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Forest foods and healthy diets: quantifying the contributions

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SUMMARY

Forested landscapes provide a source of micronutrient rich food for millions of people around the world. A growing evidence base suggests these foods may be of great importance to the dietary quality of people living in close proximity to forests – especially in communities with poor access to markets. Despite widespread evidence of the consumption of forest foods around the world, to date, few studies have attempted to quantify the nutritional contributions these foods make. In this study we tested the hypothesis that the consumption of forest foods can make important contributions to dietary quality. We investigated the dietary contributions of wild forest foods in smallholder dominated forested landscapes from 37 sites in 24 tropical countries, using data from the Poverty and Environment Network (PEN). We compared quantities of forest foods consumed by households with dietary recommendations and national average consumption patterns. In addition, we compared the relative importance of forests and smallholder agriculture in supplying fruits, vegetables, meat and fish for household consumption. More than half of the households in our sample collected forest foods for their own consumption, though consumption patterns were skewed towards low-quantity users. For high-quantity consuming households, however, forest foods made a substantial contributions to their diets. The top quartile of forest food users in each site obtained 14.8% of the recommended amounts of fruits and vegetables, and 106% of the reference quantity of meat and fish from forests. In 13 sites, the proportion of meat and fish coming from forests was greater than from domestic livestock and aquaculture, while in 11 sites, households procured a greater proportion of fruits and vegetables from forests than from agriculture. Given high levels of heterogeneity in forest food consumption, we identify four forest food use site typologies to characterize the different use patterns: 'forest food dependent', 'limited forest food use', 'forest food supplementation' and 'specialist forest food consumer' sites. Our results suggest that while forest foods do not universally contribute significantly to diets, in some sites where large quantities of forest foods are consumed, their contribution towards dietary adequacy is substantial.

Keywords: animal source foods, bushmeat, diets, forests, fruits, micronutrients, nutrition, vegetables, wild foods

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INTRODUCTION

Ensuring adequate nutrition is a global public health concern (Ezzati *et al.* 2002; Lopez *et al.* 2006; Beaglehole *et al.* 2011). Poor nutrition is the single largest risk factor for increased susceptibility to infectious diseases, and is a major risk factor for a wide range of non-communicable diseases (Ezzati *et al.* 2002; Lopez *et al.* 2006). Undernutrition in children under 5 years of age is the cause of 3.1 million deaths a year – equivalent to around 45% of all child deaths (Black *et al.* 2013).

Poor quality diets, lacking in diversity and micronutrients (Black *et al.* 2013), are a major cause of malnutrition. While fewer than one billion people do not have access to sufficient calories, an estimated two billion people suffer from one or more micronutrient deficiencies (FAO 2012; Muthayya 2013). Despite this, food security and agricultural policies have overwhelmingly focused on increasing the production of staple crops (Burchi *et al.* 2011; Declerck *et al.* 2011; Pinstrupp-Anderson 2013). The historical emphasis on tackling hunger has arguably come at the expense of creating agricultural systems capable of producing a diverse range of micronutrient-rich foods. The result has been a dramatic homogenization of the global agricultural system (Khoury *et al.* 2014). Just 12 crops and 14 animal species make up 98% of agricultural food supply while just three crops – wheat, maize and rice – supply over half of global calories (Prescott-Allen & Prescott Allen 1990; Frison *et al.* 2011; Sunderland 2011). While agricultural policies focusing on staple crop yields have helped reduce the prevalence of hunger, more attention must be paid to dietary quality.

In the context of widespread micronutrient deficiencies and an increasingly homogenized global food system the role that wild foods (i.e., uncultivated foods collected/hunted from the natural environment) may play in diversifying people's diets is gaining increasing attention. Wild foods can be obtained from forests and other areas of natural diversity or from agricultural land or around the home (Bharucha & Pretty 2010). The consumption of wild foods appears to be common across the world (Scoones *et al.* 1992; Grivetti & Ogle 2000; Bharucha & Pretty 2010) and in certain contexts may provide a significant proportion of fruits, vegetables and animal source foods (Powell *et al.* 2015).

Wild forest foods (hereafter referred to as forest foods) are a subset of wild foods and refer to uncultivated foods from forested areas (i.e., not including forest based agriculture, e.g., shifting cultivation or agroforestry systems). Many forest foods such as bushmeat, fish, fruits, leafy vegetables, nuts and seeds tend to be high in micronutrients (Vinceti *et al.* 2008; Arnold *et al.* 2011). As a result, they may be important for the dietary quality of people living in proximity to forests (Blaney *et al.* 2009; Golden *et al.* 2011). Although few studies have quantified this contribution, recent evidence suggests that tree cover is positively associated with dietary diversity in Malawi (Johnson *et al.* 2013) and in many other sub-Saharan African countries (Ickowitz *et al.* 2014). While such studies suggest a link between forests and dietary quality, it is unclear whether such associations are due to forest-based agriculture, social–cultural and economic factors or the consumption of forest foods. Only a handful of studies have been conducted that directly quantify the consumption of forest foods (Powell *et al.* 2015; Rowland *et al.* 2015). These studies originate from case studies of single communities in different locations, ecological, social and cultural contexts, use different methodologies and have mixed results (Blaney *et al.* 2009; Golden *et al.* 2011; Termote *et al.* 2012; Powell *et al.* 2013).

We tested the hypothesis that the consumption of forest foods can make important contributions to dietary quality in a wide range of sites across the tropics. Drawing on data collected using a standardized methodology in 58 forest-adjacent communities in 24 countries across the tropics, we estimated the contributions that micronutrient-rich forest foods make to meeting individual dietary recommendations, compared quantities of forest foods consumed with national averages, and compared the relative contributions of forest foods to that of smallholder agriculture. To our knowledge this is the first study to use standardized survey methods across many different sites to quantify the consumption of forest foods. Our study can best be seen as a multi-site case study approach and is not an attempt to make broad generalization across countries, regions or all forest communities. We focused specifically on nutritionally important food groups: fruits, vegetables and animal source foods, as these food groups are known to be among the most important for micronutrient intake.

METHODS

About the data

We used data from the Poverty and Environment Network (PEN), a collaborative research project led by the Centre for International Forestry Research (CIFOR) (CIFOR 2016). The PEN project was designed to investigate the relative contributions of agricultural, forest and non-forest environmental income and contains data collected on the quantities of forest products (including foods) used by households. The PEN surveyed forest and wild non-forest resource use and income from 8313 households in 333 villages living in, or adjacent to, forested landscapes in 58 sites across 25 tropical countries. Surveys were conducted in one 12 month period per site between the years 2004–2010. Research sites were selected to represent 'smallholder-dominated rural landscapes in which households have at least some degree of access to forest resources' (Wunder *et al.* 2014). In some countries, the sample size of households in each site surveyed was extremely low (especially of forest food using households). In addition, not all food use data could be successfully converted into quantities (see data cleaning and limitations). Thus, where fewer than 10 households in a site collected forest foods, the sites were merged within countries. A total of 37 sites were therefore used (Fig. 1; please note some sites are merged).

The PEN collected village and household information on demographics, resource use, forest institutions and background economic context. In addition, a quarterly household survey was conducted covering direct and indirect income from agriculture, forest and non-forest ('wild' sources other than forest) sources. The latter household survey included a one-month recall of the quantity and value of all forest products collected, a one-month recall of wild non-forest products collected and a three-month recall of agricultural crops, livestock and aquaculture production. The quantity of these outputs collected by the household and the proportion sold were included along with their local market price.

Data cleaning and limitations

Analysis of the dietary contributions of forest foods required data on the quantity of forest foods consumed in kilograms adjusted for household size and composition. As income was the primary outcome of interest to the PEN project, many food products were recorded in local units. We converted local units into kilograms, where possible, using conversion tables provided by PEN partners. However, some of the data were in units that were not convertible in this fashion. In these cases, data were converted using price per unit data where available, or through estimates of volumes and conversions, made in consultation with PEN partners, or by using secondary sources. As data were collected at the household level it was necessary to standardize consumption data across households of different sizes and compositions. Intakes were weighted according to age and sex, relative to

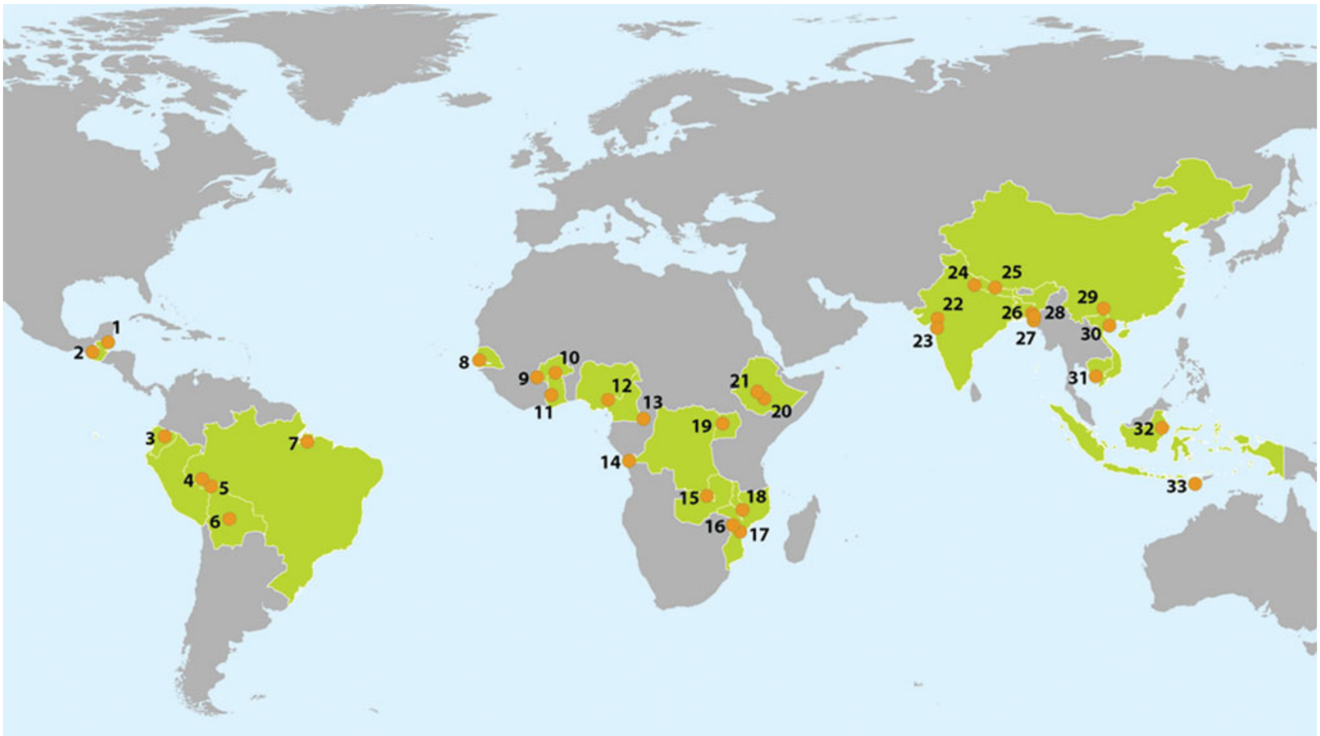

Figure 1 PEN site names and locations. Bangladesh 1 (Rangamati & Banderban Districts); Bangladesh 2 (Khagrachari District); Bangladesh 3 (Bandarban & Rangamati District); Belize 2; Brazil 1 (Municipalities of Abaetetuba & Limoeiro do Anjuru); Brazil 2 (Acre State 1); Brazil 3 (Acre State 2); Burkina Faso 1 (Banfora, Comoe Province); Burkina Faso 2 (Nobere, Zoundweogo Province); Cambodia; Cameroon (Department of Boumba-et-Ngoko); China (N.W. Guangxi Province); DRC (Bas-Fleuve District, Bas-Congo Province); Ecuador (Sumaco Bioshpere Reserve in Western Napo Province); Ethiopia 1 (Arsi Negele District 1); Ethiopia 2 (Arsi Negele District 1); Ghana 1 (wet site (Tarkwa Nsuaem & Prestea-Huni Valley); Ghana 2 (Districts of Ofinso, Techiman & Nkoranza); Guatemala (Western Highlands); India 1 (Gujarat state 1); India 2 (Gujarat State 2); Indonesia 1 (E. Kalimantan Province); Indonesia 2 (Kupang District, Nusa Tenggara Timor); Malawi (Kasungu & Machinga Districts); Mozambique 1 (Central Manica Province); Mozambique 2 (Central West Sofala Province); Nepal 1 (Mustang District); Nepal 2 (Gorkha District); Nigeria (Cross River State); Peru (Madre de Dios Province); Senegal (Fatick Region); Uganda (Masindi & Buliisa District); Vietnam (Cat Ba Island); Zambia (Mufulira & Kabombo Districts).

one adult female using calorie requirements from the World Health Organization to obtain the number of adult equivalents per household (Claro *et al.* 2010). Amount of food consumed (in grams) by the entire household divided by the number of adult equivalents in the household was used to generate consumption quantities relative to one adult female individual.

The PEN project mainly recorded quantities of resources in their unprocessed form (e.g., animal carcasses, whole fruits etc). We did not convert quantities of unprocessed foods into the proportion of edible foods due to lack of local information allowing for this process. The quarterly survey covered a one-month recall period at four points during one year so the annual quantity of foods used by households was generated by multiplying the sum of this quantity by three. Based upon the distribution of the data, outliers greater than two standard deviations from the mean (excluding zero values) were excluded. Outliers may be attributed to measurement errors, or seasonal collection of foods, which if captured in the four single-month recall periods, could be overestimated by our extrapolation. However, quarterly surveys reduce the risk that seasonal consumption of forest foods is overlooked entirely. Quantities of forest foods collected are subdivided in the PEN data set into the quantities used by the household and the quantities sold. The dataset does not include food products gifted or bartered with other households, nor does it contain information about the consumption of purchased foods. As individual food consumption is not recorded, we make the assumption that food collected for a household's own use was consumed by household members only.

Despite the above data cleaning and assumptions potentially leading to overestimation of quantities of forest foods consumed, overall we believe our data to be conservative estimates of forest food consumption. The well-acknowledged problem of recall bias of data collected using a one-month recall period is likely to underestimate quantities of foods consumed – especially infrequently consumed foods (Rustihauser 2005) – and non-capture of seasonal foods is also likely to have occurred. In addition opportunistic collection and consumption of forest foods is unlikely to be recorded. Hunting events are likely to be more memorable to respondents than opportunistic collection of fruits and vegetables. This tendency is to be even further exaggerated since respondents were mostly male heads of households who engage in hunting while in most cultures, women and children tend to be the primary collectors of fruits and vegetables. Even though hunting is more likely to be recalled, in some countries it is either restricted or illegal, making it less likely to be openly reported if respondents are not completely confident in the confidentiality or purpose of the survey. Thus it is likely that both the collection of plant foods and bushmeat are under-reported.

After converting data to kilograms, the resulting dataset included 95.66% of forest foods, 92.94% of wild non-forest food and 98.48% of agricultural food from the original data set. Data from one country (Pakistan) was dropped entirely from the study due to a very small sample size remaining after conversions had been conducted. The final data set analysed for this paper thus consisted of 7569 households across 24 countries.

Analysis

We focused our analysis on household consumption of forest fruits, vegetables and animal source foods (including meat and fish) using definitions of food groups provided by the World Health Organization (Agudo 2005). Vegetables included leaves, mushrooms and legumes but excluded roots and tubers (which are classified as staples). These food groups were selected because of their nutritional importance and under-consumption in many low-income countries (Hall *et al.* 2009).

Comparison of forest foods and agricultural foods

We compared the quantities of nutritionally important food groups originating from agricultural land and forests. The total quantity of forest fruits, vegetables, meat and fish was compared with the quantity of foods produced from smallholder agriculture. The proportion of foods coming from forest was calculated by dividing the quantity of forest foods by the quantity of foods coming from forests and agriculture.

$$\frac{Quanity\ forest\ foods\ (kg)}{Quantity\ forest\ foods\ (kg)\ +\ quantity\ agricultural\ foods\ (kg)}$$

Comparisons with dietary guidelines

We compared per capita consumption of fruits and vegetables with international dietary recommendations and the meat and fish consumption with a reference quantity derived from a well-known randomised control trial. Quantities of forest fruits and vegetables consumed are compared with the upper bound (500 g) of the WHO recommendation of 400–500 g of fruits and vegetables per capita per day (WHO/FAO 2002). There are no internationally recognized guidelines concerning the optimum or minimum quantity of meat consumption. The World Cancer Research Fund recommends a maximum of 500 g of meat per week (WCRF 2007) – a recommendation referring mainly to red meat and not including fish. This recommendation is mainly targeted at people in high-income countries where the main dietary problem is over-nutrition. In low- and middle-income countries where micronutrient deficiencies are highly prevalent, animal source foods are considered amongst the most important food groups for prevention (Murphy & Allen 2003). Although there is no international standard for minimum animal source food consumption, some context can be given through comparisons with data from randomized controlled interventions. We use a reference quantity based on a well-known randomized control intervention in Kenyan schools that found that diets supplemented with 425 g of meat per week (22.1 kg per year) resulted in improved child nutritional status, growth and cognitive development compared to a control group given an equal amount of plant sourced protein (Neumann *et al.* 2007).

Comparison with national and sub-regional consumption

Worldwide, populations in very few countries consume sufficient quantities of fruits and vegetables (Ruel *et al.* 2005; Hall *et al.* 2009). Average consumption quantities of animal source foods is considered excessive in many middle- and high-income countries whilst many low-income countries consume on average very low quanities. We compared the quantities of forest foods consumed with national and sub-regional estimates obtained from secondary sources. Data on average consumption of fruits and vegetables was taken from the World Health Organization Global Burden of Disease 2000 study (Pomerleau *et al.* 2004), which provides estimates of consumption of fruits and vegetables derived from national population survey data and food supply statistics, stratified by sub-region based upon geographical and epidemiological criteria. We also compared the consumption of meat and fish from forest sources with national average per capita consumption figures from the FAO (Speedy 2003). Yearly quantities of fruits and vegetables and animal source foods from forests were calculated as a percentage of national/sub-regional average consumption levels.

RESULTS

Table 1 presents the median quantity of forest foods consumed by all households as well as by those who consumed at least one forest food in the past year. It also shows the median quantity of forest foods consumed by the top quartile of forest food consumers in each site. Overall, 53.5% of households in the dataset consumed one or more forest food, but the median quantity of food consumed was relatively low. Across all sites, the median forest food users consumed 10.4 kg of forest foods per year, while the top quartile of forest food user consumed a median quantity of 38.8 kg per adult equivalent per year.

There is significant variation in both the prevalence of forest food consumption (participation) and quantities of forest foods consumed between and within sites. In three sites there are no consumption of fruits, vegetables, meat or fish collected from forests by households for their own consumption (Ecuador, Indonesia 2, Vietnam). Amongst the remaining 34 sites used in the analysis, participation in the collection of forest foods is generally high, with over half the sampled households having consumed at least

Table 1 Percentage of households consuming forest foods and average quantities of forest foods consumed (kg) by all households, forest food consuming households and top quartile of forest food consumers by site. HH = Household.

Site name	*Number of households*	*Percentage of HHs who are forest food users*	*Median quantity (kg) of forest foods consumed by all HHs*	*Median quantity (kg) of forest foods consumed by forest food consuming HHs*	*Median quantity (kg) of forest foods consumed by top quartile forest food consuming HHs*
Bangladesh 1	280	70.0	4.00	6.15	126
Bangladesh 2	138	49.0	0.00	182	239
Bangladesh 3	81	91.6	88.4	121	207
Belize	141	75.0	33.4	98.6	208
Bolivia 1	47	72.0	5.94	18.4	60.4
Bolivia 2	111	93.8	38.5	52.1	182
Bolivia 3	73	84.7	42.5	52.9	164
Brazil 1	81	96.5	153	185	233
Brazil 2	452	94.8	57.9	77.1	167
Brazil 3	124	58.2	0.00	15.5	120
Burkina Faso 1	110	40.6	0.00	30.3	69.6
Burkina Faso 2	305	18.0	0.00	7.21	26.3
Cambodia	122	63.0	1.80	7.28	48.3
Cameroon	74	100	68.1	68.1	156
China	180	22.9	0.00	158	228
DRC	207	24.2	0.00	2.35	6.83
Ecuador	198	0.00	0.00	0.00	0.00
Ethiopia 1	229	5.68	0.00	1.92	5.36
Ethiopia 2	304	68.8	4.66	9.38	35.5
Ghana 1	186	41.3	0.00	4.05	30.2
Ghana 2	70	39.5	0.00	6.78	25.1
Guatemala	239	22.1	0.00	3.60	13.2
India 1	574	23.4	0.00	28.3	47.8
India 2	303	1.6	0.00	7.59	9.69
Indonesia 1	60	26.4	0.00	65.4	159
Indonesia 2	117	0.00	0.00	0.00	0.00
Malawi	139	79.6	3.07	4.53	18.5
Mozambique 1	22	61.7	0.67	67.6	193
Mozambique 2	298	92.3	21.9	25.0	76.8
Nepal 1	299	100	7.01	7.01	18.7
Nepal 2	190	59.7	0.96	3.62	9.68
Nigeria	349	57.7	0.60	3.81	58.4
Peru	261	60.0	0.00	34.0	167
Senegal	521	77.9	2.73	4.05	24.3
Uganda	405	66.6	2.20	5.85	21.5
Vietnam	139	0.00	0.00	0.00	0.00
Zambia	196	80.5	4.26	16.4	66.9

one forest food in 22 sites, participation over 75% in 11 sites and universal in two sites. The two sites with 100% participation in forest food consumption reveal two different patterns of forest food use. In the Nepal 1 site, the median yearly quantity of forest foods consumed was only 7 kg per adult equivalent per year with the top quartile consuming 18.7 kg. This suggests that in this site, while forest food consumption is widespread, it is infrequent and typified by relatively low-level extraction. By contrast, the Cameroon site showed widespread, high-level forest food consumption with an average quantity of 68.1 kg per adult equivalent per year and with the top quartile consuming 158 kg per adult equivalent per year.

We created four forest food typologies, based upon the relative levels of participation in forest food consumption (prevalence), the average quantity of forest foods consumed, and the quantity of forest foods consumed by the top quartile of forest food users (Table 2). Half the sites could either be classified as 'limited forest food users', where a small proportion of the households consumed small quantities of forest foods (India 2, Ethiopia 1, Burkina Faso 2, Guatemala, Democratic Republic of Congo (DRC), Ghana 1, Ghana 2, Nigeria and Nepal 2) or 'forest food dependent' sites where a high proportion of households consumed forest foods in significant quantities (Bangladesh, Belize, Brazil 1, Brazil 2, Bolivia 2, Bolivia 3, Cameroon, Mozambique, Zambia). Widespread

Table 2 Site level forest food consumption typologies.

Site typology	*Description*	*Example sites*
Forest food dependent	Widespread, high level forest food consumption	Bangladesh, Belize, Brazil 1, Brazil 2, Bolivia 2, Bolivia 3, Cameroon, Mozambique, Zambia
Limited forest food use	Low–medium prevalence of forest food use in low quantities	India 2, Ethiopia 1, Burkina Faso 2, Guatemala, DRC, Ghana 1, Ghana 2, Nigeria, Nepal 2
Forest food supplementation	Widespread, low level consumption	Bolivia 1, Cambodia, Ethiopia 2, Malawi, Nepal 1, Senegal, Uganda
Specialist forest food consumers	Low–medium level prevalence with low–medium average consumption levels, combined with a small subset of households engaged in high level forest food consumption	Bangladesh 1, Brazil 3, India 1, Indonesia 1

but low level consumption ('forest food supplementation') was found in seven sites (Bolivia 1, Cambodia, Ethiopia 2, Malawi, Nepal 1, Senegal, Uganda). In addition, we found sites where low–medium levels of consumption are the norm, with a small proportion of households consuming high quantities of forest foods (Bangladesh 1, Brazil 3, India 1, Indonesia 1). The latter is exemplified by the Indonesia 1 site, where only around one quarter of households consumed any forest food products, but the top quartile consumed in excess of 150 kg of forest foods a year.

Comparison of forest foods and agriculturally produced foods

All communities surveyed in the PEN consist predominantly of smallholder agriculturalists. The nutritional contribution of forest foods must therefore be placed within the context of an agricultural landscape. To estimate the contribution of forest foods compared to agriculture we calculated the proportion of fruits and vegetables consumed originating from forests, relative to agriculture (Figures 2 and 3). Across all sites, forests contributed around 14% of the total supply of forest and agricultural fruits and vegetables. Variation between sites is extremely high ranging from zero to 96% of fruits and vegetables sourced from forest and zero to 92% of meat and fish coming from forest. Where the proportion from forests is zero (e.g., Vietnam) all non-purchased foods consumed were from agricultural sources. In 11 sites, fruit and vegetable producing households procured a greater proportion from forests than from agriculture. In 13 sites, the proportion of meat and fish coming from forest was greater than from domestic livestock and aquaculture. In some cases where the proportion of fruits and vegetables from forests is high, for example in the Guatemala 1 site, the average quantity of forest fruits and vegetables is still low, yet the proportion is high because agricultural foods were overwhelmingly focused on the production of staple crops. Likewise, in the Bangladesh 2 site, meat and fish producing agriculture (i.e., livestock and aquaculture) contributes very little to the overall supply of meat and fish and therefore despite relatively low quantities coming from forests, the contribution of forests appears to be very high compared to agriculture. Although we have no data on the availability and consumption of fruits, vegetables, meat and fish from other sources, forests are clearly important in terms of the overall supply of animal source foods in many of the sites.

Fruits and vegetables

To determine whether forest fruits and vegetables contribute to dietary quality it is necessary to determine whether the quantities of forest foods consumed are sufficient to make an impact on nutrition. We calculated the quantities of forest fruits and vegetables consumed relative to international dietary intake guidelines. The data are skewed towards low-level consumption, and the average forest fruits or vegetables user obtained just 3.7% of their recommended intake of fruits and vegetables from the forest, as many forest fruits and vegetables consuming households consumed only one or two items per year. For these households, the quantities consumed are too small to affect dietary quality. We focused on households for whom the collection of forest foods is a regular part of their livelihood strategy and examined the top quartile of forest food users in each site and compared the quantity of forest foods consumed with dietary guidelines (Table 3).

Variation between sites is extremely high, with very large quantities of fruits and vegetables being consumed in some sites, such as Brazil 1 and Cameroon, while in several sites, including the Ecuador, Vietnam and Indonesia 2 sites, no forest fruits and vegetables were consumed. In one site (Brazil 1), households in the top quartile of forest fruit and vegetable users consume more than the minimum dietary recommendation of fruits and vegetables from forests, while in Peru and Cameroon sites, the top quartile consume over half their minimum dietary recommendation from forests. In addition, in nine other sites the top quartile of forest fruit and vegetable users consumed more than 20% of the minimum dietary recommendation from forests (Bolivia 1, Bolivia 2, Bolivia 3, Burkina Faso 1, China, Ethiopia 2, India 1, Mozambique 2, Zambia). Considering that individuals in almost all countries fail to meet the recommendations for fruit and vegetable intake (Ruel *et al.*, 2005; Hall *et al.* 2009), this represents a likely sizable contribution in some sites and contexts.

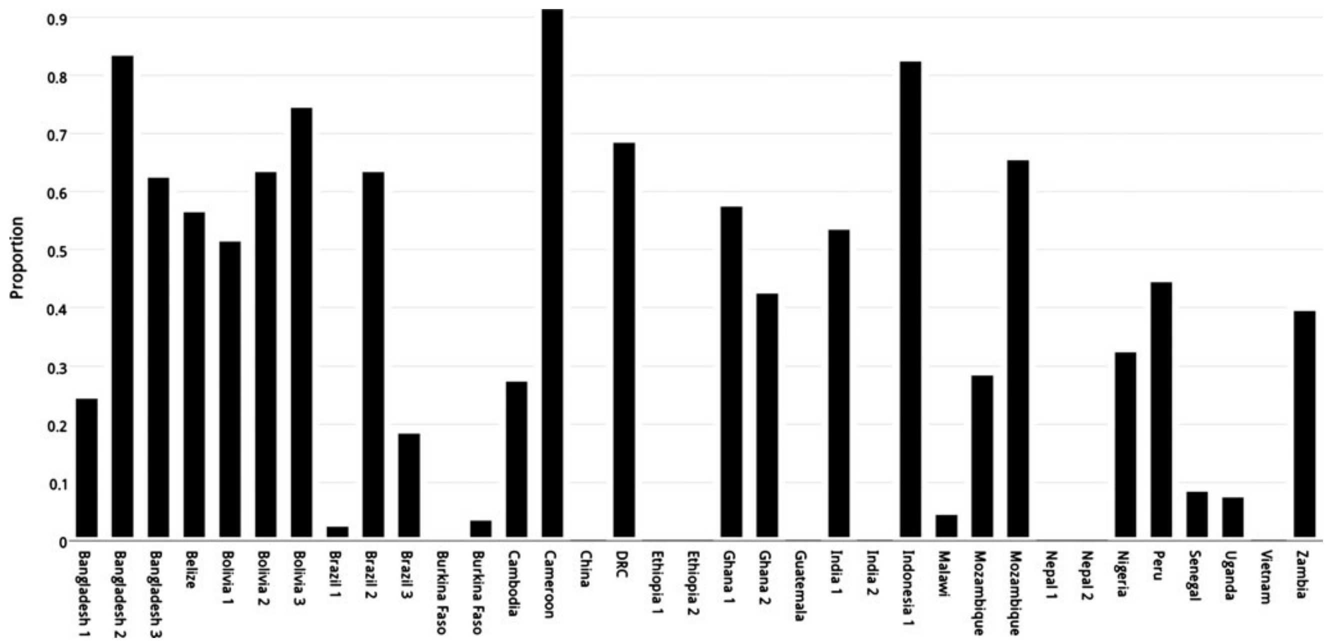

Figure 2 Proportion of agriculturally produced and wild forest meat and fish that come from forests. A proportion of 1 indicates 100% of meat and fish comes from forest, a proportion of 0 indicates all meat and fish comes from agricultural production.

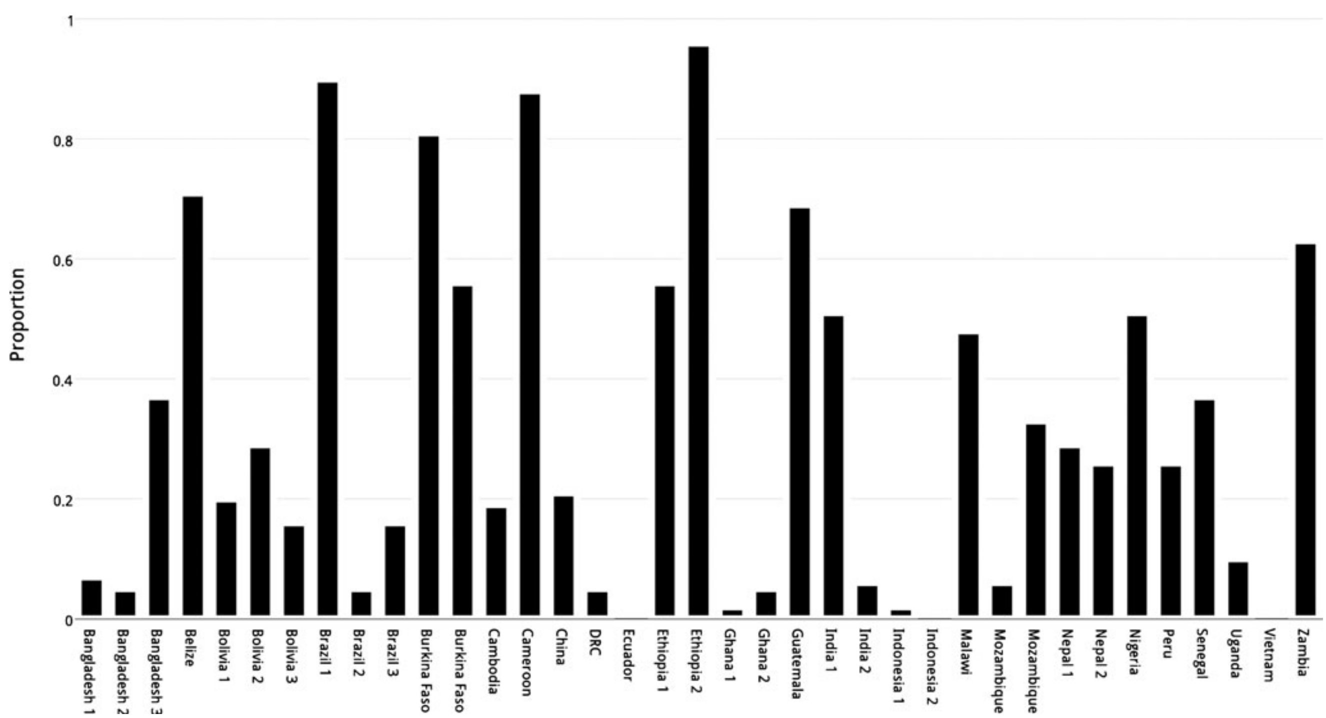

Figure 3 Proportion of agriculturally produced and wild forest fruits and vegetables that come from forests. A proportion of 1 indicates 100% of fruits and vegetables come from forest, a proportion of 0 indicates all fruits and vegetables come from agricultural production.

To understand the quantities of forest fruits and vegetables being consumed within the context of average diets in the respective countries, we compared the figures with sub-regional average intake figures from the World Health Organization. In one site (Brazil 1), the average forest fruits and vegetables user consumed more than her/his average national counterpart, and the top quartile of users consumed more than twice the average national quantity of fruits and vegetables. The only other site in which the top quartile of fruit and vegetable consumers obtained more than the national average from forests was in Cameroon. In four other sites (Bolivia 2, Burkina Faso 1, Peru, Zambia), the top quartile

Table 3 Percentage of minimum dietary recommendation and percentage of sub-regional average intake of fruit and vegetable consumption consumed by households who consumed at least one forest fruit or vegetable during the recall period (columns 1 and 2) and the top quartile of forest fruit and vegetable users in each site (columns 3 and 4).

Site name	*Forest fruits and vegetables consuming households*		*Top quartile of forest fruits and vegetables consuming households*	
	Percentage of minimum recommended intake	*Percentage of average sub-regional intake*	*Percentage of minimum recommended intake*	*Percentage of average sub-regional intake*
Bangladesh 1	3.18	5.55	5.43	9.49
Bangladesh 2	1.21	2.11	3.68	6.43
Bangladesh 3	1.70	2.98	4.51	7.87
Belize	1.03	1.88	11.0	20.2
Bolivia 1	6.18	7.44	20.2	24.4
Bolivia 2	5.90	7.11	42.3	51.0
Bolivia 3	7.99	9.62	28.7	34.6
Brazil 1	126	231	156	286
Brazil 2	3.67	6.74	5.55	10.2
Brazil 3	6.27	11.5	19.4	35.6
Burkina Faso 1	18.5	20.9	45.4	51.5
Burkina Faso 2	4.94	5.59	16.4	18.6
Cambodia	2.12	2.54	9.43	11.3
Cameroon	39.3	44.5	89.4	101
China	15.6	18.7	35.8	42.9
DRC	1.07	1.82	2.69	4.56
Ecuador	–	–	–	–
Ethiopia 1	0.80	1.35	1.51	2.57
Ethiopia 2	6.42	10.9	24.0	40.8
Ghana 1	0.37	0.42	1.64	1.86
Ghana 2	0.15	0.17	3.63	4.12
Guatemala	2.47	2.97	9.02	10.9
India 1	13.9	24.4	23.6	41.2
India 2	3.43	5.99	4.98	8.69
Indonesia 1	1.98	4.07	4.76	9.77
Indonesia 2	–	–	–	–
Malawi	3.08	5.22	12.0	20.4
Mozambique 1	1.52	2.58	6.33	10.7
Mozambique 2	9.54	10.8	27.2	30.8
Nepal 1	4.47	7.81	10.5	18.4
Nepal 2	1.21	2.12	3.36	5.87
Nigeria	1.91	2.17	11.9	13.5
Peru	19.8	23.8	69.9	84.3
Senegal	2.43	2.75	13.8	15.6
Uganda	3.77	6.39	14.3	24.3
Vietnam	–	–	–	–
Zambia	11.7	19.8	46.6	79.1
Total	3.71	5.61	14.8	21.6

of forest fruit and vegetable users consumed over half of the national average from forest sources. The households who consumed the most forest foods, consumed greater quantities of fruits and vegetables than their national counterparts and thus are likely to have diets higher in micronutrient-rich foods.

Meat and fish

There are no internationally accepted dietary guidelines for the optimal intake of animal source foods. On the one hand, increased consumption and expenditure on animal source foods has been shown to be correlated with improved nutritional status (Neumann *et al.* 2002; Sari *et al.* 2010; Dror & Allen 2011) and intervention studies have demonstrated remarkable effects of meat supplementation. On the other hand, people in many countries consume, on average, too much meat which is associated with increased risk of a variety of non-communicable diseases including cancers (Wagner & Brath 2012). Confusingly, different sources of dietary advice use different definitions. For instance, the World Cancer Research Fund recommends a maximum of 500 g of red meat per week and no processed meat (WCRF 2007), whilst the UK Department of Health recommends that people consuming over 630 g per week of red and processed meat cut down to around 490 g (NHS 2013). Meanwhile the USDA recommends an adult male consume no more than 737 g of meat, poultry and eggs (USDA 2010).

Our study examined relatively low-income communities living in forested landscapes in tropical countries where lack of adequate micronutrients is a greater concern than over-nutrition. We therefore focused on the benefits that meat and fish make to diets that may be lacking other sources of micronutrients. In the absence of optimum or minimum guidelines, we used a reference quantity of 425 g per capita per week (for reasons discussed above). The quantities of meat and fish consumed from forest sources was calculated as a percentage of this reference quantity. Table 4 shows the percentage of this reference quantity for all households consuming at least one forest meat and fish item (Table 4, Column 2) and for the top quartile of forest meat and fish consuming households (Table 4, Column 6). Overall forest meat and fish consumers obtained around one quarter (24.8%) of the reference quantity from forests, whilst the top quartile of forest meat and fish users consumed on average more than the reference quantity (106%). Quantities of forest meat and fish consumed range from zero in the Indonesia 2, Vietnam, Nepal and Ecuador sites to 54.2 kg per year in the India 1 site.

We compared dietary intake of forest meat and fish with average national consumption figures. The percentage of the national average intake of meat and fish and meat and fish that come from forest foods for forest food using households and the top quartile of users are shown in Columns 3 and 5 (Table 4). Forest meat and fish consumers consumed on average less than one fifth (18.1%) of the national average from forests and the top quartile of forest meat and fish consumers in each site consumed on average 72.5% of their respective national average intake. In nine sites, the top quartile of forest meat and fish consumers consumed more than the national average solely from forest sources (Bolivia 2, Bolivia 3, Brazil 2, Brazil 3, Ghana 1, India 1, Indonesia 1, Nigeria 1, Zambia).

DISCUSSION

Past research on the relationship between forests, trees and dietary quality has shown varied results (Powell *et al.* 2015). Despite compelling correlations between dietary quality and tree cover using coarse data (Johnson, *et al.* 2013; Ickowitz *et al.* 2014; Ickowitz *et al.* 2016), individual case studies using better quality data have shown mixed effects. For example, it was found in the DRC that despite widespread consumption of wild edible plants, consumption levels were insignificant relative to other foods in the diet in terms of their contribution towards dietary adequacy for most nutrients (Termote *et al.* 2012); a significant effect of the consumption of bushmeat in Madagascar on anaemia rates in children has been demonstrated (Golden *et al.* 2011); and a comparison of the nutritional intake of bushmeat users and non-bushmeat users in tri-frontier region of Brazil, Peru and Columbia found diets of bushmeat users to be marginally higher in micronutrients (van Vliet *et al.* 2014). In each case, sample sizes were relatively small and studied either a single or handful of communities. To our knowledge, this study is the first to measure forest food use across a broad suite of communities in different countries.

Inconsistencies and conflicting conclusions in previous studies can partially be explained by the wide variety of forest food consumption patterns found in this analysis. We found more than half of the households in our data set collected wild forest products for consumption, but that the data were skewed towards low-level consumption. We identified four typologies of forest food using sites: 'forest food dependent', 'limited forest food use', 'forest food supplementation' and 'specialist forest food' consumers. In 'forest food dependent' sites, a large proportion of the population is engaged in the consumption of relatively large quantities of forest foods that make a substantial contribution to dietary quality. In 'limited forest food use' sites, the contribution of forest foods to dietary adequacy is likely to be low as only a relatively small proportion of households are engaged in the consumption of forest foods and the quantities consumed are relatively low. Forest foods are also likely to have limited contributions to dietary quality in 'forest food supplementation' sites, though the pattern of widespread but low-level consumption could be important if diets are otherwise lacking in micronutrient-rich food groups. In 'specialist forest food' consuming sites, most households do not consume substantial quantities of forest foods although a small subset of households (specialists) consume substantial quantities that could make a difference to dietary quality.

The average consumer of forest meat and fish in the study consumed around one quarter of the reference quantity of 425 g per week from forests. This would suggest that for many forest meat and fish consumers, the quantities being consumed are sufficient to make an impact on dietary quality, particularly for otherwise malnourished children. For the top quartile of forest meat and fish users, the average household consumed just more than minimum threshold suggesting that those households heavily engaged in bushmeat hunting and fishing in forests enjoy diets adequate in animal source foods. Compared with average intakes at the national level, our data suggest that forest meat and fish users consume around one fifth of the average meat intake of their compatriots solely from forests, while the top quartile of users in each site obtained on average around three quarters of the national average intake.

Fruits and vegetables are excellent sources of dietary fiber, vitamin A, vitamin C and folate, and vegetables can contain significant quantities of iron and calcium (Slavin & Lloyd 2012). Fruits and vegetables also supply phytochemicals with proven health benefits, including antioxidants and phytoestrogens (Slavin & Lloyd 2012). Increased consumption of fruits and vegetables is associated with reduced risk of chronic diseases including cancers, cardiovascular disease and stroke, and diabetes (Liu 2003; Boeing *et al.* 2012).

We found that the majority of users of forest fruits and vegetables obtained relatively low quantities of fruits and vegetables from forests, consuming 3.7% of the minimum

Table 4 Percentage of dietary threshold and percentage of national average intake of meat and fish consumption consumed by households who consumed at least one forest fruit or vegetable during the recall period (columns 1 and 2) and the top quartile of forest meat and fish users in each site (columns 3 and 4).

Site name	*Forest meat and fish using households*		*Top quartile of forest meat and fish using households*	
	Percentage of minimum recommended intake	*Percentage of average sub-regional intake*	*Percentage of minimum recommended intake*	*Percentage of average sub-regional intake*
Bangladesh 1	6.36	6.79	8.76	9.36
Bangladesh 2	11.3	12.1	21.3	22.8
Bangladesh 3	6.44	6.87	20.1	21.4
Belize	16.7	7.94	110	52.2
Bolivia 1	47.8	20.2	142	60.0
Bolivia 2	127	53.6	272	115
Bolivia 3	192	81.1	584	247
Brazil 1	19.2	5.21	74.6	20.2
Brazil 2	178	48.3	554	150
Brazil 3	69.7	18.9	383	104
Burkina Faso 1	3.68	5.98	5.15	8.37
Burkina Faso 2	10.8	17.5	23.2	37.7
Cambodia	14.6	9.17	53.8	33.7
Cameroon	63.8	55.1	120	104
China	5.95	1.57	5.95	1.57
DRC	6.49	10.0	26.70	41.3
Ethiopia 1	–	–	–	–
Ethiopia 2	–	–	–	–
Ghana 1	24.1	15.0	194	121
Ghana 2	31.3	19.6	111	69.6
Guatemala	–	–	–	–
India 1	233	439	304	573
India 2	–	–	–	–
Indonesia 1	237	167	577	406
Malawi	1.21	1.81	8.14	12.2
Mozambique 1	5.54	15.49	30.0	83.8
Mozambique 2	71.8	25.79	215	77.4
Nepal 1	–	–	–	–
Nepal 2	–	–	–	–
Nigeria	35.2	52.6	197	294
Peru	73.4	32.8	184	82.5
Senegal	0.27	0.10	0.69	0.25
Uganda	8.74	7.02	34.0	27.3
Vietnam	–	–	–	–
Zambia	6.15	5.46	65.2	57.8
Total	24.8	18.1	106	72.5

recommended intake and on average 5.6% of average sub-regional consumption quantities. The top quartile of forest fruit and vegetable consumers, however, obtained on average 14.8% of the minimum recommended intake of fruits and vegetables from forest sources and 21.6% of sub-regional average consumption levels. Globally, consumption of fruits and vegetables is far below recommended levels (Hall *et al.* 2009). In addition, current agricultural production is far below what is needed to meet global per capita recommendations (Siegel *et al.* 2014). Wild foods may therefore be an essential resource for filling the shortfall in global need where available.

A few studies have previously reported the most common types of foods obtained from the forest (Vinceti *et al.* 2008; Powell *et al.* 2013). In this study, forest foods are composed almost exclusively of fruits, vegetables, bushmeat and fish as well as nuts, confirming past reports. Staple foods are almost completely absent in the data set with the exception of small quantities of edible roots. It is therefore clear that forest foods do not form the main source of food (in terms of calories) in any site included in the study – a finding consistent with previous estimates of caloric contributions (FAO 2014). However, in many sites, smallholder agriculture generates relatively small quantities of fruits and vegetables and relatively little livestock and fish. Although we cannot account for the consumption of purchased foods, communities where agriculture is focused upon staple food production, forest meat, fish, fruits and vegetables likely contribute important sources of micronutrient-rich foods that may otherwise be absent.

The results presented in this paper should be treated with caution. Sample sizes in sites are relatively small, and the number of forest food using households in many sites is only a subset of households. In addition, site selection was not representative of regions or nations, but was designed to reflect smallholder use of tropical forests for livelihoods (Wunder *et al.* 2014). This study likely underestimates quantities of forest foods consumed as it only analyses the consumption of forest foods that were collected by the household itself. Trades and gifts of forest products are common in forested communities and bushmeat markets can extend hundreds of miles (Nasi *et al.* 2008). In addition the recall period of one month, four times a year, may miss high seasonal use of forest foods and infrequently consumed forest foods. Recall methods in general tend to underestimate consumption and the recall bias increases with time. This may be especially true of forest fruits and vegetables, which are more likely to be forgotten than a successful hunting episode (Gersovitz *et al.* 1978; Fleuret 1979; Ferguson *et al.* 1989). In addition, recall by the head of the household on behalf of the whole household often misses consumption by other members – especially as women are the primary food preparers but are in the minority as head of the household.

Future studies focusing on individual consumption are needed to confirm the results in this study. Such studies should include the consumption of purchased and gifted food in order to compare the wider dietary context in which the consumption of forest foods is taking place. Future studies should also account for the pattern ('typology') of forest food use in the local context, taking into account how the collection and consumption of forest food fits within the overall occupations, lifestyles and activities of local people.

CONCLUSION

This study shows that forests play an important role in the diets of some households and communities living in close proximity to tropical forests. For 'forest food dependent' and 'specialist forest food' sites, households that consume high quantities of forest foods obtain a high proportion of the recommended intake of fruits and vegetables and animal source foods from forests. For both 'limited forest food use' and 'forest food supplementation' sites, the quantities of fruits, vegetables and animal source foods consumed (by those who consume forest foods) are quite low. If these foods are otherwise lacking in households' diets, however, even these small quantities may be nutritionally important.

Comparisons of quantities consumed with dietary recommendations may understate the significance of forest foods – as most people in low income countries do not reach the recommended minimum dietary requirements. We find some forest food consumers enjoy nutritionally superior diets to their national counterparts, but this applies mostly to those households heavily engaged in the extraction and consumption of forest foods.

Our findings suggest that deforestation and land use change may have unforeseen consequences on the quality of local people's diets. A better understanding of the contribution of forest foods to local diets is needed to understand the true impact that the loss of forests may have for nutrition in the face of agricultural expansion. If indeed forests substantially contribute to dietary quality in some areas as the results here imply, forest loss may result in unforeseen, adverse consequences on nutrition for local people.

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