Women, wellbeing and WMAs: Supplementary material

This supplementary material can be read in conjunction with Bluwstein et al 2018a and the associated dataset deposit at http://reshare.ukdataservice.ac.uk/852960/ for additional detail on data collection protocols, sample structure and data management for the wider study and household survey. Here we give detail of:

1. Figures and tables supporting quantitative and statistical findings referred to in the main text
2. Detail of quantitative and statistical analyses underpinning our findings and their causal attribution (Bayesian Hierarchical Models; post-stratification regression adjustments);
3. Additional, less salient findings on access to natural resources, and on income-generating activities.
4. Supplementary data on females heads of household
5. References supporting all the above

1. ***Figures and tables supporting quantitative and statistical findings presented in main text***

Resource access to:	Much worse	Worse	No change	Better
Land for settlement	17.4 (14.1, 20.6)	52.8 (49.3, 56.3)	28.9 (26.0, 32.0)	1.0 (0.4, 1.6)
Land for cultivation	22.0 (18.6, 25.6)	50.4 (46.8, 53.9)	26.8 (23.6, 29.6)	0.9 (0.4, 1.4)
Firewood	5.5 (4.0, 7.1)	16.1 (13.7, 18.8)	73.6 (70.5, 76.5)	4.7 (3.3, 6.4)
Water	13.0 (10.0, 16.2)	39.1 (35.6, 42.4)	46.7 (43.7, 49.4)	1.2 (0.6, 2.1)
Construction materials	12.9 (10.0, 15.9)	43.1 (39.8, 46.4)	42.5 (39.6, 45.8)	1.5 (0.8, 2.2)

Table S1 percentages of married women overall reporting change in resource access (lower and upper range in parentheses)

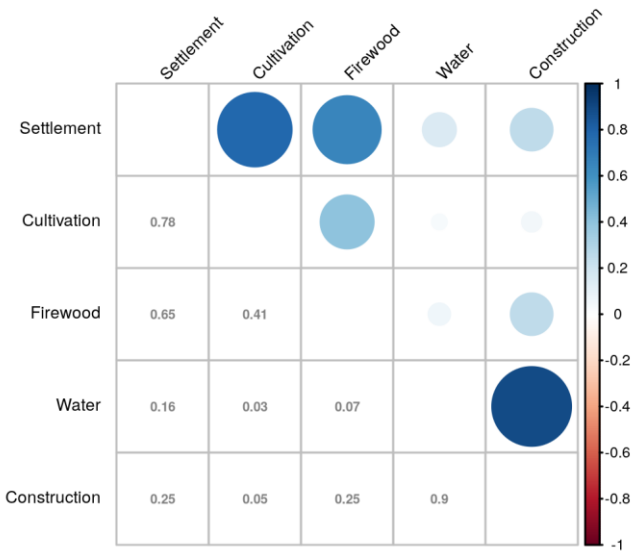


Figure S1: Village-level correlations on married women's changing access to different natural resources through time. Size of dot and intensity of colour indicate strength of correlation, with corresponding quantitative values displayed in the lower segment. Blue indicates positive and red, negative, correlation

Table S2 Overall percentages of wives generating income from different activities (lower and upper range in parentheses)

Activity	Percentage
Livestock	28.4 (19.8, 36.7)
Crops	2.8 (0.0, 6.5)
NTFPs	0.7 (0.0, 1.9)
Water	0.7 (0.0, 1.5)
Kibarua	23.1 (12.4, 34.6)
Crafts	1.4 (0.0, 4.5)
Petty vending	4.5 (0.5, 8.4)
Cooked food	0.0 (0.0, 0.3)
Paid work	0.0 (0.0, 0.1)
Remittances	21.1 (3.0, 28.6)
External aid	1.2 (0.0, 4.7)

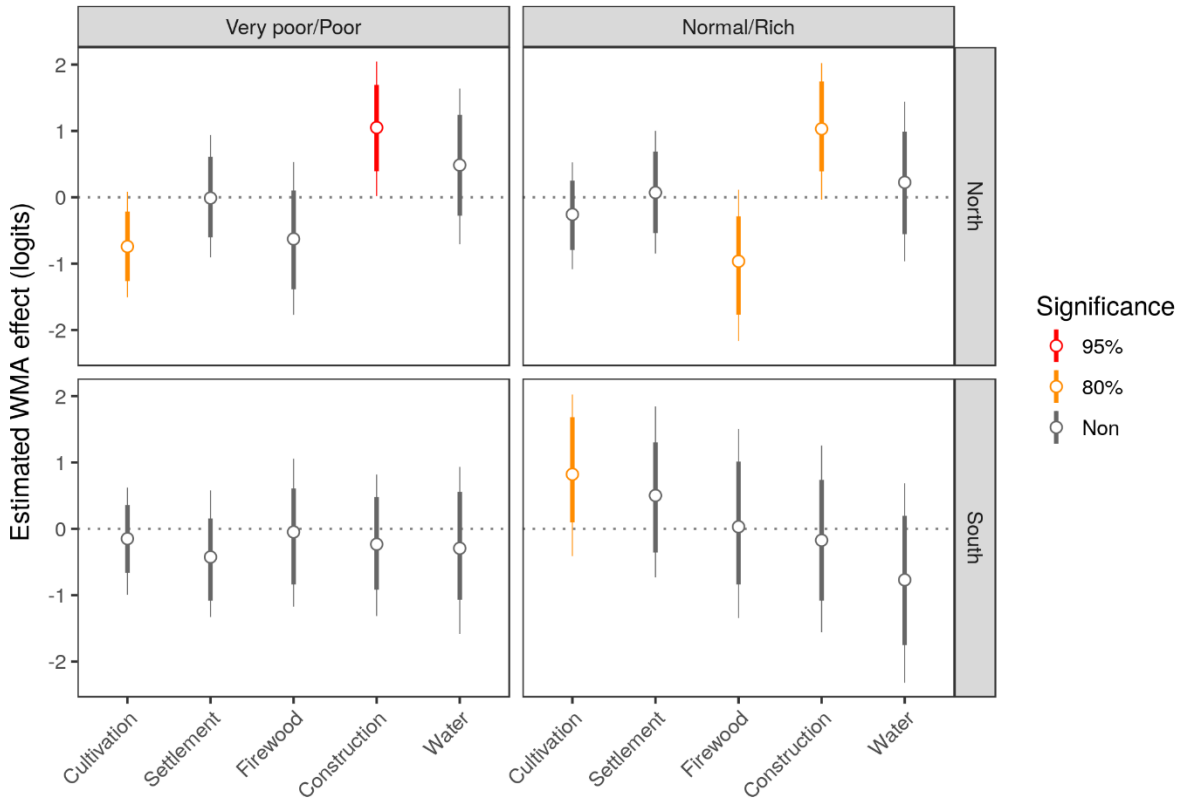


Figure S2: WMA impacts on married women's access to natural resources, disaggregated by region and by pooled wealth group. Thick and thin lines show 80% and 95% credible intervals around means respectively. Effects traditionally considered statistically significant (where 95% confidence intervals (CIs) do not overlap zero) display in red; weaker evidence for an effect (where 80% CIs do not overlap zero) in orange. Negative outcomes (below the zero line) indicate WMAs are associated with a worse outcome.

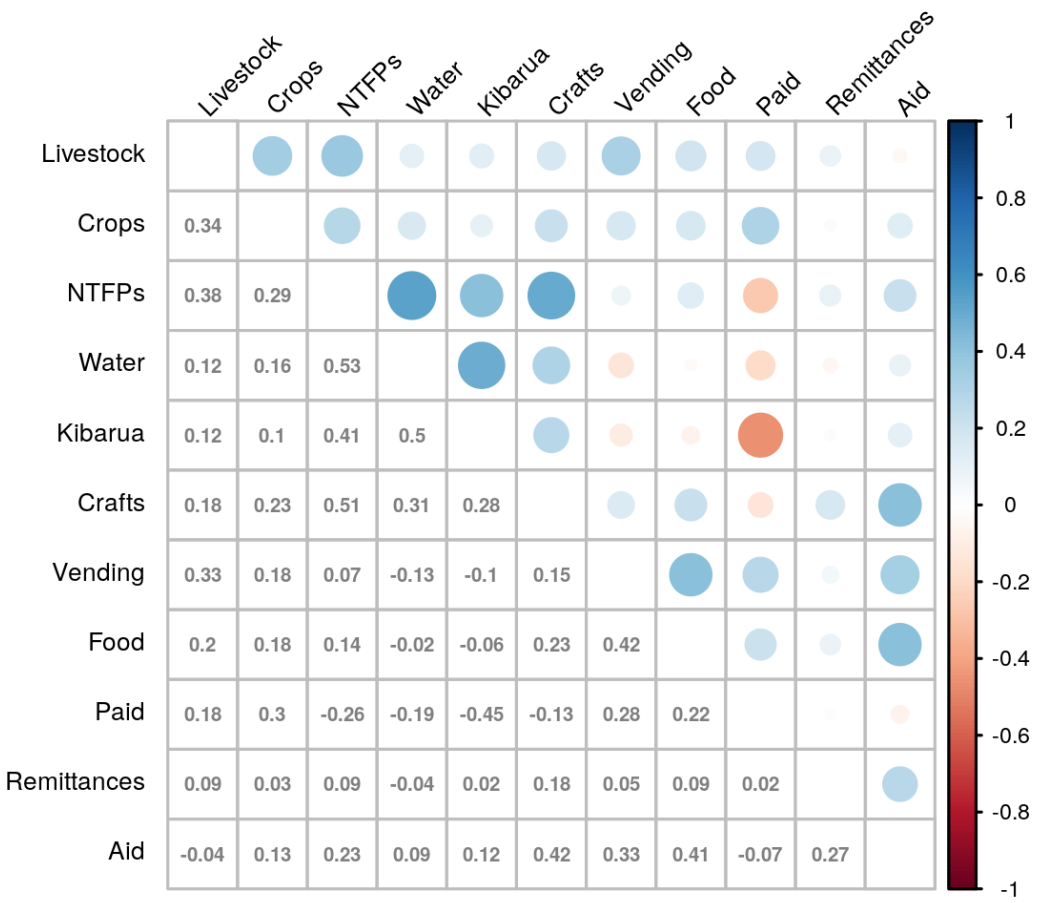
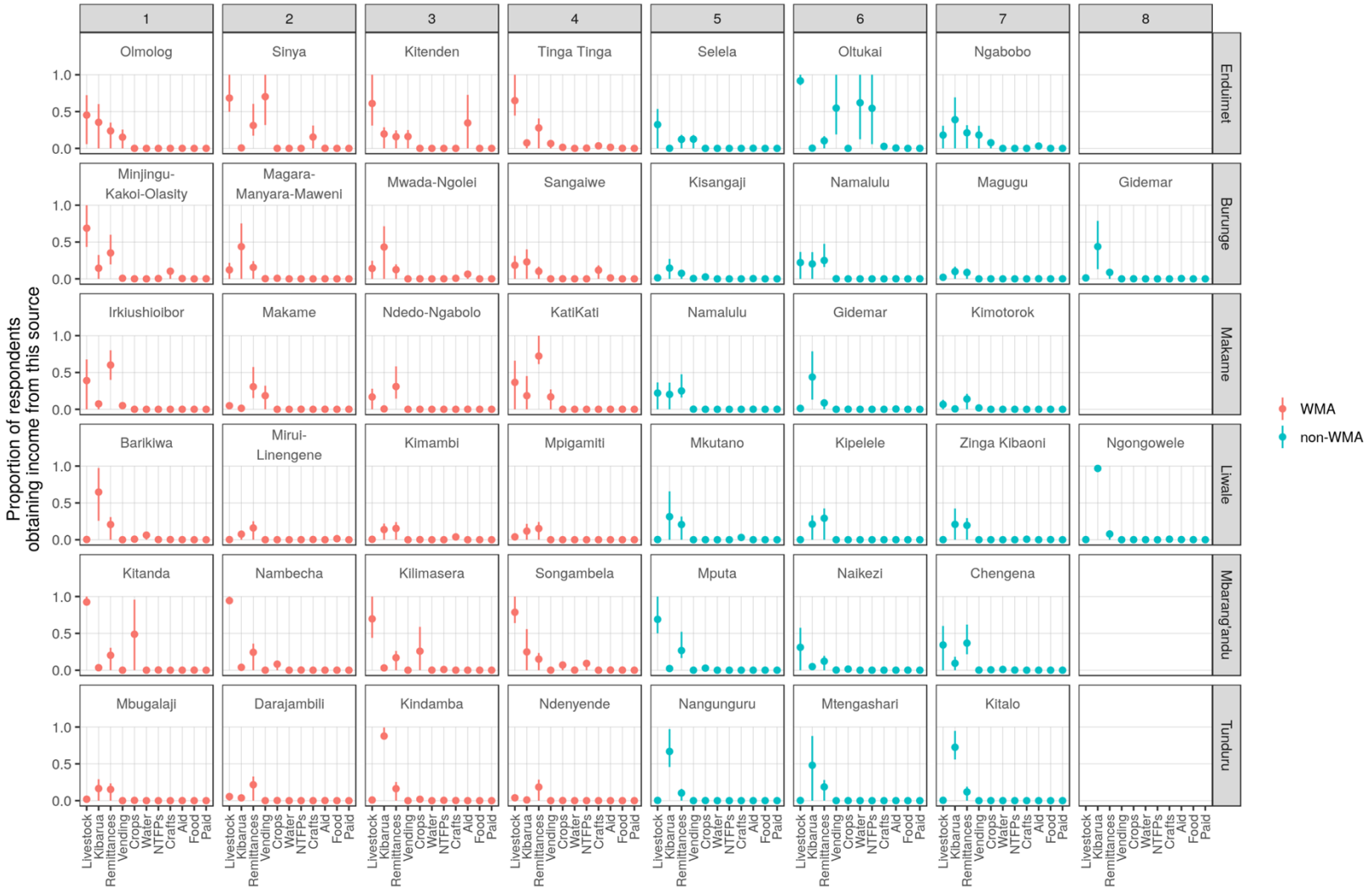


Figure S3: Individual-level correlations among income-generating activities. Size of dot and intensity of colour indicate strength of correlation, with corresponding quantitative values displayed in the lower segment. Blue indicates positive and red, negative, correlation

Fig S4 Wives' income-generating activities by village and WMA status



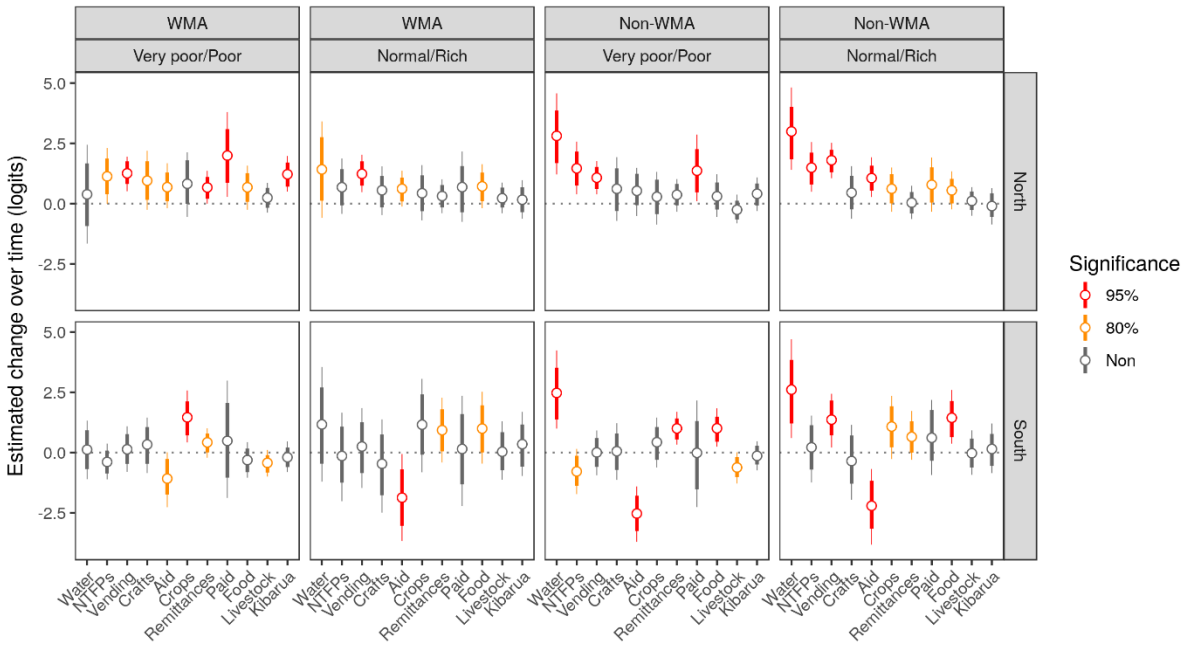


Fig S5: Change of income-generating activities through time, disaggregated by region, by pooled wealth group, and by WMA/non-WMA status. Thick and thin lines show 80% and 95% credible intervals around means respectively. Effects traditionally considered statistically significant (where 95% confidence intervals (CIs) do not overlap zero) display in red; weaker evidence for an effect (where 80% CIs do not overlap zero) in orange. Negative outcomes (below the zero line) indicate WMAs are associated with a worse outcome.

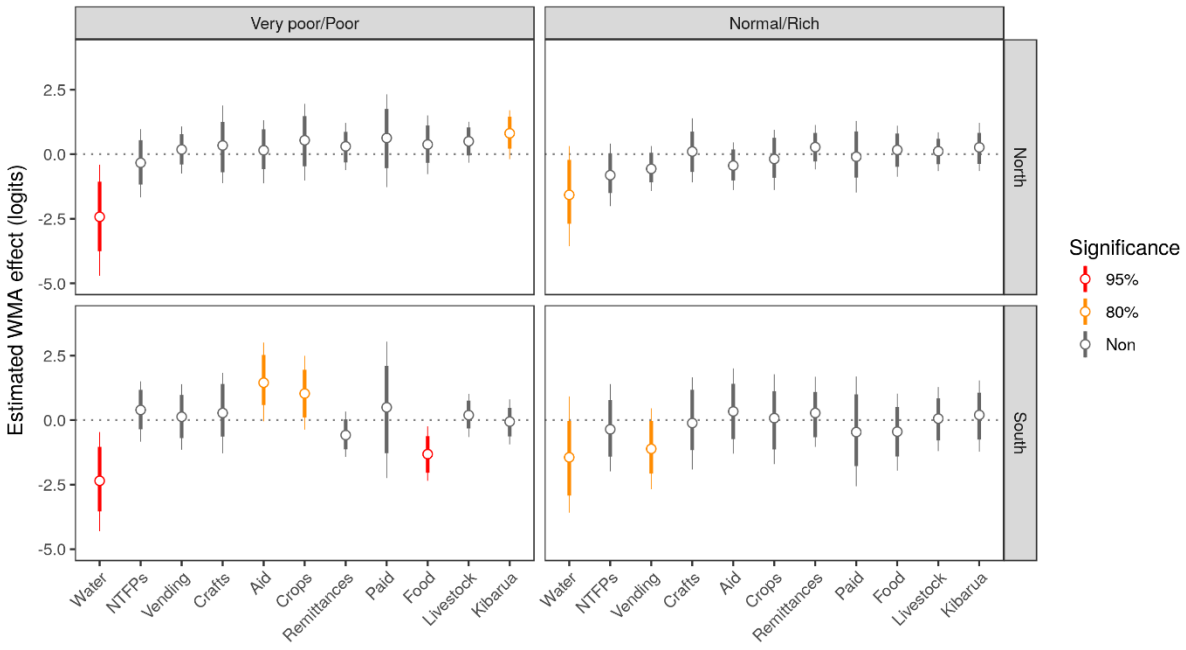


Figure S6: WMA effect on married women's income-generating activities, disaggregated by region and by pooled wealth group. Thick and thin lines show 80% and 95% credible intervals around means respectively. Effects traditionally considered statistically significant (where 95% confidence intervals (CIs) do not overlap zero) display in red; weaker evidence for an effect (where 80% CIs do not overlap zero) in orange. Negative outcomes (below the zero line) indicate WMAs are associated with a worse outcome.

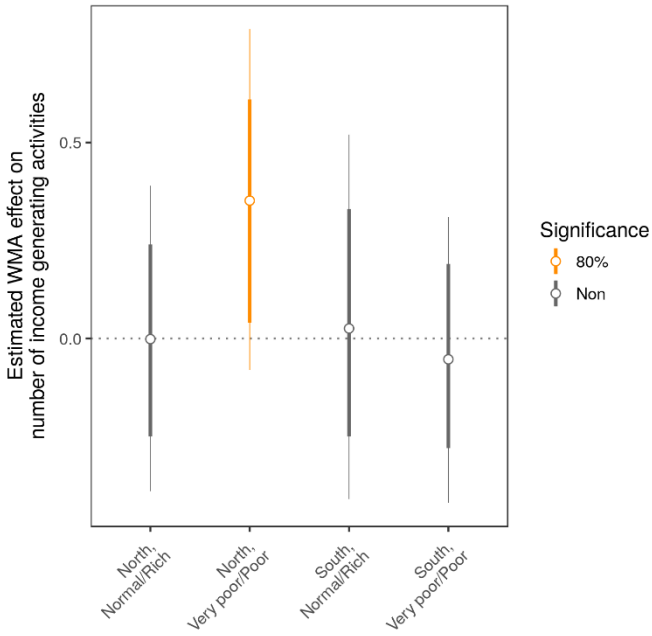


Figure S7: WMA effect on number of income-generating activities. Thick and thin lines show 80% and 95% credible intervals around means respectively. Effects traditionally considered statistically significant (where 95% confidence intervals (CIs) do not overlap zero) display in red; weaker evidence for an effect (where 80% CIs do not overlap zero) in orange. Negative outcomes (below the zero line) indicate WMAs are associated with a worse outcome.

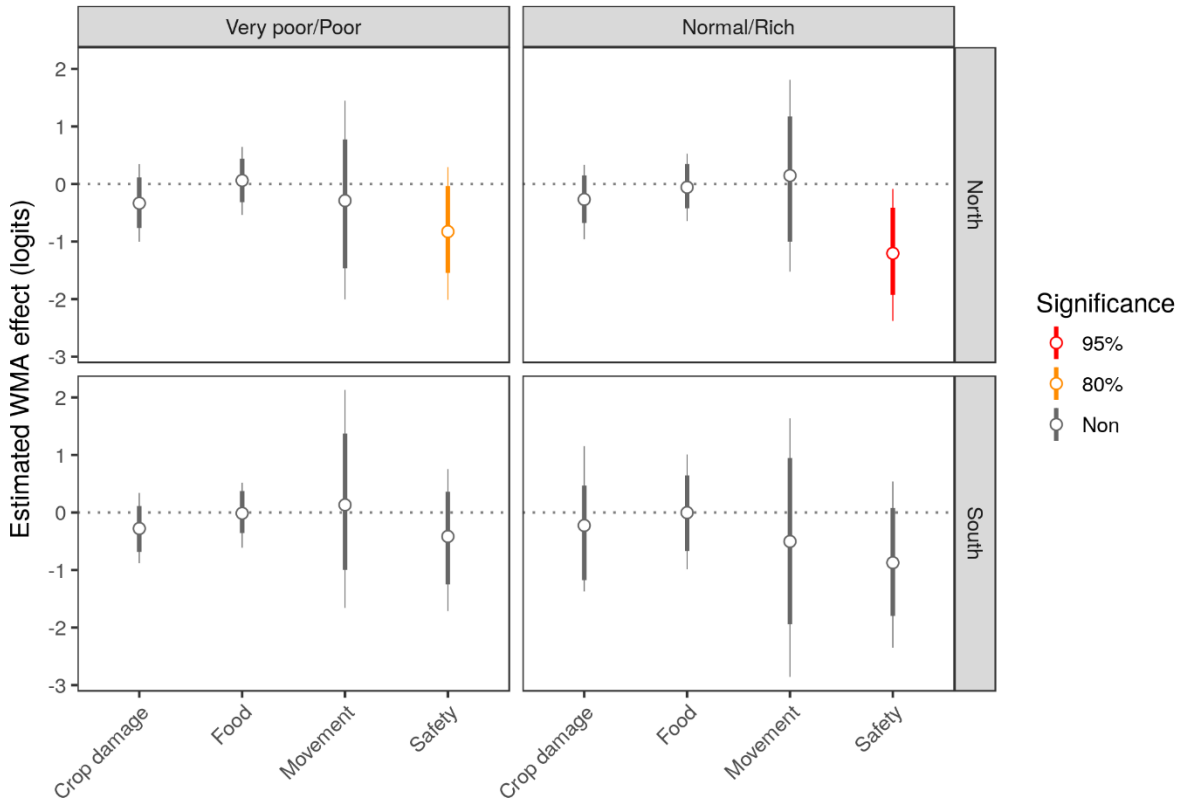


Figure S8: WMA effect on dimensions of food and physical security, disaggregated by region and wealth. Thick and thin lines show 80% and 95% credible intervals around means respectively. Effects traditionally considered statistically significant (where 95% confidence intervals (CIs) do not overlap zero) display in red; weaker evidence for an effect (where 80% CIs do not overlap zero) in orange. Negative outcomes (below the zero line) indicate WMAs are associated with a worse outcome.

Table S3 Overall reported change in dimensions of security (lower and upper range in parentheses)

Outcome	Much worse	Worse	No change	Better	Much better
Crop damage by wildlife	8.1 (6.1, 10.4)	29.6 (25.7, 33.5)	32.9 (29.5, 36.3)	23.4 (19.9, 27.2)	5.9 (4.2, 7.6)
Ability to provide food	3.2 (1.9, 4.3)	35.8 (31.8, 39.5)	28.0 (25.0, 30.8)	31.2 (27.6, 35.0)	1.9 (1.0, 2.8)
Freedom of movement	3.7 (2.6, 4.8)	11.0 (8.8, 13.1)	83.9 (81.3, 86.2)	0.6 (0.2, 1.1)	0.8 (0.3, 1.3)
Worry about wildlife	8.9 (7.1, 10.7)	19.1 (16.2, 21.7)	38.6 (35.2, 41.8)	19.2 (16.3, 22.0)	14.2 (11.7, 17.0)

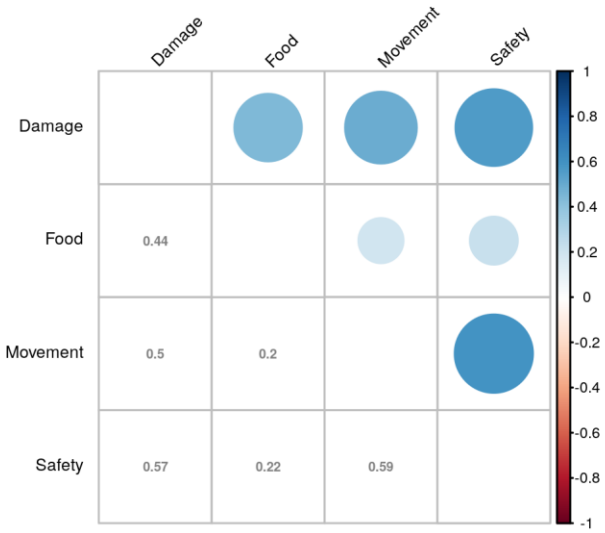


Figure S9 Correlation between dimensions of security**.** Size of dot and intensity of colour indicate strength of correlation, with corresponding quantitative values displayed in the lower segment. Blue indicates positive and red, negative, correlation

2. ***Analysis: Estimating WMA effects***

WMA effects on income-generation, access to assets, security and wildlife damage were estimated using Bayesian hierarchical models (Gelman et al. 2013). Our dataset contained 20 questions which captured responses relevant to these three domains (11 questions on income generation, five on access to natural resources and four relevant to safety and food security). Conducting separate analyses of each of these questions inflates the risk of finding spurious relationships, so we constructed three multivariate models which jointly modelled the responses falling within each domain, including correlations between them (cf. Seemingly Unrelated Regressions models; Greene 2018, Ch.10).

Responses were recorded as either ordinal variables derived from Likert-type items (e.g. change in wildlife damage: five-point scale from 'Much less now' to 'Much more now') to which we fit cumulative link submodels, or binary variables derived from Yes/No questions, to which we fit binomial sub-models (Agresti & Kateri, 2011). In all models, predictor variables included dummy variables indicating WMA membership, whether the household wealth was ranked as average or rich (N/R), as opposed to very poor or poor (VP/P) in 2007, and whether the village was located in the South or North. Where responses captured conditions in 2007 and 2014/5 separately (rather than asking directly about change over time) our models included a dummy variable indicating whether responses referred to 'after' (i.e. 2014/5) and their interaction with the WMA membership dummy.

To adjust for any covariate imbalance remaining post-matching, we also included the following matching variables (measured prior to WMA establishment) as predictors in our models: distance to nearest road, nearest town, nearest wildlife corridor; perpendicular distance to edge of nearest national park/ game reserve; population density, and proportion of village land covered by forest (Bluwstein et al. 2018a).

To properly account for our data structure, our models also included separate intercepts for individual villages, groupings of WMA villages and their matched non-WMA 'controls' and, in the case of binary responses, individual households, with each batch of parameters given its own hierarchical Gaussian prior. Correlations between outcomes within each domain were modelled using an unstructured covariance matrix between household parameters (for sources of income) or village parameters (for access to resources and safety). Unmodelled predictor variables and the standard deviations of groups of modelled predictors were given

weakly informative Student's-t priors centred on zero, with 7 degrees of freedom and scale 1 (Gelman et al. 2013). The intercept terms were given weakly informative Gaussian priors centred on zero with standard deviations of 10.

Where responses referred to conditions in specific periods of time, our estimate of WMA effect followed before/after-control/impact (BACI) design logic, whereby changes over time are compared between WMA and non-WMA areas to produce a form of 'difference-in-differences' (DiD). In our models this was represented by the coefficient of the term for the first-order interaction between the dummies for WMA membership and the 'after' period. Where questions referred to changes over time, our estimate of WMA effect was calculated as the difference between WMA and non-WMA areas, represented in our models by the coefficient of the term for WMA membership. In both cases, differences in WMA effects between subgroups were estimated from their higher-order interactions with the variables indicating subgroup characteristics.

Post-stratification

Our stratified sampling deliberately over-represented households that were either poorer or richer than normal or occupied a leadership position in 2014 (see Bluwstein et al 2018a for details). To arrive at an unbiased overall estimate of the distributions of income-generating activities, perceptions of access to resources and safety at the time of data collection, we therefore constructed a second set of models and carried out a poststratification procedure, adjusting our estimates to reflect the population (averaging quantities of interest over the sub-groups defined by wealth, WMA membership, leadership status, region, village and WMA grouping in proportion to these characteristics' distribution in the study population: Ghitza & Gelman, 2013). The structure of the models used in this step was similar to that described

above, with two modifications: an additional dummy variable was included, indicating whether anyone in the household occupied a leadership position in 2014, and the dummy variable indicating rich households was replaced with a four-level factor indicating the household's wealth rank in 2014. To reduce the risk of overfitting these subgroups, the parameters for wealth rank were given a hierarchical Gaussian prior.

Data preparation, analysis and post-processing were carried out in R version 3.3.2 (R Core Team 2016). Models were fitted using Stan version 2.14.1 via the brms interface (Bürkner 2017). In each case we ran four Markov Chain Monte Carlo (MCMC) chains for 2000 iterations, discarding the first 1000 iterations as a warm-up to give a total of 4,000 post-warmup MCMC draws. We assessed model convergence visually by consulting trace plots of MCMC draws and numerically with Gelman-Rubin statistics, with values <=1.01 taken to indicate convergence. We also checked the effective sample size and Monte Carlo standard error to ensure MCMC chain lengths were sufficient to provide stable parameter estimates. Model adequacy was assessed using posterior predictive checks (Gelman et al. 2013). In the following text, model-based results are presented as mean estimates followed by their 95% credible intervals (CI) calculated as highest posterior density intervals (Gelman et al. 2013).

3. Findings: supplementary detail on less salient income-generating activities

Women's main income-generating activities (Table S2) are dealt with in the main text (see also Fig S5 and S6). Here, region- and wealth-related changes through time are briefly outlined for less frequent income-generating activities, alongside the extent to which effects are attributable to WMAs. Overall, few women engage in petty vending (4.5%) and craft

sales (1.4%), with fewer than 1% engaging in sales of NTFPs or of cooked food, or paid work other than farm labour (Table S2: for *kibarua*: see main text).

NTFPs, petty vending, craft sales:

Petty vending: Between 2007-2014, numbers of respondents generating income from petty vending (sale of small quantities of tea, sugar, tobacco etc., often from the homestead) nearly doubled (2007 = 12%, CI: 1-46%; 2014 = 21%, 1-60%). There were pre-existing differences between regions, with more wives reporting petty vending in the North; and between wealth groups, with more Rich respondents reporting such income than other wealth categories (Very poor = 11%, Poor = 12%, Average = 13%, Rich = 20%, difference between very poor and rich = 9%, CI: 0-27%) in 2007; but no pre-existing WMA/non-WMA differences (WMA = 14%, Non-WMA = 10%, difference = 3%, CI: -2-14%).

In the North, married women have significantly increased NTFP sales and petty vending over time, irrespective of wealth or WMA membership (apart from North WMA normal/rich wives' NTFP sales which remain unchanged). In the South, NTFP sales decrease over time among Very poor/Poor non-WMA wives, and vending increases are only seen among Normal/Rich wives in non-WMA villages. These site- and wealth-specific changes do not translate into significant WMA effects. Other than weak evidence for an increase among Very poor/poor North WMA wives, craft sales show no change through time with region or wealth, and there is no overall WMA effect.

Paid work, cooked food sales: Despite vanishingly low incidence overall (Table S2) there is strong evidence for a significant increase in paid work among Very poor/Poor North wives

(both WMA and non-WMA) over time, and weaker evidence for an increase among Normal/Rich North non-WMA wives. Cooked food sales increase significantly 2007-2014 among South non-WMA wives of both pooled wealth groups, with weak evidence for an increase among Normal/Rich WMA wives in the South. Together, these translate into strong evidence of a significant negative WMA effect on Very poor/Poor South WMA wives. This could be linked to the fact that cooked food sales requires investment in oil, flour, and other ingredients as well as time to prepare and to sell in trading centre. However, weak evidence for an increase among North WMA wives (both pooled wealth groups) is balanced by that among Normal/Rich non-WMA wives in the North (Fig S5), and does not translate into evidence for a WMA effect in the North (fig S6, and main text).

Water sales: While in both North and South, WMAs reduce income generation from water sales for Very poor /Poor women (strong evidence) and Normal/Rich WMA wives (weaker evidence), village-by-village data (Fig S4) suggests this is driven almost entirely by changes in Oltukai control village, with a very large increase 2007-2014 in respondents reporting income from water, representing a tiny proportion of households (<1% overall). This creates a spurious WMA effect we do not consider to be meaningful.

4. Female-headed households

Of 1924 heads of household completing the main PIMA livelihoods survey (Bluwstein et al 2018a), 187 were women, mostly residing in the two North WMAs Burunge and Enduimet. Though sample size and clustered structure limited the analyses we were able to perform, preliminary results suggest female-headed households (FHH) in our study are (relative to male-headed households) unaffected by the implementation of WMAs (Keane et al under review: referenced in main text).

Table S4: Female vs male-headed households.

TLU=Tropical Livestock Units, calculated following Njuki et al. 2011; Acres are the locally used measure of land owned and/or cultivated; all measures recalculated per AE (Adult Equivalent: Claro et al 2010). MHH: Male-headed household; FHH: Female-headed household. Sample weights were used in calculations as the inverse of the probability of household inclusion based on the sampling strategy. Numbers in brackets are standard errors

		NORTH n= 962		SOUTH n= 962	
	MHH: N=1737 FHH: N=187	WMA MHH=405 FHH = 76	Control MHH=420 FHH = 61	WMA MHH=458 FHH = 22	Control MHH=454 FHH = 28
Mean household size (AE)	MHH	8.10 (5.26)	8.98 (6.18)	5.50 (2.15)	5.51 (2.24)
	FHH	6.13 (4.87)	5.15 (2.69)	3.25 (2.15)	3.57 (1.63)
Mean TLU/AE	MHH	3.85 (8.50)	5.95 (13.56)	0.07 (0.17)	0.08 (0.24)
	FHH	1.90 (3.03)	1.48 (2.64)	0.03 (0.14)	0.10 (0.23)
Mean acres farmed/ AE	MHH	1.06 (1.29)	1.28 (1.72)	1.06 (0.73)	1.02 (0.94)
	FHH	0.76 (0.96)	0.56 (0.64)	1.04 (1.63)	0.80 (0.68)

% primary income source livestock	MHH	28.15	27.14	0.66	0.22
	FHH	17.11	18.03	0	0
% primary income source farm	MHH	44.44	45.24	88.43	86.56
	FHH	48.68	42.6	68.18	75.00

FHH access to crop and livestock produce: Female-headed households had on average smaller livestock holdings, and were less likely to derive their primary income from livestock (or, in the South, farming) than male-headed households (Table S4).

FHH political participation: FHHs were an order of magnitude less likely than male-headed to have a person in a position of influence, such as a village council member, village or ward executive officer; member of the Authorised Association or other community-based organization; or a village game scout (0.53% in both 2007 and 2014, as against 2.9 and 4.4% for male heads).

FHH receipt of remittances and external aid: Of the 187 female-headed households in our survey, 26% recalled receiving remittances, pensions or external aid in 2007, and 41% reported such income in 2014-5, double the figure for married women (see main text). FHHs are on average less well off in terms of land, livestock and livelihoods than their male counterparts (Table S4). But not all FHHs are poor: in addition to this study's two outlier landowning FHHs (footnote 8, main text), receipt of remittance by two-fifths FHHs in 2014 (cf. 1/5 of wives overall) suggests a degree of support for many from absent male household members (cf. Bradshaw et al 2017). Despite the 2007-2014 increase in proportion of FHHs receiving remittances, and the associated implication of male household members

increasingly moving away for work, this is happening across the board with no evidence of a WMA effect. Across Africa, FHHs receiving remittances are on average considerably better off than other FHHs (Milazzo and van de Walle 2015), bearing out intersectional analyses unpacking the assumption of FHHs as universally poor (Chant 2003).

5. References

Agresti, A., & Kateri M. 2011 Categorical data analysis. Springer Berlin Heidelberg.

Bradshaw, Sarah, Chant, Sylvia and Linneker, Brian. (2017). Gender and poverty: what we know, don't know and need to know for agenda 2030. Gender, Place, and Culture ISSN 0966- 369X

Bürkner P.-C. 2017 brms: An R Package for Bayesian Multilevel Models Using Stan. Journal of Statistical Software, 80, 1-28

Chant, S 2003 Female household headship and the feminisation of poverty. LSE Gender Institute New Working Paper Issue 9

Claro R., Levy R., Bandini D., & Mondini L 2010 Per capita versus adult-equivalent estimates of calorie availability in household budget surveys Cad. Saúde Pública, Rio de Janeiro, 26(11):2188-2195. http://www.scielosp.org/pdf/csp/v26n11/20.pdf

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2013). Bayesian Data Analysis, Third Edition. CRC Press.

Ghitza, Y., & Gelman A.2013. 'Deep Interactions with MRP: Election Turnout and Voting Patterns Among Small Electoral Subgroups.' Amer. J. Political Science 57: 762–76.

Milazzo A. & van der Walle D., 2015 Women left behind? Poverty and headship in Africa. World Bank Development Research Group. Policy Research Working Paper 7331

Njuki,J., Poole, J., Johnson, J., Baltenweck, I., Pali, P.N., Lokman, Z., & S. Mburu. 2011. Gender, livestock and livelihood indicators. Nairobi, Kenya: ILRI. http://hdl.handle.net/10568/3036

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Stan Development Team (2016). RStan: the R interface to Stan. R package version 2.14.1. http://mc-stan.org/.

Stuart, E. A. (2010). Matching Methods for Causal Inference: A Review and a Look Forward. Statistical Science: A Review Journal of the Institute of Mathematical Statistics, 25(1), 1–21