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Protected areas, household environmental incomes and well-being in the Greater Serengeti-Mara Ecosystem

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ABSTRACT

Protected areas are an important cornerstone in the attempt to halt habitat and species losses. While it is widely recognized that local communities impact on conservation outcomes, there is a limited understanding of the economic importance of environmental resources in protected areas to local household incomes and well-being. This inhibits the development and implementation of efficient conservation policies. This paper, using the iconic case of the Greater Serengeti-Mara Ecosystem and its surrounding local communities in Tanzania and Kenya, quantifies the household-level economic importance of this protected area. Data was collected using well-being and environmentally augmented structured household surveys administered to 985 randomly selected households in 25 communities. Results documented high reliance on environmental income of the poorest, a negative relationship between environmental reliance and well-being, with households closer to the protected area having higher environmental reliance and lower well-being. Hence, degradation of protected area habitats will negatively and disproportionately affect the income and may further reduce the well-being of the poorest households. Sustainable protected area management must address human well-being as well as conservation objectives. Increasing access to education and building skills to promote alternative non-environmental based livelihood activities will promote both conservation and development objectives.

1. Introduction

Protected areas are designed to conserve natural habitats and species, by imposing restrictions on human activities. Protected areas are often subject to mounting pressure from nearby communities, especially in low income countries in locations where household income partially relies on resources within protected areas leading to conflicts between conservation and development (Chao et al., 2018; Hampson et al., 2015; Knapp et al., 2013; Wittemyer et al., 2008). This suggests that conservation in protected areas can benefit from an improved understanding of the compositions of local incomes and the determinants of well-being (MA, 2005; Wells and McShane, 2004), in particular in relation to the harvest of environmental products. Environmental products are harvested from non-cultivated habitats, including forests, grass-, bush- and wetlands, and fallows (PEN, 2007b) and include products such as firewood, timber, bushmeat, medicinal plants, and wild foods.

A global comparative study covering 7978 rural households in 24 countries across Latin America, Asia, and Sub-Saharan Africa estimated that an average of 28% of total annual household income originated directly from such products (Angelsen et al., 2014). Here we use the term environmental income to define the sum of such cash and subsistence income. Poor households tend to rely most on environmental income (as a percentage of their total household income, commonly called environmental reliance), whereas wealthier households tend to generate higher absolute environmental income (Angelsen et al., 2014; Vedeld et al., 2007). This pattern suggests that poorer households may be disproportionately negatively affected by habitat degradation, while wealthier households exercise higher pressure on environmental resources. However, quantification of the economic importance of environmental products to households living in and around protected areas is sparse (Chao et al., 2018; Kalaba et al., 2013; Rayamajhi et al., 2012; Silvestri et al., 2013; Summers et al., 2012; Wenny et al., 2011), with few studies reporting high environmental reliance in the vicinity of protected area.

Recent investigations of environmental reliance have proceeded to capture poverty dynamics by incorporating asset analysis (Charlery and Walelign, 2015; Dokken and Angelsen, 2015; Nielsen et al., 2012) and
following households over time (Walelign et al., 2017). No studies, however, have yet combined analyses of environmental income with well-being. Well-being reflects the satisfaction of human needs and the associated life quality (Gough et al., 2007; Yang et al., 2013a). While well-being is an evolving concept and difficult to define and measure (Butler and Oluoch-Kosura, 2006), there has been recent progress. The Millennium Ecosystem Assessment (MA) has developed a conceptual framework for understanding the relationships between ecosystem services and human well-being, encompassing five components: “Basic Material for a Good Life”, “Security”, “Health”, “Good Social Relations”, and “Freedom of Choice and Action” (MA, 2003). Yang et al. (2013a) build on this to develop a human well-being index based on self-evaluation of satisfaction within each of the components, and an index of human dependence on ecosystem services (Yang et al., 2013b). However, evaluations of the relation between ecosystem services reliance and well-being remain scarce (Butler and Oluoch-Kosura, 2006).

There are, to the best of our knowledge, yet no studies on the relationship between environmental income and well-being adjacent to protected areas.

Despite the unique conservation value of the world-renowned Greater Serengeti-Mara Ecosystem and its substantial contribution to regional and national economies through tourism (Sekar et al., 2014), there is little information about environmental income and its relationship with human well-being in the area. Local harvesting of environmental products is a source of conflict (Dobson, 2009) but environmental reliance remains unquantified. This study quantifies total household incomes, including environmental income, examines environmental reliance patterns and determinants across the study area, and investigates the relationship with human well-being. Specifically, we test four hypotheses: (1) Environmental reliance is inversely related with total household income; (2) Absolute environmental income is positively associated with total household income; (3) Well-being is inversely related with environmental reliance; and (4) Distance to the protected area boundary is negatively associated with absolute environmental income and reliance but positively associated with well-being. Hypotheses 1 and 2 are tested through plots against income quintiles and multivariate regression analysis using various indicators of wealth while controlling for relevant socioeconomic covariates. Hypothesis 3 is tested through plots of the relationship between well-being and environmental reliance and by regressing environmental reliance on well-being while controlling for relevant covariates. Hypothesis 4 is tested by including distance to the nearest protected area boundary in the models predicting absolute environmental income and reliance, and well-being. Including relevant socioeconomic control variables furthermore enables us to explore their significance and direction of influence in determining the outcome variables of interest.

2. Theoretical framework and concepts

2.1. Theoretical framework

The study is theoretically grounded in the conceptual framework of the Millennium Ecosystem Assessment and theories about sustainable rural livelihoods (Ellis, 2000; MA, 2003; Scoones, 1998; Winters et al., 2001) (Fig. 1). Both local communities and protected areas are key components in this framework. In this paper, we focus on incomes as the outcome of assets and capabilities, drawing on the Sustainable Livelihoods Framework, and Millennium Ecosystem Assessment work on human well-being to guide our empirical data collection and analysis. We make use of the Poverty and Environment Network (PEN) technical guidelines to develop and structure our data collection instruments (PEN, 2007b).

2.2. Concepts and definitions applied

Ecosystem services are benefits obtained by people from ecosystems contributing directly or indirectly to human well-being, encompassing provisioning, regulating, cultural, and supporting services (MA, 2005; TEEB, 2010). Here our focus is on provisioning services, specifically on household environmental income defined as the monetary cash and subsistence value of consumptive use of environmental resources. Human well-being is measured as satisfaction in five dimensions: “Basic Material for a Good Life”, “Security”, “Health”, “Good Social Relations”, and “Freedom of Choice and Action”, with each dimension investigated using four to seven indicators (MA, 2003; Yang et al., 2013a). Environmental income consists of subsistence and cash income from environmental goods, wage from natural resource-based activities, and direct transfer payments for environmental services. Environmental reliance is operationalised as the share of environmental income in total household income reflecting its relative importance (Angelsen et al., 2014). Total income is composed of three income categories: environmental income, agricultural income (from crop and livestock production) and non-farm income (wages, business, remittance, pension, and other income sources). Assets are stocks of capital owned and accessed by the households used to generate the means of living and maintain well-being, and contains five categories of natural, physical, financial, human and social capitals (Ellis, 2000).

3. Methods

3.1. Study area

The transboundary Greater Serengeti-Mara Ecosystem covers an area of approximately 30,000 km² on the Tanzania-Kenya border and hosts the world’s largest remaining wildlife migration of more than two million large herbivores, primarily wildebeests (Velthuis et al., 2019). The ecosystem is a complex of protected areas, including the Serengeti National Park, Ngorongoro Conservation Area, Maswa, Grumeti and Ikorrongo Game Reserves, and Loliondo Game Controlled Area in Tanzania, and the Maasai Mara National Reserve in Kenya (see Fig. 2). Around the protected areas are pastoral and agro-pastoral communities with a population of more than three million people and numerous livestock, both growing at a high rate (Dublin and Ogutu, 2015; Dybas, 2011; Estes et al., 2012; URT, 2013). Ethnic groups include the Maasai to the north and east, the Sukuma to the south, and the Kuria and other Bantu tribes to the west.

3.2. Data collection

Data was collected in 25 rural villages in the five Tanzanian districts Ngorongoro, Meatu, Bariadi, Serengeti, and Tarime, and in Narok county in Kenya. Site and village selection aimed to capture variations in characteristics such as population density, distance to the boundary of the nearest protected area, ethnic composition, dominant livelihood strategy, precipitation, soil quality, habitat, and infrastructure. To further enable evaluation of the impact of protected area adjacency, villages were as far as possible selected in clusters of three in each district at increasing distance (up to 42 km) from the closest protected area boundary where consumptive activities (e.g. settlement, agriculture, livestock grazing, or environmental product collection) are not allowed (i.e. the National Park and Game Reserves in Tanzania, and the Maasai Mara National Reserve in Kenya). Boundaries of multiple-use zones such as Conservation Areas, Game Controlled Areas and Conservancies were not considered when calculating the distance to nearest protected area boundary.

Approximately forty households were selected in each village based on a stratified random sample selection strategy: 15 poor, 15 intermediate, and 10 rich households. Sampling weights were used in the analysis, defined as the inverse of the probability of being included in the sample at the village level. Replacement of drop-out households from a list of back-up household was applied to minimise attrition (n = 18). Data from at least three quarters were required for inclusion.
of households in the analysis. Hence, no replacement was allowed after the second round of four quarterly surveys. Households with two or more missing quarterly surveys were dropped from the dataset resulting in an attrition rate of 3.2%. The final dataset consisted of 985 households. No systematic pattern of attrition was observed.

Survey instruments were adapted from the PEN prototype questionnaire (PEN, 2007a) and technical guidelines (PEN, 2007b), involving two annual and four quarterly household surveys over the course of a year (May 2016 – April 2017). The quarterly surveys used short recall periods (1–3 months depending on income source – 1 month for environmental income) to improve accuracy and minimise errors arising from long recall periods and seasonal fluctuations in income (Angelsen et al., 2011). The quarterly surveys recorded detailed information about cash and subsistence income in the categories environmental, crop, livestock, business, wage, and other income sources (e.g., remittance or pensions). The first annual survey, implemented at the beginning of data collection, focused on household demographics and assets owned. The second annual survey, implemented at the end of fieldwork, collected information on shocks and changes in asset holdings during the survey year, and included questions about household well-being (see Appendix A) adapted from Yang et al. (2013a). In addition, two village surveys collected data common to all households in the village at the beginning and the end of the fieldwork period. Data was collected through face-to-face questionnaire interviews by trained Swahili speaking enumerators using an Open Data Kit (ODK) tablet interface.

3.3. Data analysis

Three main analyses were undertaken: 1) Calculation of absolute and relative household income for all income sources and analysis of environmental income across well-being quintiles; 2) Construction of well-being sub-indices and an overall Well-Being Index (WBI) using confirmatory factor analysis; and 3) Multivariate regression analysis of models specified to test the four hypotheses (cf. above).

Own reported farm-gate prices were used in calculating the value of environmental, crop, and livestock products wherever possible. Local market price, substitute price, or the opportunity cost of time was used for products not commonly traded locally. Annual household income from each source was calculated by aggregating (and extrapolating – for information obtained using 1 month recall – i.e. environmental income) income data from the four quarterly surveys. Missing household quarterly income \( n = 42 \) households missing one quarter) was estimated from average household income in the three sampled quarters multiplied by a factor to capture seasonal variation at the village level following Angelsen et al. (2014). Incomes were converted to Adult Equivalent Units (AEU) following Cavendish (2000) and corrected for Purchasing Power Parity to facilitate comparison across households and between the two countries. District or regional level reliance is calculated as the share of mean income from a particular source in mean total income in that district or region, to avoid distorted values of reliance (share of total income) caused by the negative crop and livestock incomes occurred due to crop failure and/or livestock death during a drought year.

Confirmatory factor analysis (CFA) was used to construct the five sub-indices (“Basic Material for a Good Life”, “Safety”, “Health”, “Social Relations”, and “Freedom of Choice and Action”) and the overall WBI following Yang et al. (2013a). The internal validity and reliability of indicators were assessed using Cronbach’s alpha coefficients and item-correlations (Brown, 2006). Two indicators were excluded due to low consistency with other indicators (the local crime incidence in the “Safety” sub-index, and the leisure activities in the “Health” sub-index). The WBI has satisfactory internal validity with a Cronbach’s alpha value of 0.89 and item-total correlations ranging from 0.41 to 0.82 within each sub-index (see Appendix A for details). All model fit statistics for the WBI and the individual sub-indices have high goodness-of-fit. The Comparative Fit Index (CFI) is above 0.99, and both the Root Mean Squared Error of Approximation (RMSEA) and the Standardized Root Mean Squared Residual (SRMR) are < 0.08 in all cases. The latent variables and paths of indicators for all five well-being sub-indices have
significant coefficients \( p < .01 \). The overall model indicates that the five dimensions of human well-being are not independent of each other. The sub-index of “Freedom of Choice and Action” is significantly positively associated with the sub-index of “Social Relations” and “Basic Materials for a Good Life”, and the sub-index of “Safety” is significantly positively associated with the Social Relations sub-index. The overall WBI and the sub-indexes were normalised (to a range of 0–100) to enable cross-group comparisons (see Appendix B).

Multivariate regression models were applied to test hypotheses 1–4 and to explore the significance and direction of influence of covariates of environmental reliance, absolute environmental income, and the well-being indices (i.e. the control variables). Control variables were selected based on empirical evidence on the determinants of environmental reliance (e.g. Angelsen et al., 2014; Charlery and Walelign, 2015; Nielsen et al., 2012), rural livelihoods (e.g. Ellis, 2000; Jiao et al., 2017; Scoones, 2015; Walelign et al., 2017), and well-being (e.g. Reyes-García et al., 2016; Yang et al., 2015). Control variables included: household characteristics (tribe, age, and gender of the household head), number of income shocks experienced by the household during the past 12 months (e.g. crop failure, illness, or death of household members), and a country variable. Years of education of the household head, size of the household cropland and the combined value (PPP USD per AEU) of household asset holdings (e.g. motorbikes, mobile phones, equipment) were included as indicators of wealth to test Hypotheses 1 and 2. The size of cropland and value of asset holdings are reflected in the basic material dimension of WBI and were therefore excluded from models for the well-being indices to avoid endogeneity (i.e. circular conclusions in relation to the variables used to construct these indices).

Relative environmental income is included in the models predicting WBI and the well-being sub-indices to test Hypothesis 3. In addition, heteroskedasticity-based instrument variables for environmental reliance were applied to address potential endogeneity in the model for the sub-index for “Basic Material for a Good Life” (see Appendix K). Following Lewbel (2012), heteroscedastic based instruments are generated through the interaction between the demeaned (centered) regressors and the error term of the environmental reliance regression model (see Appendix K). Distance from the household to the nearest protected area boundary was included in all models to test Hypothesis 4. Expected signs of explanatory variables and summary statistics are presented in the Table 1 and Appendix B, respectively.

The sample included households nested in 25 villages and five districts and one county, constituting communities of numerous ethnic groups distributed in a matrix of different geographic and cultural contexts. Mixed (or hierarchical) models were therefore used to capture between village and district heterogeneity by including random intercepts (or random coefficients). In addition, random slopes were included at the appropriate level allowing relevant variables to have different effects at different administrative levels (Gelman and Hill, 2006). Comparison of various candidate models was undertaken using likelihood ratio tests (interclass correlation coefficient ICC, the Bayesian and Akaike’s Information Criteria, i.e. BIC and AIC) with the most parsimonious models selected (see Table 3). Eq. (1) describes the generic formula of a model with a random intercept \( \mu_y \) and \( \mu_k \) for district and village levels, respectively and a random slope \( \mu_1 \) and \( \mu_2 \) at district
Table 1
Explanatory variables and expected signs of coefficients in the multivariate regression models predicting environmental reliance, absolute environmental income, the overall well-being index (WBI) and the well-being sub-indexes.

| Environmental income       | Well-being sub-indexes |
|----------------------------|------------------------|
| Relative (Reliance)        | Absolute               |
| Overall WBI                | Basic material         |
| Safety                     | Heath                  |
| Social relations           | Freedom of choice      |
| Tribe                      | ±                      |
| Household education (years)| +                      |
| Female headed household (0/1)| +                     |
| Age of household head (years)| +                     |
| Crop land size (Hectares)  | ±                      |
| Total asset value (USD PPP)| +                      |
| Country – Kenya (Tanzania as the base group) | −                     |
| Distance to protected area (km)| −                     |
| Environmental reliance (%) | −                      |

\[
Y_{jki} = \beta_0 + \beta_i + \beta_k + \beta_{jki}X_{jki} + \mu_1X_{j1} + \mu_2X_{j2} + \ldots + \epsilon_{jki}
\] (1)

We expect that the geographical location affects how age and gender influence environmental income and reliance through variations in environmental and/or habitat quality characteristics between villages irrespective of districts, and through social and cultural differences between tribes residing in different areas (also irrespective of district). Hence, the model predicting environmental reliance was specified with a village level random intercept and random slopes of gender and age of the household head. The model predicting absolute environmental income was specified with village as a random intercept and random slopes of gender and age of the household head and asset value. The models predicting WBI and the well-being sub-indices were specified with random intercepts of both village and district as different policies at the district level affect well-being. These models included a random slope of environmental reliance at the district level, capturing variation in overall habitat types across districts.

Support for the random intercepts and slopes were evaluated using likelihood ratio tests. Dependent variables were mean centred and standardized (by subtracting the mean and dividing by the standard deviation) to normalise the distribution, except environmental reliance which was logit transformed to accommodate the proportional nature of the variable (Baum, 2008). The model predicting logit transformed environmental reliance was implemented using a procedure equivalent to the fractional logit model described in Baum (2008). No normal values of environmental reliance (i.e. values below 0, originating from rare cases of negative total income due to input costs exceeding gross income, or values above 1, caused by negative total income due to crop failure or livestock death and hence negative crop and/or livestock income while positive environmental income), were adjusted to 1. The alternative approach of replacing such values with village averages tends to underestimate reliance for such households. All models were estimated with heteroscedasticity robust standard errors.

4. Results

First, we estimate total household income and examine differences in income portfolios across geographical and administrative units in the study area. We then test the four hypotheses.

4.1. Environmental income and reliance

Total annual household absolute and relative incomes across geographical locations and administrative units are presented in Table 2 (see Appendix C for pairwise comparison of income sources). In general, the lowest mean total annual household income was observed in the Southern part of the study area, while households in Loliondo to the East in Tanzania and in Narok County in Kenya in the Northern area enjoyed the highest total income. Total annual household environmental income averaged 378 USD PPP/AEU in Tanzania and 281 in Kenya, primarily obtained as subsistence income from firewood, wild foods, water for domestic use, and construction material (the proportion of cash vs subsistence environmental income is presented in Appendix J). Households in Loliondo earn the highest average environmental annual income of 741 USD PPP/AEU, while the lowest environmental income is 167 USD PPP/AEU in the Southern part. The average environmental reliance was 20%, ranging from 39% in the Eastern part in Tanzania to 8% in Narok County in Kenya. Despite high average environmental reliance (30%) in the Western part, the average absolute environmental income is almost half that of the Eastern side.

Livestock is by far the most important income source in the Greater Serengeti-Mara Ecosystem, ranging between on average 29%–60% of total annual household income. Average livestock reliance is 52% on the Kenyan side and 45% in Tanzania. Households in Loliondo and Narok obtained livestock income about five-fold higher than in the Western part, and almost ten-fold greater than in the Southern part of the Greater Serengeti-Mara Ecosystem. Average absolute annual crop income was relatively low, ranging from 22 USD PPP/AEU (in Ngorongoro Conservation Area) to 317 (in Loliondo). Crop income contributed on average 12% of total household income in Tanzania but only 1% in Narok County in Kenya. Average crop income reliance was significantly higher in Meatu district (p-value < 0.05), but no significant differences were observed between other districts. In total, ecosystem derived income (i.e. combined environmental, agricultural and livestock derived income) accounted on average for 75% of total income, varying from 70% to 89% in Ngorongoro Conservation Area and Narok, respectively. The main non-ecosystem dependent income sources are wage income and business, contributing on average 11 and 10% of total income, respectively. Business and wage income were most important for households in the Ngorongoro Conservation Area.

4.2. Income, assets and environmental reliance

Here we focus on the variation of absolute environmental income and reliance across income quintiles testing Hypotheses 1 and 2. In both Tanzania and Kenya, absolute environmental income increases whereas reliance decrease as income increase (Fig. 3 and Appendix D). Environmental reliance for the poorest quintile (20% of the sample with the lowest income) was 81% on average in Tanzania. This extremely high reliance follows from negative crop income as the case study year was characterized by drought. Absolute environmental income was six times higher in the most well-off income quintile compared to the poorest. In Kenya, the two highest income quintiles relied minimally,
Table 2
Total annual household absolute (USD PPP) and relative (%) income per adult equivalent unit by income source across regions and districts in the Greater Serengeti-Mara Ecosystem, 2016–2017. Standard errors in parenthesis.

| Regions & Districts          | Environmental income (1) | Crop income (2) | Livestock income (3) | Ecosystem derived income (4 = 1 + 2 + 3) | Business income (5) | Wage income (6) | Other income (7) | Non-ecosystem derived income (8 = 5 + 6 + 7) | Total income (4 + 5 + 6 + 7) |
|------------------------------|--------------------------|-----------------|----------------------|----------------------------------------|---------------------|----------------|-----------------|---------------------------------------------|-----------------------------|
|                             | Abs a                    | Rel b           | Abs                  | Rel                  | Abs                  | Rel             | Abs             | Rel             | Abs                                        | Abs                          |
| Southern                    |                          |                 |                      |                       |                      |                 |                 |                 |                                            |                             |
| Meatu district              | 167 (8)                  | 23              | 135 (22)             | 19                    | 263 (29)             | 36              | 565 (39)        | 78              | 43 (10)                     | 91 (30)         | 13             | 24 (6)         | 3              | 158 (38)        | 22              | 723 (52)        |
| Baridi district             | 190 (15)                 | 28              | 184 (35)             | 25                    | 285 (50)             | 41              | 543 (59)        | 79              | 44 (16)                     | 88 (45)         | 13             | 14 (2)         | 2              | 146 (58)        | 21              | 689 (79)        |
| Western                     |                          |                 |                      |                       |                      |                 |                 |                 |                                            |                             |
| Serengeti district          | 383 (22)                 | 33              | 183 (24)             | 16                    | 395 (66)             | 34              | 961 (83)        | 82              | 72 (14)                     | 107 (37)        | 9              | 29 (10)        | 2              | 220 (39)        | 18              | 1226 (78)       |
| Turome district             | 407 (45)                 | 30              | 317 (39)             | 12                    | 535 (100)            | 40              | 1098 (122)      | 82              | 73 (16)                     | 157 (56)        | 12             | 13 (3)         | 1              | 243 (60)        | 18              | 1341 (133)      |
| Eastern (Ngorongoro district)| 659 (41)                 | 23              | 203 (45)             | 7                     | 1543 (194)           | 55              | 2405 (217)      | 85              | 292 (81)                    | 113 (28)        | 4              | 14 (3)         | 0              | 419 (86)        | 15              | 2825 (226)      |
| -Ngorongoro Conservation Area| 531 (57)                 | 39              | 22 (15)              | 2                     | 399 (80)             | 29              | 952 (121)       | 70              | 188 (66)                    | 205 (63)        | 15             | 18 (8)         | 1              | 411 (100)       | 30              | 1363 (159)      |
| Loliondo                    | 741 (54)                 | 20              | 317 (70)             | 8                     | 2286 (294)           | 60              | 3324 (318)      | 85              | 358 (10)                    | 55 (20)         | 4              | 12 (2)         | 0              | 425 (125)       | 15              | 3749 (328)      |
| Northern (Narok county)     | 281 (20)                 | 8               | 31 (11)              | 1                     | 1924 (467)           | 52              | 2236 (467)      | 89              | 521 (75)                    | 644 (143)       | 1              | 311 (41)       | 0              | 1477 (190)      | 11              | 3713 (525)      |
| All Sample                  | 362 (13)                 | 20              | 145 (13)             | 8                     | 845 (90)             | 47              | 1353 (94)       | 75              | 180 (21)                    | 197 (29)        | 11             | 69 (8)         | 4              | 445 (42)        | 25              | 1799 (107)      |

a Abs= absolute income.
b Rel = relative income (% of total income). These are calculated as the share of mean income from a particular source in mean total income in that district or region. Thus no standard errors are reported.
i.e. < 10%, on environmental income, while reliance in the two poorest income quintiles was around 20% on average. Absolute environmental income was similar in the four highest income quintiles, at a level double that of the lowest quintile. These trends are also supported by the results in Appendix E presenting linear fitted trend lines for absolute environmental income and reliance plotted against total household income in Tanzania and Kenya. The slope coefficients of the fitted lines are significant in all models although model explanatory power (R-squared) is low. A more detailed account of annual total household income composition across income quintiles is presented in Appendix D and pairwise comparisons between income quintiles in Appendix H.

The results of the multivariate regression models are presented in Table 3. Age and years of education of the household head were negatively associated with both absolute environmental income and reliance (at the 0.1 level). Area of cropland owned was negatively related to environmental reliance only. The value of asset holdings, an indicator of more permanent as opposed to more transitory wealth reflected by income, is positively associated with absolute environmental income and negatively associated with reliance. Evaluating the effect of the control variables, both absolute environmental income (on the 0.1 level) and reliance decrease as the number of shocks experienced during the past 12 months increase. In the model predicting reliance, the positive correlations of the village level random slope of asset value, age and gender of the household head with the village level intercept reveal that the observed effects of these variables are larger in villages with lower average environmental income.

4.3. Environmental income and reliance across well-being quintiles

Here we focus on the variation of annual household environmental income and reliance across well-being indicie quintiles (Fig. 4). Absolute environmental income does not differ significantly between well-being quintiles in Tanzania or Kenya (see Appendix I for pairwise comparisons between well-being quintiles). Environmental reliance exhibits a declining pattern with increasing well-being quintiles in both Tanzania and Kenya, except households in the fourth quintile. The relationships are also examined using scatterplots and fitted lines in Appendix G, confirming the negative association between well-being and environmental reliance. A more detailed account of annual household income composition across well-being quintiles is presented in Appendix F.

The results of the multivariate regression models are presented in Table 3. Environmental reliance is negatively associated with WBI and the sub-indices for “Basic Material for a Good Life” and “Health”. Results from the Two-Stage Least Squares Instrumental Variable (2SLS IV) regression model (see Appendix K) confirm the negative relationship between environmental reliance and the sub-index of “Basic Material for a Good Life”. The positive correlation of the district level random
Table 3
Multivariate regression models predicting (i) environmental income and reliance, and (ii) overall well-being index (WBI) and well-being sub-indices in the Greater Serengeti-Mara Ecosystem, 2016–2017.

|                               | Environmental income | Well-being Index and sub-indices | Model statistics |
|-------------------------------|----------------------|---------------------------------|------------------|
|                               | Reliance             | Absolute                        | Overall WBI      |
| Environmental income         |                      |                                 | Basic materials  |
| Reliance                     | −0.467*** (0.226)    | −0.715*** (0.263)               | −0.177 (0.131)   |
| Household education (years)  | −0.047 (0.026)       | −0.052 (0.030)                  | −0.344 (0.171)   |
| Female headed household (0/1)| 0.175 (0.165)        | 0.060 (0.094)                   | −0.286 (0.336)   |
| Age of household head (years)| −0.009*** (0.004)   | −0.009*** (0.004)               | 0.001 (0.001)    |
| Crop land size (hectares)    | −0.072*** (0.012)    | 0.010 (0.012)                   | 0.033 (0.020)    |
| (log)Total Asset value (USD  | −0.164*** (0.058)    | 0.090 (0.038)                   | −0.007 (0.014)   |
| Shocks experienced           | −0.149*** (0.068)    | −0.063 (0.036)                  | 0.037 (0.027)    |
| Distance to protected area   | 0.031 (0.049)        | −0.041*** (0.012)               | 0.031 (0.012)    |
| Tribe                        |                      |                                 | 0.031 (0.012)    |
| Maasai                       | −0.093 (0.616)       | −0.359 (0.570)                  | −0.073 (0.122)   |
| Sukuma                       | −0.063 (0.352)       | −0.299 (0.204)                  | −0.073 (0.122)   |
| Kuria                        | 1.243 (0.869)        | 0.480 (0.400)                   | 0.033 (0.029)    |
| Country                      |                      |                                 | 0.250 (0.174)    |
| Kenya                        | −2.296*** (0.849)    | 0.328 (0.501)                   | 0.572 (0.294)    |
| Constant                     | −0.337 (0.326)       | 0.054 (0.307)                   | −0.235 (0.284)   |
| Village constant (sd)        | 0.778 (0.085)        | 0.652 (0.108)                   | 0.328 (0.203)    |
| District constant (sd)       | 0.189 (0.151)        | 0.056 (0.063)                   | 0.189 (0.102)    |
| Random slope (sd)            |                      |                                 |                  |
| Female headed household       | 0.813 (0.121)        | 0.530 (0.110)                   |                  |
| Age of household head         | 0.017 (0.002)        | 0.013 (0.003)                   |                  |
| (log)Asset value (Village level) | 0.119 (0.018)      | 0.119 (0.018)                   |                  |
| Environmental reliance (District level) | 0.491 (0.085) | 0.541 (0.107) | 0.260 (0.043) | 0.375 (0.092) | 0.772 (0.291) | 0.952 (0.232) |
| Correlation of random slope and model constant |                  |                  |
| Female headed household       | 0.173 (0.210)        | −0.280 (0.366)                  |                  |
| Age of household head         | 0.276 (0.206)        | −0.259 (0.285)                  |                  |
| (log)Asset value              | −0.044 (0.256)       |                                |                  |
| Environmental reliance       | 0.101 (0.533)        | 1.000 (0.0061)                  | 1.000 (0.0007)   |
| Model statistics              |                      |                                 | 0.136 (0.722)    |
| Log-likelihood               | −328,811             | −225,118                        | −220,871         |
| AIC                           | 657,660              | 450,282                         | 444,884          |
| BIC                           | 657,753              | 450,395                         | 444,962          |
| ICC (Village)                | 0.3797               | 0.487                           | 0.228            |
| ICC (District)               | 0.166                | 0.253                           | 0.133            |
| N (Households)               | 985                  | 985                             | 985              |
| N (Villages)                 | 25                   | 25                              | 25               |
| N (Districts)                | 6                    | 6                               | 6                |

Note: standard errors in parentheses.

* Indicates level of significance at the 10% level.
** Indicates level of significance at the 5% level.
*** Indicates level of significance at the 1% level.
The slope of reliance and the district level random intercept implies that the negative effect on well-being is stronger in districts with higher average well-being. Households with more educated heads have significantly higher WBI. Education is also significant for all sub-indices except “Social Relations” (at the 0.1 level for “Health”). Female-headed households have significantly lower well-being sub-indices on “Basic Material for a Good Life” and “Health” (on the 0.1 level). The sub-indices on “Safety” and “Freedom of Choice and Action” are significantly positively associated with household head age (on the 0.1 level). Unsurprisingly, a higher number of shocks experienced was negatively associated with WBI and all sub-indices except “Social Relations” that represents a particularly important capital when coping with shocks.

4.4. The effect of distance to the protected area boundary

The results of the multivariate regression models (Table 3) show that distance to the boundary of the core protected area is negatively associated with environmental income, implying that households living closer to protected areas have higher environmental income. There was no significant relationship with distance in the regression model predicting reliance. However, the plot in Fig. 5 show a negative relationship between distance to protected area boundary and environmental reliance. The relationship between WBI and the sub-indices and distance was positive with the exception of the “Safety and Social Relations” sub-indices. This indicates that households further from protected areas generally experience higher well-being ceteris paribus (i.e. all else equal). Distance had a negative effect on the “Social Relations” sub-index suggesting that households living closer to protected area boundaries tend to form more closely-knit communities. Maasai households have lower well-being on the “Basic Material for a Good Life” and “Freedom of Choice and Action” sub-indices but higher on the “Safety” sub-index compared to other tribes. Sukuma households tend to have higher well-being on the “Safety” and “Social Relations” sub-indices and the Kuria have higher “Social Relations” sub-index compared with other tribes (on the 0.1 level). Holding all other variables equal, households living in Narok County in Kenya tend to have lower well-being on most indices.

5. Discussion

5.1. Importance of environmental income

Environmental income is important to households in villages in and around the Greater Serengeti-Mara Ecosystem. Environmental income accounts for 8–39% of total household income, with an average of 20%. Adding crop (8%) and livestock (47%) incomes, the average ecosystem derived income accumulates to 75% in the study area, and is hence higher than the equivalent 69% reliance recorded in the global PEN survey (Angelsen et al., 2014). Such high ecosystem reliance implies that the study communities are highly vulnerable to declining ecosystem services provisioning. Hence, to fully understand household income portfolios and rural realities in the Greater Serengeti-Mara Ecosystem, environmental income cannot be disregarded and needs to be integrated into the design of processes modifying environmental resource access regulations. We found considerable variation in environmental income patterns. Communities in the Western part of the study area and the Ngorongoro Conservation Area rely most on environmental income. This may be attributed to restrictions on livelihood activities, in particularly crop production in the Ngorongoro Conservation Area (Charnley, 2005; Masao et al., 2015), in
combination with poor infrastructure restricting market access. It should also be noted that although environmental income appears to be high in the study area, the estimates should be considered conservative since illegal extraction activities may be underreported (Nuno and John, 2015). For instance, only around 2% (1.7 and 2.7% including and excluding Maasai) of our sampled households reported bushmeat income while estimates from Western Serengeti report such income from 3 to 73% of households depending on survey methods (Holmern et al., 2002; Johannesen, 2005; Knapp, 2007; Knapp et al., 2010; Mfunda and Roslash, 2010). A recent study using methods designed specifically for assessing the prevalence of sensitive activities reported the involvement of 18% of households in illegal bushmeat hunting (e.g. Nuno et al., 2013). However, that survey was conducted in areas where hunting is known to be common.

5.2. Patterns of environmental income

As postulated by Hypothesis 1, we observed a negative association between income and environmental reliance confirming findings in a range of other locations in Africa (Angelsen et al., 2014; Babulo et al., 2009; Dokken and Angelsen, 2015; Mamo et al., 2007; Vedeld et al., 2007). As predicted by Hypothesis 2, we also found that higher income quintiles earn more absolute environmental income, again consistent with most studies of links between poverty and the environment (Angelsen et al., 2014; Babulo et al., 2009; Vedeld et al., 2007). However, these patterns were less pronounced in the Kenyan part of the study area, where environmental reliance is high only among households in the lowest income quintiles, and where absolute environmental income did not vary much above the lowest income quintile. This

Fig. 5. The relationships between absolute environmental income and environmental reliance and distance to the core protected area boundary in Tanzania and Kenya.
indicates that wealthier households in Tanzania extract more environmental products than in Kenya where such households may prefer and have access to substitute products (e.g. gas for cooking or bricks for housing).

The multivariate regression analyses also support Hypothesis 1. There was a negative association between reliance and education, cropland, and total asset value owned. However, Hypothesis 2 was only supported by the positive association between absolute environmental income and total asset value. Contrary to Hypothesis 2, the association with total income was negative which may be explained by wealthier household heads engaging in more profitable income generating activities than environmental product harvesting. We also found a negative association between shocks experienced and absolute environmental income and reliance suggesting that households do not rely on environmental income as a safety net to cope with shocks. This observation is consistent with findings from the global PEN study (Wunder et al., 2014) as well as more recent work on environmental reliance dynamics (Walelign and Jiao, 2017) although other patterns have also been observed (Debela et al., 2012; Eriksen et al., 2005; Völker and Waibel, 2010). In line with previous studies (e.g., Angelsen et al., 2014; Babulo et al., 2008; Mamo et al., 2007), we found that households with younger and less-educated household heads have higher environmental income and reliance reflecting fewer other livelihood opportunities.

Overall, the results support Hypotheses 1 and 2 indicating that the poorest households are not responsible for the highest direct extractive pressure on the GSME. Better-off households, in terms of wellbeing scores and income without controlling for other aspects, extract a larger amount of environmental products. The poorer households, however, are more vulnerable to reduced ecosystem service provision due to their higher environmental reliance.

5.3. Well-being is inversely related to environmental reliance

As expected by Hypothesis 3, well-being increased as environmental reliance declined. There was no significant relationship between absolute environmental income and well-being. Hence, low well-being households rely more on environmental income, and higher absolute environmental income does not lead to improved well-being. The finding highlights the importance of using multi-dimensional welfare measures as different patterns are observed for both environmental income and reliance when compared as a function of well-being groups and income groups. Previous studies have also found varied patterns of environmental reliance across welfare grouping when measured using income, asset and a combination of the two (Charlery and Walelign, 2015; Dokken and Angelsen, 2015; Nielsen et al., 2012; Walelign et al., 2017). Interestingly, Kenyan households had lower well-being despite having higher incomes (p-value < 0.01) than Tanzanian households. This suggests that higher income and more assets do not translate directly into higher well-being emphasising the multidimensional nature of well-being.

The multivariate regression analyses generally support Hypothesis 3. There was a negative association between environmental reliance and WBI. Reliance was also negatively associated with the sub-indices of “Basic Material for a Good Life” and “Health”. Households with higher environmental reliance may self-evaluate their well-being lower for two reasons: (i) environmental reliance means increased vulnerability to environmental conditions (e.g. rainfall) and access restriction enforcement (e.g. changing policies and conservation initiatives), and (ii) environmental product collection may be considered an arduous and low prestige activity. The negative relation between well-being and reliance were more pronounced in districts with lower average well-being scores, implying that households with higher environmental reliance living in the low well-being communities are likely to be additionally marginalised. Hence, overall our results support Hypothesis 3. The positive association between education and WBI and most sub-indices underscores the benefit of investing in building human capital in rural communities (Angelsen et al., 2014; Walelign and Jiao, 2017).

The number of shocks experienced diminished WBI and all sub-indices except “Social Relations”. This reflects the value of networks and social capital in rural communities for coping with shocks and the importance of the resulting resilience for well-being (Eriksen et al., 2005; Moller et al., 2018; Shiferaw et al., 2014).

5.4. Distance to a protected area boundary is negatively associated with absolute environmental income and reliance but positively associated with well-being

Living adjacent to a protected area is often assumed beneficial as households can extract environmental products and benefit from outreach and integrated conservation and development projects, which has been associated with immigration and high population growth at the boundaries (Chao et al., 2018; Naidoo et al., 2019; Wittemyer et al., 2008). Our results show that households residing closer to the protected area boundaries as expected have higher environmental income. However, they also have lower well-being, and we thus find support for Hypothesis 4. Although households living closer to protected areas benefit from access to natural resources, they are disadvantaged in terms of WBI, “Basic Materials for a Good Life”, “Health”, and “Freedom of Choice”. The lower well-being may be explained by remoteness and the consequent lack of physical infrastructure including limited access to health services and markets, fewer livelihood options, and restrictions imposed by authorities in consideration of conservation objectives. In addition, communities close to protected areas experience higher levels of wildlife crop raiding and livestock depredation. These challenges may, in turn, foster stronger “Social Relations” in communities adjacent to protected areas (Estes et al., 2015; Oglethorpe et al., 2007).

The study year was characterized by a drought that affected household income portfolios compared to a “normal” year. Crop production was seriously reduced, particularly for Sukuma and Kuria agro-pastoralists living in the southern and western parts of the study area (Sewando et al., 2016). Obtaining valid and accurate information on the economic contribution of bushmeat is complicated by the illegal nature of the practice and respondents’ fear of sanctions (Contet et al., 2015; Nuno and John, 2015). Hence, the presented estimates of environmental income and reliance are probably conservative.

6. Conclusion

Nature provides a substantial economic contribution to households residing in and around the Greater Serengeti-Mara Ecosystem. Poorer households are most reliant on income generated by harvesting environmental products while better-off households harvest larger quantities. While environmental income is essential in households’ income portfolios, high environmental reliance is also associated with lower well-being. Hence, according to local own-reported perceptions, a higher quality of life is connected with lower reliance on harvesting environmental products. The reasons for this remain to be better understood but could be driven by restrictions on household activities or a desire to shift out of such arduous activities. Nevertheless, the findings
provide inputs for the design of interventions aimed at solving conflicts between enhancing local livelihoods and conservation objectives in the Greater Serengeti-Mara Ecosystem. Such initiatives should acknowledge the high current household reliance on environmental income and then proceed to build on households’ association of environmental reliance with lower well-being. This is a positive starting point for engaging households in activities outside environment product harvesting. Potential policy interventions derived from the key findings include enhancing access to education and providing technical assistance and low-interest loans or credit for alternative non-environmental based income generation activities and promoting and strengthening capacity building for sustainable protected area management.

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**Appendices**

**Appendix A**

Descriptions of indicators and statistics for constructing well-being indices

| Indicator | Indicator/indices description | Coefficients (Std. Err) |
|-----------|-------------------------------|-------------------------|
| Sub-index 1 | Q1. Basic Materials for a Good Life | 0.506*** (0.037) |
| Overall satisfaction with access to basic goods and services | Q1.0: Overall, you are satisfied with the basic goods and services available to your household (e.g., food, clothes, living conditions, transportation) for your daily life | 0.80 0.966*** (0.045) |
| Accessibility and affordability of basic goods and services | Q1.1: It is convenient and affordable for your household to access/purchase necessities (basic goods and material) for daily life | 0.82 1.031*** (0.044) |
| Affordability to necessary food | Q1.2: Your household can afford enough food to stay healthy | 0.76 1.003*** (0.044) |
| Affordability to basic facilities and services | Q1.3: Your household can afford to access basic facilities (e.g., health centre, electricity) and services (e.g., transportation, education) | 0.75 0.957*** (0.043) |
| Satisfaction with housing condition | Q1.4: You are satisfied with your housing condition (including size and quality) | 0.71 0.879*** (0.048) |
| Sub-index 2 | Q2: Security | 0.372*** (0.035) |
| Overall satisfaction with security | Q2.0: Overall, you are satisfied with the security of your household (e.g., life and property/assets) | 0.76 0.991*** (0.027) |
| Life safety | Q2.1: Your household members' safety in daily life is secure | 0.77 0.865*** (0.024) |
| Property safety | Q2.2: Your household's property safety in daily life is secure | 0.76 0.932*** (0.026) |
| Local crime incidence | Q2.3: The local crime incidence (e.g., theft, robbery, murder, other violent incidents) is low | – – |
| Access to government protection | Q2.4: The police and judicial system is always ready to help | 0.65 0.239*** (0.037) |
| Reliability of government protection | Q2.5: The police and judicial system can be trusted | 0.65 0.260*** (0.038) |
| Security for resource access | Q2.6: It is health wise safe (no contaminations or quality concerns) to access basic goods and services such as food, water, and medicine | 0.56 0.401*** (0.042) |
| Sub-index 3 | Q3: Health | 0.734*** (0.043) |
| Overall satisfaction with health status | Q3.0: Overall, you are satisfied with your household’s health status | 0.76 0.754*** (0.048) |
| Rest | Q3.1: How often do you feel you do not get enough rest or sleep? | 0.58 0.380*** (0.041) |
| Energy for daily life | Q3.2: How often your household members are not healthy or do not have enough energy for everyday life? | 0.71 0.533*** (0.034) |
| Emotion | Q3.3: How often do you have negative feelings such as unhappy, sad, or worrying? | 0.65 0.486*** (0.034) |
| Physical health | Q3.4: You are satisfied with your household’s physical health (including illness and injury) | 0.79 0.791*** (0.044) |
| Mental health | Q3.5: You are satisfied with your household’s sense of happiness and healthy mind-set | 0.68 0.705*** (0.038) |
| Leisure activities | Q3.6: How often do your household members have the opportunity for leisure activities? | – – |
| Sub-index 4 | Q4: Good Social Relations | 0.210*** (0.033) |
| Overall satisfaction with social relationships | Q4.0: Overall, you are satisfied with your household’s social relationships with others | 0.78 0.495*** (0.022) |
| Close neighborhood | Q4.1: This is a close-knit neighborhood | 0.77 0.501*** (0.025) |

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Appendix A (continued)

| Indicator | Indicator/indicators description | $r_{it}$ | Coefficients (Std. Err)$^b$ |
|-----------|---------------------------------|---------|-----------------------------|
| Trust in the community | Q4.2: Most people in this village (refer to the village name) are basically honest and can be trusted. | 0.69 | 0.621*** (0.034) |
| Opportunities of neighborhood interactions | Q4.3: There are many opportunities to meet neighbors and work on solving community problems | 0.80 | 0.660*** (0.026) |
| Participation in community activities | Q4.4: Your household members are actively involved/participate in social activities in your community groups or village | 0.71 | 0.551*** (0.024) |
| Help and mutual support within community | Q4.5: There are always some people ready to help if someone in your village/neighborhood had something unfortunate happen to them, such as a family member's sudden death | 0.64 | 0.362*** (0.020) |
| Sub-index 5 | Q5: Freedom of Choice and Action | | 0.527*** (0.037) |
| Overall satisfaction with freedom of choice and action | Q5.0: Overall, you are satisfied with your freedom of choice and actions | 0.56 | 0.262*** (0.035) |
| Freedom from discrimination | Q5.1. Your household members are always treated equally without regard to gender, tribe, race, language, religion, political beliefs, socioeconomic status and more within your community | 0.41 | 0.224*** (0.040) |
| Affordability to quality and nutritious food | Q5.2: Your household has affordable access to quality and nutritious food for a satisfied life | 0.72 | 0.698*** (0.048) |
| Affordability to healthcare | Q5.3: You have access to affordable healthcare as you wish | 0.77 | 1.021*** (0.049) |
| Affordability to education | Q5.4: You have access to affordable education as you wish | 0.73 | 0.943*** (0.049) |
| Affordability to quality housing | Q5.5: You have access to affordable quality housing as you wish | 0.78 | 1.051*** (0.050) |
| Free choice of employment | Q5.6: How difficult is finding a satisfactory job or undertake a livelihood activity? | 0.50 | 0.371*** (0.029) |
| Freedom of choices and actions to help others | Q5.7. How often do you feel that you want to help others but you cannot, because of limited socioeconomic or physical conditions? | 0.45 | 0.327*** (0.036) |

***$p < .001$, **$p < .005$. Two indicators were excluded due to low consistency with other indicators (i.e. Q2.3 and Q3.6). Paths between observed indicators and sub-indices are not shown here.

Options for all indicator contents are designed in the five-category Likert scale. All the responses are coded in the order from the lowest score of 1 to the highest score of 5. A higher score represents a higher level of well-being.

$^a$ $r_{it}$: item-total correlations.

$^b$ Coefficients (Std. Err). coefficients are derived from confirmatory factor analysis, standard errors are presented in parentheses.

Appendix B

Descriptive statistics for variables used in the regression models

| Variables | Mean | Standard deviation | Min | Max |
|-----------|------|--------------------|-----|-----|
| Dependent variables | | | | |
| Environmental reliance (relative environmental income %) | 0.38$^a$ | 0.29 | 0 | 1 |
| Environmental income (adult equivalent USD PPP) | 362.31 | 400.95 | 20.21 | 4427.52 |
| Overall Well-being index score (0−100) | 64.55 | 17.76 | 0 | 100 |
| Basic material for a good life sub-index socre (0–100) | 53.77 | 27.21 | 0 | 100 |
| Safety sub-index score (0-100) | 83.21 | 23.49 | 0 | 100 |
| Health sub-index score (0–100) | 65.87 | 19.12 | 0 | 100 |
| Social Relations sub-index score (0–100) | 87.32 | 14.76 | 0 | 100 |
| Freedom of Choice and Action sub-index score (0–100) | 48.10 | 23.30 | 0 | 100 |
| Independent variables | | | | |
| Age of household head (years) | 47.38 | 14.00 | 19 | 92 |
| Household education (years) | 4.98 | 4.37 | 0 | 30 |
| Female headed household (%) | 0.18 | 0.39 | 0 | 1 |
| Crop land size (Hectares) | 2.50 | 5.90 | 0 | 101 |
| Total asset value (USD PPP) | 614.42 | 4033.49 | 0 | 94,501 |
| Shocks experienced in the past 12 months (numbers) | 1.63 | 1.23 | 0 | 11 |
| Distance to protected area (km) | 9.09 | 9.42 | 0 | 42.11 |

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Appendix B (continued)

Variables | Mean | Standard deviation | Min | Max
---|---|---|---|---
Tribe
Maasai (%) | 0.33 | 0.47 | 0 | 1
Sukuma (%) | 0.31 | 0.46 | 0 | 1
Kuria (%) | 0.20 | 0.40 | 0 | 1

* The mean of environmental reliance at household level here is calculated as the means of individual household income shares (and not the share of mean environmental income in mean total income at district or region levels).

Appendix C
Pairwise comparison of annual total household income (USD PPP per adult equivalent unit) across regions and districts in the Greater Serengeti-Mara Ecosystem using ANOVA with Bonferroni test

| Regions & districts | Environmental income | Crop income | Livestock income | Ecosystem derived income | Business income | Wage income | Other income | Non-ecosystem income | Total income |
|---|---|---|---|---|---|---|---|---|---|
| Southern vs. Western | *** | NS | NS | NS | NS | NS | NS | NS | NS |
| Southern vs. Eastern-Ngorongoro Conservation Area | *** | *** | *** | *** | *** | NS | NS | NS | *** |
| Southern vs. Eastern-Loi | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Southern vs. Northern | NS | NS | *** | *** | NS | NS | NS | NS | NS |
| Western vs. Eastern-Ngorongoro Conservation Area | *** | *** | *** | *** | NS | NS | NS | NS | NS |
| Western vs. Eastern-Loi | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Western vs. Northern | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Eastern-Ngorongoro Conservation Area vs. Northern | *** | *** | *** | *** | NS | NS | NS | NS | NS |
| Eastern-Ngorongoro Conservation Area vs. Loiondo | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Eastern-Loi vs. Northern | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Meatu vs. Bariadi | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Serengeti vs. Tarime | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Ngorongoro vs. Narok | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Serengeti vs. Tarime | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Ngorongoro Conservation Area vs. Loiondo | NS | NS | NS | NS | NS | NS | NS | NS | NS |

** and *** signify statistical significance at 0.1, 0.05 and 0.01 levels, respectively. NS = not significant.

Appendix D
Annual total household income in absolute (USD PPP) and relative (%) per adult equivalent unit across income quintile groups in the Greater Serengeti-Mara Ecosystem

| Income source | INC Q1 | INC Q2 | INC Q3 | INC Q4 | INC Q5 |
|---|---|---|---|---|---|
| Tanzania (N = 825) | Abs² | Rel² | Abs | Rel | Abs | Rel | Abs | Rel | Abs | Rel |
| Environmental income | 148 (7) | 81 | 226 (9) | 49 | 297 (14) | 37 | 489 (30) | 34 | 731 (54) | 17 |
| Crop income | −27 (12) | −15 | 87 (9) | 19 | 143 (14) | 18 | 173 (21) | 12 | 462 (63) | 11 |
| Livestock income | 37 (6) | 20 | 85 (10) | 18 | 263 (18) | 33 | 568 (37) | 39 | 2230 (250) | 52 |
| Business income | 9 (3) | 5 | 27 (6) | 6 | 38 (7) | 5 | 108 (22) | 7 | 384 (93) | 9 |
| Wage income | 7 (2) | 4 | 22 (5) | 5 | 38 (9) | 5 | 84 (20) | 6 | 401 (93) | 9 |
| Other income | 9 (1) | 5 | 12 (2) | 3 | 18 (4) | 2 | 25 (9) | 2 | 44 (14) | 1 |
| Total income | 183 (9) | 100 | 460 (7) | 100 | 796 (9) | 100 | 1447 (22) | 100 | 4252 (239) | 100 |
| Kenya (N = 159) | | | | | | | | | | |
| Environmental income | 165 (14) | 21 | 302 (43) | 21 | 267 (43) | 12 | 299 (34) | 8 | 376 (66) | 5 |
| Crop income | 19 (12) | 2 | −3 (5) | 0 | 78 (43) | 3 | 30 (22) | 1 | 32 (27) | 0 |

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Appendix D (continued)

| Income source    | INC Q1 Abs | INC Q1 Rel | INC Q2 Abs | INC Q2 Rel | INC Q3 Abs | INC Q3 Rel | INC Q4 Abs | INC Q4 Rel | INC Q5 Abs | INC Q5 Rel |
|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Livestock income| 358 (34)   | 47         | 695 (61)   | 47         | 1074 (107)| 47         | 1747 (168) | 47         | 3563 (419) | 44         |
| Business income  | 121 (26)   | 16         | 165 (30)   | 11         | 366 (82)  | 16         | 732 (161)  | 20         | 1158 (292)| 14         |
| Wage income      | 58 (20)    | 7          | 189 (51)   | 13         | 256 (60)  | 11         | 617 (141)  | 17         | 2169 (657)| 27         |
| Other income     | 50 (15)    | 6          | 122 (29)   | 8          | 243 (58)  | 11         | 314 (75)   | 8          | 849 (146) | 10         |
| Total income     | 770 (42)   | 100        | 1469 (33)  | 100        | 2284 (60) | 100        | 3740 (88)  | 100        | 8148 (746)| 100        |

Notes: Standard errors in parenthesis.

* Abs = absolute income (USD PPP).

* Rel = relative income (% of total income). For each income source and quintile, these are calculated as the share of the aggregated income in aggregated total income due to negative income sources incurred, thus no standard errors are reported.

Appendix E. The absolute environmental income and environmental reliance as functions of total income in Tanzania and Kenya.
Appendix F

Annual total household income composition across income sources in absolute (USD PPP) and relative (%) measures (per adult equivalent unit) for well-being quintiles in Tanzania and Kenya

| Income source          | WB Q1 Abs | Rel | WB Q2 Abs | Rel | WB Q3 Abs | Rel | WB Q4 Abs | Rel | WB Q5 Abs | Rel |
|------------------------|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
|                        |           |     |           |     |           |     |           |     |           |     |
| Tanzania (N = 825)     |           |     |           |     |           |     |           |     |           |     |
| Environmental income   | 320 (25)  | 37  | 354 (27)  | 30  | 357 (32)  | 25  | 427 (36)  | 29  | 433 (41)  | 20  |
| Crop income            | 163 (30)  | 19  | 149 (21)  | 13  | 188 (33)  | 13  | 168 (39)  | 11  | 170 (41)  | 8   |
| Livestock income       | 315 (47)  | 37  | 509 (150) | 43  | 773 (152) | 53  | 661 (98)  | 45  | 924 (128) | 42  |
| Business income        | 15 (4)    | 2   | 58 (29)   | 5   | 59 (14)   | 4   | 75 (20)   | 5   | 360 (89)  | 16  |
| Wage income            | 33 (15)   | 4   | 75 (26)   | 6   | 52 (17)   | 4   | 117 (37)  | 8   | 276 (84)  | 13  |
| Other income           | 14 (2)    | 2   | 26 (13)   | 2   | 16 (3)    | 1   | 16 (4)    | 1   | 35 (11)   | 2   |
| Total income           | 860 (70)  | 100 | 1171 (170)| 100 | 1445 (182)| 100 | 1464 (128)| 100 | 2198 (187)| 100 |
| Kenya (N = 159)        |           |     |           |     |           |     |           |     |           |     |
| Environmental income   | 249 (32)  | 13  | 273 (36)  | 13  | 236 (36)  | 8   | 384 (68)  | 9   | 262 (34)  | 5   |
| Crop income            | 20 (19)   | 1   | 28 (19)   | 1   | 38 (25)   | 1   | 42 (38)   | 1   | 29 (24)   | 1   |
| Livestock income       | 1040 (200)| 53  | 1263 (206)| 61  | 1595 (291)| 56  | 1510 (259)| 37  | 1966 (409)| 37  |
| Business income        | 232 (57)  | 12  | 211 (59)  | 10  | 614 (151)| 21  | 688 (164)| 17  | 780 (272)| 15  |
| Wage income            | 189 (80)  | 10  | 201 (72)  | 10  | 188 (58)  | 7   | 1025 (302)| 25  | 1624 (605)| 31  |
| Other income           | 216 (53)  | 11  | 96 (32)   | 5   | 198 (48)  | 7   | 444 (106)| 11  | 604 (141)| 11  |
| Total income           | 1945 (257)| 100 | 2072 (224)| 100 | 2869 (320)| 100 | 4094 (523)| 100 | 5266 (938)| 100 |

Note: Standard errors in parenthesis.

- Abs = absolute income (USD PPP).
- Rel = relative income (% of total income). For each income source and quintile, these are calculated as the share of the aggregated income in aggregated total income due to negative income sources incurred, thus no standard errors are reported.
Appendix G. The absolute environmental income and reliance as functions of well-being score in Tanzania and Kenya

Appendix H
Pairwise comparison of total annual household income (USD PPP per adult equivalent unit) across income sources and income quintiles using ANOVA with Bonferroni test

| Income source | INC Q1 vs INC Q2 | INC Q1 vs INC Q3 | INC Q1 vs INC Q4 | INC Q1 vs INC Q5 | INC Q2 vs INC Q3 | INC Q2 vs INC Q4 | INC Q2 vs INC Q5 | INC Q3 vs INC Q4 | INC Q3 vs INC Q5 | INC Q4 vs INC Q5 |
|---------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Tanzania      |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| Environmental income | NS               | ***              | ***              | ***              | NS               | ***              | ***              | ***              | ***              | ***              |
| Crop income   | *                | ***              | ***              | ***              | NS               | NS              | ***              | NS               | ***              | ***              |
| Livestock     | NS               | NS               | ***              | ***              | NS               | NS              | ***              | NS               | ***              | ***              |
| Business income | NS             | NS               | NS               | ***              | NS               | NS              | ***              | NS               | ***              | ***              |

(continued on next page)
Appendix H (continued)

| Income source | INC Q1 vs INC Q2 | INC Q1 vs INC Q3 | INC Q1 vs INC Q4 | INC Q1 vs INC Q5 | INC Q2 vs INC Q3 | INC Q2 vs INC Q4 | INC Q2 vs INC Q5 | INC Q3 vs INC Q4 | INC Q3 vs INC Q5 | INC Q4 vs INC Q5 |
|---------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Wage income   | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Other income  | NS               | NS               | NS               | **               | NS               | NS               | **               | NS               | ***              | ***              |
| Total income  | ***              | ***              | ***              | ***              | ***              | ***              | ***              | ***              | ***              | ***              |
| Kenya (N = 159) |                |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| Environmental income | NS               | NS               | NS               | ***              | NS               | NS               | NS               | NS               | NS               | NS               |
| Crop income   | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               |
| Livestock     | **               | NS               | NS               | **               | NS               | NS               | NS               | NS               | NS               | NS               |
| Business income | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Wage income   | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Other income  | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Total income  | **               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| * , ** and *** signify statistical significance at 0.1, 0.05 and 0.01 levels, respectively. NS = not significant.

Appendix I

Pairwise comparison of total annual household income (USD PPP per adult equivalent unit) across income sources and well-being score quintiles using ANOVA with Bonferroni test

| Income source | WBI Q1 vs WBI Q2 | WBI Q1 vs WBI Q3 | WBI Q1 vs WBI Q4 | WBI Q1 vs WBI Q5 | WBI Q2 vs WBI Q3 | WBI Q2 vs WBI Q4 | WBI Q2 vs WBI Q5 | WBI Q3 vs WBI Q4 | WBI Q3 vs WBI Q5 | WBI Q4 vs WBI Q5 |
|---------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Tanzania (N = 825) |                |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| Environmental income | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               |
| Crop income   | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               |
| Livestock     | **               | NS               | NS               | **               | NS               | NS               | NS               | NS               | NS               | NS               |
| Business income | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Wage income   | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Other income  | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Total income  | **               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Kenya (N = 159) |                |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| Environmental income | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               |
| Crop income   | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               | NS               |
| Livestock     | **               | NS               | NS               | **               | NS               | NS               | **               | NS               | **               | NS               |
| Business income | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Wage income   | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Other income  | NS               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |
| Total income  | **               | NS               | NS               | ***              | NS               | NS               | ***              | NS               | ***              | ***              |

* , ** and *** signify statistical significance at 0.1, 0.05 and 0.01 levels, respectively. NS = not significant.

Appendix J

Cash and subsistence environmental incomes in absolute (USD PPP) and relative (%) per adult equivalent unit across regions and districts in the Greater Serengeti-Mara Ecosystem

| Cash environmental income | Subsistence environmental income |
|---------------------------|----------------------------------|
| Abs | Rel | Abs | Rel |
| Southern | 23.39 (6.38) | 2.05 | 1018.73 (35.47) | 97.95 |
| Meatu district | 23.80 (6.97) | 2.42 | 916.48 (44.79) | 97.58 |
| Bariadi district | 22.84 (11.70) | 1.55 | 1156.50 (55.10) | 98.45 |
| Western | 242.87 (67.06) | 5.58 | 1804.76 (78.84) | 94.42 |
| Serengeti district | 107.44 (33.40) | 3.12 | 1810.81 (77.26) | 96.88 |
| Tarime district | 517.16 (189.32) | 10.56 | 1792.52 (180.62) | 89.44 |
| Eastern (Ngorongoro district) | 117.65 (32.04) | 3.21 | 2905.13 (129.70) | 96.92 |
| Ngorongoro Conservation Area | 108.10 (42.27) | 3.42 | 2303.43 (176.98) | 96.58 |
| Loliondo | 123.69 (45.08) | 3.08 | 3285.70 (171.15) | 96.92 |
| Northern (Ngorongoro) | 375.53 (96.60) | 21.67 | 1360.53 (97.11) | 78.33 |
| All Sample | 178.41 (29.86) | 5.11 | 1724.93 (47.25) | 94.89 |

Note: Standard errors in parenthesis.

a Abs = absolute income (USD PPP).

b Rel = relative income (% of total income). For each income source and quintile, these are calculated as the share of the aggregated income in aggregated total income due to negative income sources incurred, thus no standard errors are reported.
Appendix K

Frist and second stage regressions of 2SLS IV estimation for “Basic Material for a Good Life” well-being model using heteroskedasticity-based instrumental variables for environmental reliance in the Greater Serengeti-Mara Ecosystem, 2016–2017. The instruments were generated through the interaction between the demeand (centered) regressors and the error term of the first stage regression (the environmental reliance regression model).

| Instrument                           | First stage regression | Second stage regression |
|--------------------------------------|------------------------|-------------------------|
|                                      | (Environmental reliance) | (Well-being sub-index on Basic material for a good life) |
| Environmental reliance               | −                     | −0.774*** (0.118)      |
| Household education (years)          | −0.012*** (0.001)      | 0.054*** (0.007)       |
| Female-headed household (0/1)        | 0.089*** (0.009)       | −0.121 (0.078)         |
| Age of household head (years)        | −0.002*** (0.0002)     | −0.0004 (0.0002)       |
| Shocks in the past 12 months (numbers) | −0.021*** (0.003)     | −0.084** (0.025)       |
| Distance to protected area (km)      | −0.004*** (0.0004)     | 0.004 (0.003)          |
| Tribe                                 |                        |                         |
| Maasai                                | −0.078*** (0.012)      | 0.390*** (0.103)       |
| Sukuma                                | −0.030*** (0.010)      | −0.323*** (0.089)      |
| Kuria                                 | −0.005 (0.011)         | 0.041 (0.097)          |
| Country: Kenya                        | −0.210*** (0.013)      | −0.574*** (0.113)      |
|                                      |                        |                         |
|                                      | R-squared              | 0.200                   |
|                                      | Model significance (F(18, 966) and F(10, 966) for first and second stage regression, respectively) | 414.43*** 22.06*** |
|                                      | Test of excluded instruments (F(9,966)) | 640.67***               |
|                                      | Sargan (overidentification test of all instruments, Chi-squared (8)) | 11.3612 |

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