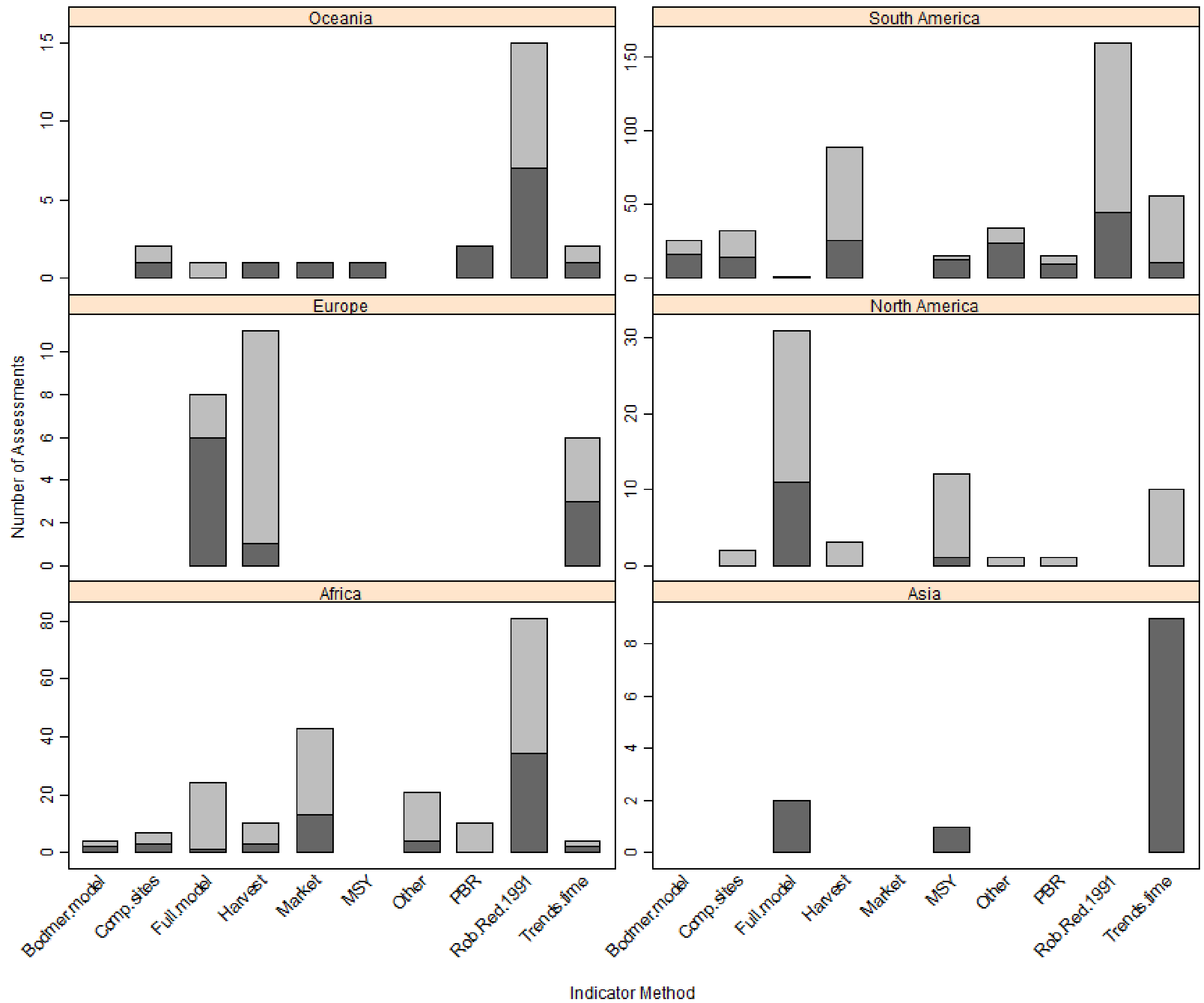


Figure S4. Number of assessments by method and by continent.



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