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Wildlife hunting in complex human-environmental systems: How understanding natural resource use and human welfare can improve conservation in the Ankarafantsika National Park, Madagascar

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ABSTRACT

Conservation officials work to manage complex and interacting human-environmental systems, where balancing needs between the two systems can become a source of tension. This study presents information on the use of natural resources by, and the health and welfare of, rural communities within and near Ankarafantsika National Park (ANP) in northwestern Madagascar. We focus on behaviors that are difficult for natural resource managers to measure themselves, including the hunting of threatened and protected wildlife and on sensitive information about human wealth, health, and food security. We surveyed 419 households and measured the health of 1860 individuals in 18 communities adjacent to or within the boundaries of ANP. We found a very high prevalence of child malnutrition, illness, and food insecurity and a heavy reliance on natural products to meet subsistence needs. More than 90% of the population reported that they hunted wildlife and harvested wild vegetables at least one day during the prior week as a direct means to cope with their food insecurity. Further, we found a high reliance on the forest for both health care and the building of adequate shelter. Efforts to improve overall food security would likely improve both human welfare and the long-term conservation of the threatened wildlife and habitat of Ankarafantsika. These data can help both conservation and community livelihood programs to find integrated solutions to the shared challenges of improving the well-being of human populations and the protection of Madagascar's unique, endemic, and highly threatened biodiversity.

RÉSUMÉ

Les gestionnaires œuvrant pour la protection de la nature sont généralement confrontés à des systèmes socio-écologiques complexes et interactifs dans lesquels la recherche de l'équilibre entre les besoins de ces deux systèmes peut s'avérer être une source de tension. Cette étude présente des informations sur l'utilisation des ressources naturelles par les communautés rurales riveraines du parc national d'Ankarafantsika (PNA) dans le nord-ouest de Madagascar, ainsi que sur la santé et le bien-être de ces communautés. L'étude s'est en particulier orientée sur les comportements difficiles à mesurer pour les gestionnaires de ressources naturelles, à savoir la chasse d'animaux sauvages menacés et protégés et les informations portant sur l'opulence, la santé et la sécurité alimentaire des gens. Une enquête a été réalisée auprès de 419 ménages et l'état de santé de 1860 personnes a été mesuré dans 18 communautés vivant à la périphérie ou à l'intérieur des limites du PNA. Une très forte prévalence de la malnutrition infantile a été observée ainsi que diverses pathologies, une insécurité alimentaire et une dépendance importante à l'égard des produits naturels pour répondre aux besoins de subsistance. Plus de 90% de la population a déclaré qu'elle avait chassé des animaux et récolté des plantes sauvages au moins un jour au cours de la semaine précédente, à titre de moyen direct pour faire face à l'insécurité alimentaire. Une forte dépendance à l'égard des forêts a également été notée pour les produits destinés à la santé et la construction de maisons. Les efforts visant à améliorer la sécurité alimentaire dans son ensemble pourraient vraisemblablement améliorer le bien-être humain aussi bien que la conservation à long terme de la faune et des habitats menacés de l'Ankarafantsika. Ces données peuvent aider les programmes de conservation et de subsistance de la communauté à trouver des solutions intégrées aux problèmes communs de l'amélioration du bien-être des populations humaines et de la protection de la biodiversité unique, endémique et hautement menacée de Madagascar.

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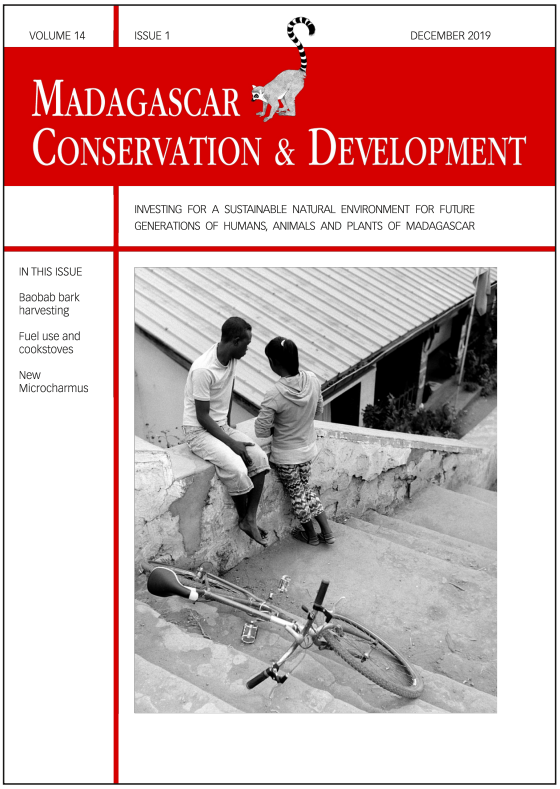

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INTRODUCTION

National parks are often located in regions of both high biodiversity and high poverty (Barrett et al. 2011, Ngonghala et al. 2016). An unsustainable reliance on these resources can lead to the collapse of both the natural environment and human condition (Dasgupta and Maler 2004, Barrett et al. 2011). If approached appropriately, the local communities near national parks are therefore natural allies in resource protection. Likewise, improving human well-being is an integral part of many conservation programs (Andam et al. 2001, Ferrarro et al. 2011, Naughton-Treves et al. 2011). Growing human populations face strong incentives to use natural resources within parks to meet their subsistence needs (Wilkie et al. 2016, Reuter et al. 2017, Poudyal et al. 2018). Yet, we often lack rigorous quantitative data on natural resource use or human well-being surrounding national parks. Without this information, it is difficult to effectively manage protected areas, implement conservation and livelihoods programs, or to quantify the impact of these activities (Gardner et al. 2013).

Madagascar is a conservation priority because of its high biodiversity, high levels of endemism and threat faced by the species (Myers et al. 2000). Order-, family-, and genus-level endemism occurs in Madagascar's terrestrial mammal species, amphibians, reptiles, birds, insects, and of plants (Vences et al. 2009, Wilmé et al. 2012). One-quarter of the world's primates are found only in Madagascar, second only to Brazil in global primate diversity (Estrada et al. 2018). This incredible diversity is threatened by both unsustainable hunting and habitat loss (Harper et al. 2007, Rakotomanana et al. 2013, Brook et al. 2018). Ninety-three percent of primate species in Madagascar are threatened with extinction, a percentage of threat higher than that of any other keystone country for primate diversity (Estrada et al. 2018). The long-term viability of much of Madagascar's flora and fauna will depend upon the effectiveness of Madagascar's protected area network.

The dry forests of western Madagascar may be one of the nation's most threatened biomes (Waeber et al. 2015). Local people depend on this ecosystem for their livelihoods. Complex interactions of landscape-use and climate change have significantly reduced the size and integrity of these fragile, understudied and biodiverse habitats (Zinner et al. 2014, Waeber et al. 2015). With an area of 135,000 ha, Ankarafantsika National Park (ANP) is one of Madagascar's largest contiguous dry deciduous forests. The park was created to ensure the long-term protection of the unique dry deciduous forest ecosystem in northwestern Madagascar (Andriamampianina and Peyrieras 1972), and is home to a variety of narrow-ranged species of flora and fauna. It contains one important watershed for the nearby agricultural center of Marovoay, one of Madagascar's largest rice production areas (World Bank 2015). The park is immediately surrounded by a human population of over 107,000 people across 133 villages, some of which legally are within its boundaries along a major highway which bisects the park (Madagascar National Parks 2018). Given its ecological importance and its complex human-ecological interactions, understanding natural resource use is important for effective management.

This study presents information on the use of natural resources by, and the health and welfare of, communities near and within ANP. We particularly focus on the behaviors that are important for natural resource managers to understand, but are difficult for managers to measure themselves because of the participants' fear of recrimination and prosecution. This includes data on hunting threatened and protected wildlife and sensitive information on human wealth, health, and food security. These data can help both conservation and community livelihood programs to find integrated solutions to the shared challenges of improving the well-being of human populations and the protection of Madagascar's unique, endemic, and highly threatened biodiversity.

METHODS

STUDY SITE. The Boeny region of northwestern Madagascar is home to Ankarafantsika National Park. The principal ethnolinguistic groups are Sakalava and Betsileo (although ethnic diversity is high) and the primary economic activity of local people is subsistence agriculture. The region is 110 km south of the city of Mahajanga, a district home to >250,000 people (INSTAT 2013). Ankarafantsika was originally classified as a Réserve Naturelle Intégrale in 1927, with the adjacent Ampijoroa Forestry Reserve to its West. These two parcels were combined to create the Ankarafantsika National Park (IUCN Category II) in 2002. Ankarafantsika National Park protects 1,350 km2 of dry deciduous forest and wooded grassland habitats and is bisected by the major highway (RN4) connecting Antananarivo to the port town Mahajanga.

SURVEY PROTOCOLS. Between November 2014 and April 2015 JFR and TRA surveyed 419 households, including 1860 individuals, in 18 communities in Ankarafantsika (15–30 households per village). All surveys were conducted in the native dialect of Malagasy spoken within each village. We consulted with the local community leaders and then held a local community meeting to discuss the goals of the project before beginning household interviews in each community. During community meetings, we described the research as an effort to understand the ways in which natural resource use and agricultural activities contributed to human food security, health and general well-being.

We selected households by one of two methods: (1) if a household census existed at the community level, then the local research team selected every third household to participate; or (2) if no household census existed in the community, then the research team selected every third household that they passed in the community. Each head of household consented verbally to participate in the research survey. We interviewed either the male or female head of each household to gather information on household demographics, diet, food security, agricultural labor, livestock raising and diseases, income generation, commercial good ownership, food taste preferences, forest resource use, and hunting behavior. Commercial goods included shoes, bicycles, radios, watches, flashlights, and guns. In general, we asked interviewees to recall wildlife consumption events over the prior year as this had been demonstrated to be successful with regard to previous wildlife harvest surveys (Golden et al. 2013). We asked interviewees to recall information on their typical diet over the prior day and week. These foods were categorized based on their micronutrient-composition to determine dietary diversity and assign a 'Women's' Dietary Diversity Score (WDDS) (FAO 2010). Food security was determined using the Coping Strategies Index (CSI) (Maxwell and Caldwell 2008), a tool which asks household members to report the number of days during the prior week they used pre-defined coping strategies to deal with household food insecurity. A weighted CSI was then determined by weighting the local severity of each coping strategy (categorical weights) using

focus groups of 5–10 individuals in each community, as the cultural appropriateness or severity of coping strategies may vary between villages (for example, in one village norms may dictate it more acceptable to borrow food than in others). During these meetings, we also recorded information on poultry disease, cost, husbandry, and mortality.

In addition to questions administered solely to the head of household, we also collected data on the health of all available individuals in the surveyed households (1860 individuals within these 419 households). We recorded the sex, age (to the nearest year), occupation and educational obtainment (in years) of each household member. We then collected specific health information including anthropometric data (height and weight), history of malaria episodes, history of deworming medication, and hemoglobin and blood oxygen level obtained using a portable hemoglobinometer (Rainbow Pulse CO-oximeter from MASIMO). This simple, non-invasive hemoglobinometer uses photospectrometry rather than a blood sample to assess hemoglobin levels. Our research was approved by the Madagascar Ministry of Health No 253/MSANP/SG/DGS/DPLMT, the Harvard T.H. Chan School of Public Health's Institutional Review Board (IRB13-1862), and from the chef *fokontany* in each local community where we worked.

DATA ANALYSIS. Simple summary statistics were calculated for most forms of environmental resource use and socio-demographic variables. Center for Disease Control (CDC) thresholds were used to calculate the prevalence of stunting, underweight, and a low body mass index (BMI) for their sex and age in children and young adults age 2–20 (CDC 2000). We used WHO (2011) guidelines for hemoglobin cut-offs when determining anemia in children and adults. Children under five years of age were considered anemic if their hemoglobin values were less than 11.0 g/dL, 5–11 year-olds if less than 11.5 g/dL, 12–14 year-olds if less than 12.0 g/dL, women of 15 years and older if less than 12.0 g/dL, and men of 15 years and older if less than 13.0 g/dL. We measured dietary diversity using the WDDS (FAO 2010) and food insecurity using responses from the CSI, which were then weighted for cultural importance using focus group data (Maxwell and Caldwell 2008). We used the statistical software JMP for analysis. We applied a partition analysis to characterize food-secure and -insecure households. For data analysis, wildlife consumption was a Log_{10}+1-transformed continuous explanatory variable and household income per capita was Log_{10}-transformed. Hemoglobin levels, the z-scores for child growth, and CSI values in this population were roughly normally distributed and did not require transformation. At the time of data collection, one United States Dollar ($US) was worth 2,600 Malagasy ariary (MGA).

RESULTS

In the 419 households we surveyed in Ankarafantsika, mean household size was 4.44 ± 2.08 individuals (median 4). Half (46.5%) of our study population was female. Nearly half of the population (44.0%) was 16 years of age or younger and 4.5% were under two years of age.

HOUSEHOLD DEMOGRAPHICS AND ECONOMIES. The heads of 39.5% of all households had been born in the community in which they now resided. Those that were not born in that community, had moved there a median of 10 years ago (mean of 13.43 ± 9.48 years), showing a relatively stable population structure in regards to immigration and emigration at the community-level. Heads of households born in their current community of residence were primarily of the Sakalava (34.5%), Betsileo (16.1%), and Betsimisaraka (10.9%) ethno-linguistic groups. Heads of households who had moved to community after their birth were primarily of the Betsileo (24.7%), Tsimihety (16.5%), and Antandroy (14.4%) ethno-linguistic groups.

The principal economic activity of local people was agriculture, and households earned an average of $US211.38 ± $US184.21 in cash income during the prior year. This provided a median of $US42.31 in cash income per person during the prior year (mean of $US57.99 ± $US110.66). Only two households (0.5% of total sample) had not purchased food during the prior week. Of food expenses, 60.3% were used to purchase meat, fish, or vegetables that would complement their rice staple. Comparatively, only 31.1% was spent on rice, 1.7% on tubers, and 3.6% on snacks. Households spent a mean of $US1.23 per person on a vegetable or meat accompaniment to their rice-staple during the prior week. People in Ankarafantsika ate an average of 554.8 grams (1.8 kapoka) of rice (measured size before cooking) per person per day.

Malagasy people often reside in a seasonal home, or *lasy*, close to their rice fields during the harvest season; 83.1% of the Ankarafantsika population used a *lasy* during the prior year. Living in a *lasy* peaked during September (79.3% of all lasy were occupied during this time). Lasy use was, however, high throughout the year. Even during the lowest month (December), 62.3% of *lasy* owning households occupied at least one of these seasonal homes.

Nearly half of interviewees had earned a wage labor (even if only for one day) during the prior year (43.1% of interviewees, 43.9% of men, and 40.6% of women). Interviewees earned a median daily salary of US$1.15 for wage labor. While both men and women earned a median salary of US$1.15, men had higher earning potential (men earned a mean daily wage of US$1.76 ± 2.57; women a mean daily wage of US$1.35 ± 1.98).

NATURAL RESOURCE USE. Nearly all (99.3%) of the population relied on firewood for cooking and harvested it themselves (98.8%) a median of two times per week (mean of 3.26 ± 3.05). Individuals traveled a median of one hour and 15 minutes (mean of 66.1 min ± 35.9 min) to collect firewood. We found a high dependence on the forest for natural products that can create shelter. Many (69.9%) households had purchased or harvested timber for housing (even if just one piece of wood) and 79.9% had collected thatch roofing in the prior year. Most of the timber and thatch used (96.8% and 91.3%) was collected by that household (and not purchased). Households traveled a median of one hour and 15 minutes to collect housing-timber and thatch roofing (means of 85.5 min ± 33.5 min; 86.4 min ± 60.8 min respectively). Half (57.4%) of households had eaten honey during the prior year. Honey was primarily collected and not purchased (95.8% of households that had eaten honey had collected it themselves). Honey was collected a median of 73 minutes from their homes (mean of 81.9 min ± 33.5 min). Few households had collected trees to build boats (3.1%) or plants for the fermentation of a local alcoholic beverage (6.5%) and none had purchased these items. These collectors traveled a median of one hour (means of 92.5 min ± 63.3 min; 83.5 min ± 38.7 min) to reach these products. Most local people relied on the forest for healthcare through eth-

nobotanical medicine collection (roughly 84.9% of the population). Those who use these traditional medicines primarily collected them (83.0%) from the forest less than once per week (mean 0.6 ± 0.7) at a median distance of one hour and 15 minutes from the home (mean of 90.5 min ± 52.6 min).

There were distinct gender roles in the collection of natural products. The collection of firewood, timber, roofing, wood for boats, bark for fermentation, honey and traditional medicinal plants were all predominantly male activities (Table 1).

At least three in four households (76.4%) ate wildlife during the prior year. Of the 1387 forest mammals eaten by 419 surveyed households, 49.8% were tenrecs, 26.0% were bush pigs, 13.0% were the small Indian civet Viverricula indica, 5.6% were lemurs, 4.7% were bats, and 0.9% were endemic, Euplerid carnivorans (Table 2). The average household reported eating a median of two forest mammals during the prior year (mean of 3.3 ± 4.4; Table 2). Nearly half of all households ate the meat of tenrecs (48.0%) and bushpigs (48.1%) during the prior year. Of households that ate these meats, each household ate a median of two tenrecs (mean of 3.44 ± 3.64), and ate bushpig-meat a median of two times (mean of 1.8 ± 1.0) during the prior year. More than one tenth of households ate lemurs (10.7%) and bats (10.3%) during the prior year. Of those households that ate lemur or bat meat, members of each household ate a median of one lemur (mean of 1.7 ± 1.0) and one bat (mean of 1.5 ± 0.9). While one in four households ate non-native carnivorans (24.6%). The hunting of endemic Euplerid carnivorans was less frequent (with 2.9% of households participating). Members of the households that hunted these animals ate a median of one endemic and/or one endemic carnivoran during the prior year (means of 1.7 ± 1.0 and 1.1 ± 0.3, respectively). Seven percent (7.2%) of households surveyed reported eating a total of 48 reptiles during the prior year. Members of these households ate a median of one reptile each (mean of 1.3 ± 0.5) (Table 2). The mean and standard deviation of the forest animals each household ate varied between villages (Table S1).

People used a diverse set of methods to catch wildlife. Trapping (21.5% of all forest animals eaten during the prior year were obtained using traps) was supplemented by opportunistic hunting (21.1%), eating the meat at the household of a friend or family member (19.3%), pursuit hunting using dogs, sling-shots, blow guns, rifles, or spears (18.4%), and purchasing the meat (18.1%) (Table 2). Only 1.7% of surveyed households owned a firearm.

Three species had been purchased during the prior year, the common tenrec (mean price per individual = US$0.82), Madagascar flying fox (US$1.15 per individual), and bushpig (US$1.15 per kilogram).

A step-wise bivariate nominal logistic regression analysis revealed that household size and dietary diversity were the best predictors of whether or not a household had consumed wildlife during the past year (DF = 2 (419), R2 = 0.04, X2 = 18.33, $p < 0.0001$) and a step-wise multiple regression analysis revealed that the most significant predictors of the amount of wildlife members of a household consumed were household size, dietary diversity, and ethnicity (DF = 16 (418), R2 = 0.12, F = 3.48, $p = <0.0001$). Income did not significantly affect wildlife hunting (DF = 1 (412), R2 < 0.00, F = 0.24, p = 0.62). Larger Betsimisaraka households with less diverse diets ate more wildlife than smaller

Table 1. The age-class and gender stratification of the collectors of forest resources in households in Ankarafantsika 2014–2015. (expressed as % households; household members self-identified their age-class and gender)

Collector	Female adult	Female child	Male adult	Male child
Firewood	8.6	3	35.3	74.7
Timber	4.5	0.4	14.2	78.9
Thatch	7.4	4.8	34.9	82.2
Honey	3.8	1.4	40.5	79
Wood for boats	0	0	63.6	81.8
Bark for alcohol fermentation	0	0	47.6	85.7
Medicinal plants	17.3	2.6	27.8	54.2
Firewood	8.6	3	35.3	74.7

Table 2. The volume of mammalian wildlife consumption in communities within Ankarafantsika, disaggregated by hunting method during 2014–2015. (The volume of consumption was reported based on the head of household's recall of number of individual animals consumed during the prior year. Species that exist in the region, but that were not reported to have been eaten during the prior year (e.g., Propithecus coquereli), are not listed here; † local people ate the meat of bush pigs (Potamochoerus larvatus) in pieces ~ 1 kg in weight, this is therefore the number of times the bush pig meat was eaten, and not whole animals)

Species	Local name	Conservation Status (IUCN 2018)	Total consumption (n individuals)	Pursuit hunting	Trapping	Opportunistic hunting	Eaten with friends or family	Purchased
TENRECS								
Tenrec ecaudatus	Trandraka	LC	583	32.6%	14.2%	12.2%	24.9%	12.9%
Setifer setosus	Sokina	LC	112	28.6%	5.4%	59.8%	3.6%	0.0%
BATS								
Pteropus rufus	Fanihy	VU	42	2.4%	9.4%	26.1%	33.8%	23.8%
All insectivorous bats	Kanavy	-	24	0.0%	0.0%	70.8%	30.2%	0.0%
EUPLERIDS CARNIVORANS								
Cryptoprocta ferox	Fosa	VU	13	7.7%	15.4%	61.5%	15.4%	0.0%
Eupleres major	Fanaloka mena	EN/LC	1	0.0%	0.0%	100.0%	0.0%	0.0%
LEMURS								
Cheirogaleus stethi	Matavy rambo	-	15	6.3%	6.3%	81.3%	6.3%	0.0%
Avahi occidentalis	Fotsy fehy	EN	2	100.0%	0.0%	0.0%	0.0%	0.0%
Lepilemur edwardsi	Repahaka	EN	12	33.3%	0.0%	48.3%	8.3%	0.0%
Eulemur fulvus	Gidro	NT	48	8.3%	10.4%	62.5%	10.4%	0.0%
Microcebus spp.		-	1	0.0%	0.0%	100.0%	0.0%	
REPTILES								
Erymnochelys madagascariensis	Rere	CE	7	14.3%	0.0%	71.4%	14.3%	0.0%
Small fresh water turtle	Kapika andrano	-	11	0.0%	0.0%	100.0%	0.0%	0.0%
Small fresh water turtle	Sokatra	-	3	0.0%	0.0%	33.3%	66.7%	0.0%
Small fresh water turtle	Kapidolo	-	5	0.0%	0.0%	100.0%	0.0%	0.0%
Acrantophis madagascariensis	Do	LC	12	0.0%	0.0%	83.3%	26.7%	0.0%
INTRODUCED SPECIES								
Viverricula indica	Jabady	LC	126	8.7%	61.1%	18.3%	15.1%	1.6%
Potamochoerus larvatus†	Lambo dy	LC	363	3.9%	28.4%	1.1%	17.4%	47.4%
Felis sp.	Kary	-	55	3.6%	50.9%	34.5%	9.1%	0.0%

households of other ethnicities with more diverse diets, regardless of whether they were born in that community (DF= 16 (418), R2 = 0.12, F = 3.48, p = <0.0001). While significant, these differences, were however, functionally very minor and may be spurious. Households that consumed wildlife contained a mean of 4.60 ± 2.21 individuals, whereas households that had not eaten wildlife contained a mean of 3.91 ± 1.55 individuals (T = 3.60, p = 0.0002) and the mean dietary diversity score was only very slightly lower in households that ate wildlife (5.22 ± 1.01) than in those that did not (5.52 ± 0.94) (T = -2.69, p = 0.008).

Wildlife consumption was similar between those who were born in their current community of residence and immigrants to the region (T = -0.77, p = 0.78). In terms of consumption of mammals, those born in their current community ate more bats (T = 2.37, p = 0.02; 0.24 ± 0.67 vs. 0.10 ± 0.43 bats per household per year) and reptiles (t = 1.95, p = 0.03; 0.13 ± 0.40 vs. 0.06 ± 0.30 bats per household per year), whereas immigrants ate more bushpig meat (T = -3.23, p = 0.001; 1.00 ± 1.20 vs. 0.65 ± 1.03 portions of bushpig per household per year). Both groups ate similar numbers of lemurs, carnivorans, and tenrecs. By ethno-linguistic group, those with heads of households who self-identified as Betsimisaraka ate significantly more wildlife than any other ethnicity (ANOVA; R^2 = 0.10, *F* = 3.33, DF = 14, p = <0.0001) (Table S2).

NUTRITION AND DIETARY DIVERSITY. Most (73.0%) of measured households ate the meat of domestic animals during the prior week, and nearly all (99.0%) had eaten any source of fish, meat, or insect. The diets of most households (87.4%) were moderately diverse during the prior week (Table 3). Most (89.0%) ate a source of fat or oil in the prior week, 43.2% sourced vitamin A from a plant, 43.4% sourced vitamin A from an animal, and 99.5% ate at least one iron-rich food during the prior week (Table 3).

HUMAN HEALTH AND FOOD SECURITY. We found a high prevalence of child malnutrition (Table 4) and a moderate prevalence of anemia throughout all sub-populations measured in the Ankarafantsika region. Just over one-quarter (27.1%) of the cases of anemia were moderate to severe. Approximately 17.6% of children 0–5 years of age (n = 272), 28.6% of children 6–11 years of age (n = 262), 28.9% of women age 12 and older (n = 575) and 44.9% of men age 12 and older (n = 608) were affected by anemia. One-third (32.7%) of all observed subjects (560 of 1715) were anemic. Men were significantly more likely to be anemic than women (X2: DF = 1 (1699), R^2 = 0.01, X^2 = 21.8; p < .00001; 53.5% of men (909) vs. 46.5% of women (790)). Over half (53.9%) of household members had a feverish illness within the prior three months and 32.6% had seen evidence of intestinal parasites (e.g., worms visible in stools).

Table 3. Foods characterizing diets with low, moderate, and high diversity using a WDDS scale. (Food categories listed were found in greater than 75% of households in that subclass)

Low dietary diversity (WDDS 0-3)	Moderate dietary diversity (WDDS 4-6)	High dietary diversity (WDDS 7-9)
0.5% of households	87.4% of households	1.2% of households
Starchy staples	Starchy staples Dark green leafy vegetables Vitamin A rich fruits and vegetables Fish/seafood, meat, and insects	Starchy staples Dark green leafy vegetables Vitamin A rich fruits and vegetables Other fruits and vegetables Fish/seafood, meat, and insects Dairy Legumes, nuts, seeds

Table 4. Percentages of individuals classified as stunted, underweight, and as having a low BMI for their age and sex in communities in and near Ankarafantsika National Park during 2014–2015. (Children are defined as stunted, underweight, or low BMI if their height-for-age, weight-for-age, or BMI-for-age is more than two standard deviations below the CDC (2000) Child Growth Standards median)

Age range (yrs)	Sex	Sample size (n)	Stunted	Underweight	Low BMI
2<5	Male	98	56.1%	62.2%	34.7%
2<5	Female	67	46.3%	43.3%	26.9%
5<12	Male	217	47.9%	47.6%	23.0%
5<12	Female	164	56.7%	47.6%	22.0%
12<20	Male	188	54.3%	43.6%	16.5%
12<20	Female	146	65.8%	42.5%	16.7%
2<20	Male & Female	791	55.0%	46.1%	21.6%

Nearly all (99%) households had used at least one strategy to cope with food insecurity during the prior week. The median unweighted and weighted household CSI scores were 18 and 44.83, respectively. The most frequently reported mechanisms for coping with food insecurity were to harvest wild vegetables and hunt wildlife (16.1% and 14.7% of all coping strategies used by a household during the prior week). 'Hunting' behavior included all days an individual of the household checked traps and/or carried a weapon in an attempt to catch food. It reflects hunting effort and not hunting success (if they successfully caught a wild animal). Most households (89.7%) reported that they hunted at least one day during the prior week to cope with household food insecurity. Households spent a median of three days hunting during the prior week (mean = 2.67 ± 1.71). Similarly, 95.0% reported that they searched for wild vegetable foods at least one day during the prior week to cope with household food insecurity, and households spent a median of three days looking for wild vegetables during the prior week (mean = 2.92 ± 1.64). Strategies that were used less often included eating next years' seed stock (9.7%), purchasing food on credit (9.2%), borrowing food (8.0%), harvesting immature crops (7.8%), limiting the portion size of all household members (6.6%), reducing the portion size of food given to adults in order to feed children (6.3%), and reducing the number of meals eaten in a given day (5.1%). Rarely reported strategies included eating at friends or families solely as a means to procure food (2.1%), begging for food (0.6%), restricting the consumption of food by non-working household members in order to feed working members (0.2%), reducing the portion size of food given to children in order to feed adults (0.2%), and not eating for an entire day and night (0.1%).

Communities that were farthest from a major road (defined as distance from a rural bush-taxi stop) experienced significantly decreased food security (ANOVA; R^2 = 0.19, *F* = 48.77, DF = 2, p = <0.0001). Households who collected many forest products and who used seasonal homes (*lasy*) were less food secure than those who did not collect these forest products or use *lasy* (Table 5).

Table 5. The relationship between food security (weighted CSI) and the collection of natural products (binary) in communities surrounding Ankarafantsika (2014–2015).

Collected/Hunted Forest Product	T	p	Mean Weighted CSI	
			Collected	Did not collect
Plants for Fermentation	3.27	**<0.01**	54.20 ± 13.55	45.20 ± 17.52
Medicinal Plants	8.53	**<0.0001**	48.36 ± 16.66	31.24 ± 14.31
Roofing	0.49	0.62	46.00 ± 17.27	44.92 ± 18.08
Honey	7.43	**<0.0001**	50.88 ± 16.67	38.90 ± 16.02
Timber	5.59	**<0.0001**	48.70 ± 17.31	39.01 ± 15.79
Firewood	0.35	0.78	45.80 ± 17.45	42.68 ± 15.38
Wildlife	-1.54	0.06	44.99 ± 16.85	48.25 ± 18.97

Table 6. The range and mean of pets and livestock assets per household in communities surrounding Ankarafantsika (2014–2015).

	Median	Mean
Cows	3	6.07 ± 10.70
Pigs	0	0.49 ± 1.76
Ducks	9	13.19 ± 15.13
Chickens	9	10.17 ± 9.45
Geese	0	0.12 ± 1.15
Cats	0	0.21 ± 0.50
Dogs	1	0.98 ± 1.03

On average, ducks were the most commonly owned domestic livestock, followed by chickens (Table 6). Focus groups in each community reported that chicken and duck meat cost a mean of $US2.40 per kilogram. All communities reported that chickens had died from disease epidemics during the prior year. Deaths were reported to be caused by diseases locally referred to as *barika*, *koropoka*, and/or *kopinda*. The reported symptoms of the diseases indicated the presence of Newcastle disease and/or avian cholera. Ducks were also reported to be affected by *ramoletaka* (symptoms consistent with fatty liver disease) and *gripam-borona* (symptoms consistent with avian cholera).

DISCUSSION

Effective conservation policy must be based on an understanding of the choices humans make within their dynamic social and ecological system contexts (Gibson et al. 2000). Conservation officials need to be able to identify what natural resources are being used, address the underlying reasons for using that resource (e.g., hunger), as well as the specific goals users have when using that resource (e.g., to eat a filling, fatty, nutritious, and/or good tasting meal), and how these and other factors affect their incentives for resource use. Yet, it is often difficult for conservation managers to gain accurate information on the behaviors that affect the resources they aim to protect.

We found a very high prevalence of child malnutrition, illness, and food insecurity both, bordering and within the Ankarafantsika National Park in Madagascar. Madagascar's national prevalence of children who are stunted, underweight, and have a low BMI is amongst the worst in the world (UNICEF et al. 2018, WHO 2018). In Ankarafantsika, one in every two children was stunted, one in two was underweight, and one in three had a severely low BMI. These rates are similar or higher than national averages, placing the region in the WHO's highest severity category for child malnutrition (WHO 2018). Nearly all (99%) households had used at least one strategy to cope with food insecurity during the prior week. An astonishing majority of the population (90% and 95% of households respectively) reported that they hunted for wild meat and/or searched for wild vegetables at least one day during the prior week, as a direct means to cope with this food insecurity. Households spent three days hunting or searching for wild vegetable foods during the prior week. In fact, in contrast to the central plateau or northeast of Madagascar (Golden et al. 2014ab, Borgerson 2015, 2016, 2018ab), the most frequently reported mechanisms for coping with food insecurity were to harvest wild vegetables and hunt wildlife. Yet, much of this hunting is conducted simultaneously while completing agricultural and other types of labor, and is often unsuccessful. While 90% reported hunting to cope with food insecurity during the prior week, only three quarters of interviewees had eaten wild meats during the prior year, reflecting either poor success rates in hunting effort, or under-reporting. Further, while food insecurity increased hunting, hunting may be an insufficient coping mechanism. Households that hunted were less food-secure than those that did not hunt. Because we collected data at a single time point, we do not know if households stopped hunting once food security was achieved or if current wildlife densities are simply too low to support sufficient catch.

Wild meat is commonly eaten in the region. While more than three-quarters of people had eaten wildlife during the prior year, they ate on average fewer wild animals per household than in many other regions of Madagascar. Wild meat eating households ate two forest mammals during the prior year, an amount similar to that of southeastern and central Madagascar, but only half to one-fifth of the number of wild mammals consumed per household in the northeast (Golden et al. 2014ab, Borgerson 2015, 2016, 2018a,b). While still uncommon, people also purchased more wild meat in Ankarafantsika than other regions of the country, even at its comparably higher price (Golden et al. 2014a,b, Borgerson 2015, 2016, 2018a,b). This may be due to the comparatively higher income and greater access to markets and transportation routes found in this area. Similar to other regions across Madagascar, the most frequently eaten mammal was the common tenrec (*Tenrec eucadatus*; IUCN Least Concern (Stephenson et al. 2016)), and the lemur genus *Eulemur* (Garcia and Goodman 2003, Golden et al. 2014a,b, Borgerson 2015, 2016, Reuter and Sewall 2016, Borgerson et al. 2018a,b, Merson 2018). Although the *Eulemur* eaten in this survey was *E. fulvus*, it does raise concern for *E. mongoz*, which is also found in the region and is Critically Endangered.

Garcia and Goodman (2003) suggested that common Sakalava taboos for lemur hunting may be eroding in the region with increasing immigration from other areas, and that this may explain the high levels of lemur hunting found in the region. We found high diversity in the ethnolinguistic composition of Ankarafantsika residents. We tested the effect of ethnicity and found that while ethnicity is significantly associated with current levels of hunting (with those who self-identify as Betsimisaraka eating significantly more wild meat than members of other ethnolinguistic groups), most Betsimisaraka had been born in the community in which they reside today. Furthermore, at the time of our survey, recently arrived households and long-term multi-generational households ate similar amounts of wildlife overall. This finding supports those of Golden and Comaroff (2015) and Reuter et al. (2016a,b) who found that immigration did not lead to increased hunting, and that taboos were not eroding. It also supports Garcia and Goodman's (2003) finding of differences in hunting rates of different ethnolinguistic groups. However, we found that while non-Sakalava did eat more wildlife, these individuals were born in these communities and were not immigrants.

An interesting deviation from hunting driven directly by food insecurity was the hunting of the endemic euplerid carnivoran, the fosa (*Cryptoprocta ferox*). Similar to findings in other regions, the hunting of fosa is primarily driven by human-wildlife conflict over poultry (e.g., Kotschwar-Logan et al. 2014, Borgerson 2016, Merson 2018), with fosa subsequently disliked by many rural households as a result (Merson 2018). Three percent of households reported eating 13 fosa in total during the prior year. Two-thirds of these fosa were caught opportunistically within a community's residential area, and not in nearby forests, when they approached or preyed upon community poultry. However, people hunted more fosa per household in Ankarafantsika than in southeastern, central, and northern Madagascar (Golden et al. 2014a, Borgerson et al. 2018a,b), but only half that of people on the Ma-

soala Peninsula. Fosa are found in Ankarafantsika at a density of 0.2 adults per square kilometer. Thus, the Ankarafantsika National Park may contain as many as ~ 270 adult fosa. Approximately 107,000 people live within or on the border of the Ankarafantsika National Park. Given our data on hunting in rural households, we suspect current hunting levels significantly exceed sustainable harvest. It is unclear from our data, whether the increased fosa hunting in the Ankarafantsika and Masoala regions reflects a higher density of fosa in these areas, or greater human-wildlife conflicts over livestock (as livestock ownership was higher in Ankarafantsika than many other areas we have surveyed (e.g., Golden et al. 2014, Borgerson et al. 2018a,b)).

Extreme poverty and biodiversity loss are intimately related and can result in biodiversity related poverty traps (cf. Barrett et al. 2011). Parks created in areas with poverty traps are capable of potentially improving the livelihoods of the poorest subset of the population. If managed well, parks can maintain essential ecosystem services that the poorest households rely most heavily on, including providing refugia for plants and animals that can be sustainably collected in their buffer zones, and support local communities through human-livelihoods initiatives, both reducing poverty and deforestation (Andam et al. 2001, Naughton-Treves et al. 2011, Ferrarro et al. 2011). In practice, however, this potential benefit is often not realized. Assessments of other protected areas in Madagascar have shown that a remote, food insecure, household has a 2% probability of receiving the benefits from a livelihoods program, whereas more accessible and food secure households in influential positions have an 85% chance of being in those same programs, even though they were less likely to be negatively impacted by the protected area or have used forest resources (Poudyal et al. 2016). The potential for a household to participate in livelihood programs is also influenced by their proximity to the center of a park's administrative activities, or their exposure to park staff. In Ankarafantsika, villages with a permanent Madagascar National Park agent are the most supportive of the park's conservation, with other villages within the park's boundary supportive but also divided, and villages on the park's boundaries least supportive, typically perceiving conservation as burden (Aymoz et al. 2013). This lack of equitable benefit sharing of livelihood programs in and around protected areas, could also explain the lack of effectiveness of many protected areas in Madagascar to reduce deforestation once other confounding factors have been accounted for (Elkund et al. 2016).

We found that both resource use and food insecurity were higher in households closest to, or within, the Ankarafantsika National Park. Remote households often rely on the ecological capital of subsistence crops, livestock, forests, wildlife and fisheries, many of which depend on intact forest systems (Ngonghala et al. 2016). Generally, in the face of deforestation less-remote households often have more economic capital to help shift to other sources of livelihood whereas rural households may simply spiral further into poverty. If efforts to improve human-livelihoods are focused in the communities closest to Ankarafantsika National Park, they are likely to have a greater effect on conservation targets.

CONCLUSIONS

People relied heavily on forest products in Ankarafantsika, including materials for shelter, ethnomedicines, and subsistence wild foods. In the face of high food insecurity, the majority of households inside and outside the park boundaries have cleared forests and fallow lands far from their homes to grow a sufficient quantity of staple crops to feed themselves, and have hunted wild animals to add essential fats and micronutrients to their diets. Conservation managers can decrease unsustainable hunting in Ankarafantsika National Park by removing the barriers to achieving food security by developing alternatives to eating wild meats and expanding agricultural fields. Efforts to improve overall food security, while reducing human-wildlife conflict over poultry, would likely improve both human welfare and the long-term conservation of the threatened wildlife and habitat of Ankarafantsika. Additional locally-specific research is needed on what local barriers prevent people from accessing preferred, high quality, and affordable food and housing in sufficient supply throughout the year. It is our hope that our findings help both conservation and community livelihood programs find integrated solutions to the shared challenges of improving the well-being of human populations and the protection of Madagascar's unique, endemic, and highly threatened biodiversity.

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SUPPLEMENTARY MATERIAL

Table S1. The variation in the mean number of forest wildlife eaten by households during the prior year between communities surveyed within Ankarafantsika (2014-2015).

Table S2. Differences in the amount of wildlife consumed during the prior year (2014–2015) within Ankarafantsika by ethnolinguistic cultural group. (Minority ethnolinguistic groups with fewer than twenty-five households surveyed in our study population are not represented in this table)

Borgerson, C., Randrianasolo, J. F., Andraina, T. R., Anjaranirina, E. J. G., Randriamady, H. J., Merson, S., Dollar, L., Golden, C. D. 2019. Wildlife hunting in complex human-environmental systems: How understanding natural resource use and human welfare can improve conservation in the Ankarafantsika National Park, Madagascar. Madagascar Conservation & Development 14, 1: 37–45. http://dx.doi.org/10.4314/mcd.v14i1.7 Supplementary material

Table S1. The variation in the mean number of forest wildlife eaten by households during the prior year between communities surveyed within Ankarafantsika (2014–2015).

Village	Tenrecs	Bats	Euplerids	Lemurs	Reptiles	Non- native Carnivorans	Bushpigs	All Forest Wildlife	Ate any Forest Animal (% households)
A	0.86 ± 1.36	0.06 ± 0.37	0.00 ± 0.00	0.10 ± 0.56	0.34 ± 0.19	0.14 ± 0.52	1.28 ± 1.28	2.48 ± 1.99	82.80%
B	0.60 ± 0.74	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.56	0.00 ± 0.00	0.20 ± 0.41	0.53 ± 0.53	1.53 ± 1.19	73.30%
C	1.40 ± 2.26	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.77	0.00 ± 0.00	0.20 ± 0.56	0.80 ± 0.80	2.60 ± 2.72	80.00%
D	1.40 ± 1.50	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.52	0.07 ± 0.26	0.27 ± 0.59	0.87 ± 0.87	2.73 ± 2.82	80.00%
E	0.83 ± 0.99	0.27 ± 0.58	0.03 ± 0.18	0.13 ± 0.35	0.33 ± 0.76	1.13 ± 1.28	1.10 ± 1.10	3.83 ± 2.67	96.70%
F	1.00 ± 1.56	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.77	0.00 ± 0.00	0.07 ± 0.26	0.40 ± 0.40	1.67 ± 2.09	60.00%
G	0.53 ± 0.99	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0.47 ± 0.47	1.07 ± 1.49	40.00%
H	0.40 ±1.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.40	0.20 ± 0.50	1.24 ± 1.24	1.92 ± 1.68	72.00%
I	5.38 ± 5.05	0.08 ± 0.27	0.15 ± 0.37	0.54 ± 0.76	0.00 ± 0.00	1.31 ± 1.38	1.35 ± 1.35	8.81 ± 6.62	100.00%
J	1.43 ± 2.62	0.07 ± 0.25	0.07 ± 0.25	0.07 ± 0.37	0.13 ± 0.43	0.23 ± 0.43	0.57 ± 0.57	2.57 ± 3.30	63.30%
K	1.93 ± 3.39	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.13 ± 0.52	0.07 ± 0.26	0.73 ± 0.73	2.93 ± 3.95	66.70%
L	1.30 ± 1.95	0.33 ± 0.84	0.03 ± 0.18	0.03 ± 0.18	0.17 ± 0.38	0.20 ± 0.55	0.53 ± 0.53	2.60 ± 2.36	83.30%
M	5.50 ± 6.46	0.20 ± 0.48	0.07 ± 0.37	0.27 ± 0.83	0.03 ± 0.18	1.57 ± 1.41	1.57 ± 1.57	9.20 ± 9.20	96.70%
N	0.47 ± 0.73	0.60 ± 1.16	0.00 ± 0.00	0.40 ± 0.97	0.10 ± 0.31	0.30 ± 0.84	0.23 ± 0.23	2.10 ± 2.16	76.70%
O	0.35 ± 0.88	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.70 ± 0.70	1.05 ± 1.36	50.00%
P	2.73 ± 2.08	0.13 ± 0.35	0.10 ± 0.31	0.47 ± 1.11	0.10 ± 0.31	0.53 ± 0.73	1.57 ± 1.57	5.63 ± 3.80	96.70%
Q	0.60 ± 1.27	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.70 ± 0.70	1.30 ± 1.92	40.00%
R	0.90 ± 1.21	0.45 ± 0.91	0.00 ± 0.00	0.21 ± 0.56	0.21 ± 0.42	0.24 ± 0.58	0.17 ± 0.17	2.17 ± 1.71	69.00%

Table S2. The variation in the mean number of forest wildlife eaten by households during the prior year between communities surveyed within Ankarafantsika (2014–2015).

	Betsileo	Sakalava	Tsimihety	Antandroy	Betsimisaraka	Betsirebaka	Merina
Households surveyed total N (% of total)	89 (21.2%)	77 (18.4%)	55 (13.1%)	45 (10.7%)	43 (10.3%)	34 (8.1%)	30 (7.2%)
Percentage born in Community	31.80%	79.00%	27.30%	22.20%	44.20%	35.30%	53.30%
Median years lived there (if not born there)	10	6	11	10	16	11	10
Median N forest animals	2	2	2	2	4	2	2