Impact of Tanzania's Wildlife Management Areas on household wealth

Authors

Aidan Keane*[1]

Jens Friis Lund[2]

Jevgeniy Bluwstein[2,3]

Neil D. Burgess[4]

Martin Reinhardt Nielsen[5]

Katherine Homewood[6]

1. School of GeoSciences, University of Edinburgh, Edinburgh, EH9 3FF, UK.
2. Department of Food and Resource Economics, University of Copenhagen, 1958 Frederiksberg C, Denmark.
3. Department of Geosciences, University of Fribourg, Fribourg, 1700, Switzerland.
4. UN Environment Programme World Conservation Monitoring Center (UNEP-WCMC), 219 Huntington Road, Cambridge, CB3 0DL, UK & Centre for Macroecology, Evolution and Climate, University of Copenhagen, Copenhagen, Denmark
5. Department of Food and Resource Economics, University of Copenhagen. Rolighedsvej 25, 1958 Frederiksberg C, Denmark.
6. Department of Anthropology, University College London, 14 Taviton St, London WC1H 0BW, UK.

* Corresponding author: aidan.keane@ed.ac.uk

Abstract

Large-scale area-based conservation measures affect millions of people globally. Understanding their social impacts is necessary to improve effectiveness and minimise negative consequences. However, quantifying the impacts of conservation measures that affect large geographic areas and diverse peoples is expensive and methodologically challenging, particularly because such evaluations should capture locally-defined conceptions of wellbeing while permitting policy-relevant comparisons. We measure the impact of Tanzania's Wildlife Management Areas (WMAs), a national community-based conservation and poverty reduction initiative. We used a novel, cost-effective impact evaluation method based on participatory wealth-ranking and Bayesian multilevel modelling. We find that from 2007-2015 the impacts of WMAs on wealth were small and variable, with no clear evidence of widespread poverty reduction. Accompanying qualitative data suggest that apparently positive effects in one WMA cannot be directly attributed to WMA activities. Our results suggest that current WMA policy needs to be revisited if it is to promote positive economic development.

Area-based conservation measures, including strict protected areas and community-based initiatives, increasingly influence global land use[1]. These measures affect millions of people in rural areas whose livelihoods depend on access to land and other resources[2]. Scholars and practitioners need to understand the social impacts of interventions in order to protect or improve the wellbeing of local communities[3], and to adopt consistent methodological approaches to produce robust, policy-relevant comparisons between sites and interventions[4]. The available evidence about the social impacts of area-based interventions has increased rapidly[e.g. 5–10] but important challenges remain when large geographic areas are affected or groups of similar interventions are rolled-out at multiple sites[9,11,12].

One such challenge relates to the increasing need for social impact assessments to draw on broad, multidimensional conceptualisations of key outcome measures such as wealth and wellbeing. These measures include subjective, relational and objective components[10,13–15], and require either intensive and costly primary data collection or relying on existing data collected for other purposes[9,10]. Wealth and wellbeing are conceptualised differently by different groups of people[16] (e.g. cattle are central to Maasai cultural identity and livelihoods, but play a lesser role for some groups in Tanzania[17]). Comparative evaluations across large areas are therefore complicated by variation in how these concepts are defined.

A second challenge arises from variation in the effects of large-scale interventions: differences in project implementation across sites can substantially shape the nature of the interventions[18,19] while the same intervention may affect people with different characteristics differently[20,21]. Heterogeneous conservation impacts can have important policy implications. However, existing methods to estimate varying treatment effects (e.g. conditioning on observable covariates[20]; pooling information across sites using multilevel models[22]) remain rarely used in conservation.

Both qualitative and quantitative data are typically essential for robust, meaningful social impact evaluation. Typically, the best-available quantitative evidence about the effects of area-based interventions comes from studies that are firmly grounded in qualitative understanding of local contexts and combine quasi-experimental designs[23] with statistical matching techniques (e.g. propensity score matching[24]) to construct reasonable counterfactuals. Even so, when interventions affect sufficiently large areas, suitable comparator groups may simply not exist. In such cases, impact estimates may be improved by combining matching approaches with regression (a “doubly-robust” approach[23,25]) and supporting their interpretation with detailed qualitative information[26,27] in order to identify and account for the unique histories and circumstances of each site.

We demonstrate a new approach to evaluating the social impacts of conservation which can be applied cost-effectively at scale while estimating heterogeneous treatment effects and measuring outcomes in a way that is appropriate to local context. We carefully control for differences between intervention and non-intervention groups in design, analysis and interpretation. We focus on Tanzania’s Wildlife Management Areas (WMAs): a set of community-based conservation interventions which illustrate the challenges of evaluating large-scale interventions[28]. WMAs aim to improve the lives of a large number of poor people, but a rich body of primarily qualitative prior research has questioned their effectiveness, and previous quantitative studies have produced conflicting results.

Overview of methods and study areas

Tanzania’s WMA programme is a form of community-based natural resource management which aims to reduce poverty and conserve priority ecosystems[28,29]. The first WMAs were formally registered in 2006 and at the time of study there were 18 WMAs nationwide[28]. In theory, WMAs can

provide benefits through investments in community development projects, the creation of new employment opportunities, regulated access to wildlife resources or direct income to villagers from tourism revenues. However, WMAs can also impose costs through restrictions on livelihoods and access to land and resources. Here we focus on the net effects of WMAs on household-level wealth to evaluate whether in practice these theoretical benefits and costs translate into measurable progress towards WMAs' stated poverty reduction objectives.

We adopted a mixed-methods approach. First we conducted a focus group-based participatory wealth-ranking to collect data for 13,573 households across 42 villages and six WMAs within a matched, quasi-experimental design. We estimate the impacts of Tanzania's WMAs using a "differences-in-differences[23]" approach that compares trends in household wealth within WMA villages with trends in matched non-WMA villages. We use a flexible Bayesian multi-level modelling framework which models variation in outcomes and explicitly accounts for village-level differences in definitions of wealth. The interpretation is supported with qualitative and quantitative data about governance and participation, livelihoods, and access to/conflict over land and resources collected during this study and prior research[e.g. 30–35].

Our focal WMAs differ in their social and ecological context and the extent to which they generate income and their rules have been fully implemented (Table 1). The three northern WMAs - Enduimet, Burunge and Makame - are located in semi-arid rangelands and their populations primarily pursue agropastoralist livelihoods. By contrast, the southern WMAs - Mbarang'andu, Tunduru and Liwale - are located in sub-humid areas dominated by miombo woodland that are less accessible to tourists, and their populations are poorer and primarily farmers. At the time of study, Enduimet and Burunge in particular were well-established, generated significant income from tourism and enforced restrictions on land use. The three southern WMAs and Makame WMA were struggling to attract tourism investors and to implement a regime of land and resource use rules and regulations. Full details of the methodology and study sites are provided in the Methods section, Supplementary Information and an accompanying data descriptor paper[29].

Table 1: *Summary of the implementation status and characteristics of the six focal WMAs at the time of data collection in 2014/5. These summaries are based on evidence from previously published research cited both here and in the discussion. Note that the year of gazettement is the year in which the WMA was formally registered, but some WMAs may not have been fully operational at this point due to lack of investors, and the level of restrictions refers specifically to the level of restrictions that were actively enforced (rather than those that existed only "on paper").*

WMA name	Region (Study Area)	Year initiated	Year gazetted	Level of restrictions	Generation of revenues
Enduimet	Arusha (North)	2003	2007	High[29,34,36]	Moderate[28,29,32,36]
Burunge	Manyara (North)	2003	2006	High[29,33,37,38]	High[28,29,36–38]
Makame	Manyara (North)	2003	2009	Low[29]	None[28,29]
Liwale	Lindi (South)	2003	2009	Low[29]	Low[28,29]
Mbarang'andu	Ruvuma (South)	2003	2006	Low[29,31,39]	Low[28,29,40]
Tunduru	Ruvuma (South)	2003	2007	Low[29,31,39]	Low[28–30]

Results

Based on carefully-anchored recall (see Methods), focus groups categorised the study villages' populations as predominantly poor in 2007, around the time of WMA establishment. The largest number of households were placed in the wealth category "Poor" (46%), followed by "Very poor" (31%), "Normal" (16%), and "Rich" (6%). Households from villages within WMAs were slightly wealthier than those from matched non-WMA villages: in WMA villages 76% of households were "Very Poor" or "Poor", compared to 80% in non-WMA villages. There was also variation between geographical areas and villages (Supplementary Figures 1 & 2). In the north, 68% of households from WMA villages and 73% of households from matched non-WMA villages were "Very Poor" or "Poor" in 2007. By contrast, households in the south were substantially poorer, with 88% of households from WMA villages and 92% of matched non-WMA villages "Very Poor" or "Poor" in 2007.

Changes in wealth from 2007 to 2014

On average, households from both WMA and non-WMA villages within our sample became better-off over the period studied (Figure 1). However, wealth ranks in 2007 and 2014 were strongly positively correlated (polychoric correlation: 0.84). Most households (62%) did not change wealth rank, 32% moved up one or more wealth ranks, and only 5% moved down one or more wealth ranks. In 2014, the largest number of households were categorised as "Poor" (43%), followed by "Normal" (30%), "Very poor" (19%), then "Rich" (7%).

Our data showed considerable heterogeneity in changes in wealth between geographic areas and between villages (Supplementary Figures 1 & 2). Households in villages with higher population densities before WMA establishment or further from the national parks or game reserves were more likely to have increased in wealth over time, while those that were further from a major road were less likely to have increased in wealth (Supplementary Figure 3). Sinya village (Enduimet WMA) uniquely shows an overall decline in wealth 2007-2014 (Supplementary Figure 1).

Averaging across the six sites included in our study, there is little evidence for a consistent difference in wealth trends between WMA and non-WMA areas (difference-in-differences = 0.09, CI95: -0.35, 0.85). However, there is important heterogeneity between the six WMAs (Figure 2 & Supplementary Figure 4). In the south of Tanzania, WMAs were associated with broadly positive differences-in-differences, particularly in Mbarang'andu (Mbarang'andu: 0.61, CI95: 0.20, 0.93; Tunduru: 0.24, CI95: -0.06, 0.50; Liwale: 0.12, CI95: -0.11, 0.32). In the north, by contrast, Burunge and Enduimet WMAs were associated with small negative differences-in-differences (Burunge: -0.13, CI95: -0.27, 0.02; Enduimet: -0.17, CI95: -0.41, 0.04) while the effect in Makame is unclear (-0.14, CI95: -0.49, 0.18).

Household-level differences

We also observed household-level differences in patterns of changing wealth between male-headed and female-headed households, and differences in access to WMA leadership opportunities between poorer and richer households in both the northern and southern study sites (Figure 3).

On average, female-headed households started off substantially poorer than equivalent male-headed households in 2007 in both WMA villages (North: -0.32, CI95: -0.59, -0.02; South: -0.32, CI95: -0.64, 0.00) and non-WMA villages (North: -0.39, CI95: -0.70, -0.06; South: -0.41, CI95: -0.71, 0.00; Figure 3A). However, there was no evidence that the differences-in-differences associated with

WMAs differed on between female-headed households and otherwise equivalent, male-headed households (North: -0.01, CI95: -0.41, 0.37; South: -0.09, CI95: -0.62, 0.45).

Households which went on to obtain WMA leadership positions tended to be richer in 2007 than those that did not (North: 0.53, CI95: 0.05, 0.92; South: 0.44, CI95: 0.03, 0.81; Figure 3A). There was no difference in the difference-in-differences estimated for this group compared to households which did not obtain leadership positions (North: 0.06, CI95: -0.27, 0.36; South: 0.10, CI95: -0.53, 0.61; Figure 3B). By contrast, there was no evidence for a difference in initial wealth ranks of households that went on to obtain positions as village game scouts within WMAs (North: 0.03, CI95: -0.22, 0.30; South: -0.01, CI95: -0.23, 0.20; Figure 3A). However, in the northern sites households whose members were employed as village game scouts were more likely to increase their wealth rank than WMA households whose members were not game scouts (0.35, CI95: 0.02, 0.67; Figure 3B). In the southern sites there was no evidence for an effect of being employed as a game scout (0.09, CI95: -0.11, 0.33).

Discussion

Our results reflect known trends of increasing wealth, but also high levels of continuing poverty in Tanzania[41]. They also show large differences in wealth between geographic areas and villages (e.g. focus groups in our southern study sites ranked households as substantially poorer than those in the northern sites, reflecting regional differences[42]). Against this background, we do not find evidence for a consistent WMA effect. The estimated WMA-level differences-in-differences (i.e. differences in average wealth trends between WMA and non-WMA villages) vary from small negative to moderate positive effects. However, the degree to which these apparent WMA impacts can be directly attributed to the WMA policy, as opposed to other factors, varies. Our results regarding WMA impacts therefore require careful interpretation, based on a clear understanding of how the specific conditions within each WMA have created costs or benefits for local residents that could translate into increases or decreases in wealth.

At the WMA level, we find the most positive apparent effects for Mbarang'andu and Tunduru WMAs. Detailed household surveys carried out in the same villages as part of our wider study[29] show that the majority of residents perceived Mbarang'andu WMA as having supported public development projects (specifically building or repairing schools and village offices[28]). However, very few households reported direct benefits from employment, scholarships, tourism or other WMA-related sources (Supplementary Results & Supplementary Figure 5).The potential benefits of WMAs are conditional on member villages accepting restrictions on their land use. In Mbarang'andu, land-use plans retain <10% of village land for agriculture and settlement, with most land being zoned for forest and wildlife conservation. At the time of study, conservation had not become a constraint on the expansion of farming in either Mbaranga'ndu or Tunduru[31,39], due to a combination of low population densities, confusion over boundaries, and the lack of enforcement of WMA rules[31]. However, despite the relatively weak constraints imposed, the limited WMA initiatives alone are unlikely to be sufficient to account for the observed increases in wealth. In Mbarang'andu, an alternative explanation points to a series of philanthropic donations from two companies mining uranium from concessions on WMA land. These companies agreed to pay US$10,000 per year "to be distributed to the local communities who will be affected by the mining activities"[40]. However, the payments cannot be attributed to the WMA itself and there is considerable uncertainty about their longer term sustainability[40].

By contrast, Burunge and Enduimet produced the clearest evidence for WMAs having a negative effect on wealth. Both WMAs are well-placed to benefit from Tanzania's northern safari circuit and have annual revenues amongst the highest of any WMAs[28]. In common with other WMAs, however, government taxes and WMA administration costs leave only a small proportion of revenues to be distributed to member villages (typically 25%-33%, equivalent to ~USD 3.5/capita/year in Burunge and ~USD 0.6/capita/year in Enduimet[36]). Most of these remaining funds are invested in community development projects[32,36]. Up to half of residents perceived these WMAs to have supported village-specific development projects but, as in Mbarang'andu, very few reported receiving direct benefits (Supplementary Results & Supplementary Figure 5). Although the proportion of village land set aside for conservation is lower in these WMAs than in Mbarangandu (60% in Enduimet, reduced from 90% initially[36], and 31% in Burunge[33]), previous studies have found that their stricter enforcement of WMA rules severely constrain rural livelihoods[34,37,38].

Both Enduimet and Burunge WMA have also been the subject of long-standing conflicts, with complaints that the initial process of designation was coercive, lacking meaningful participation and informed consent of the communities involved[35]. For example, Sinya in Enduimet WMA is the only village within our data set to show an overall decline in wealth from 2007-2014 (Supplementary Figure 2). Sinya has significant wildlife populations and before WMA establishment earned considerable tourism revenue[32]. It joined the WMA reluctantly, subsequently seeing its revenues decline because WMA revenue is divided equally amongst member villages irrespective of their contributions of land or wildlife and the availability of other opportunities. Sinya also became engaged in a dispute with a tourist camp operator, leading to tourist vehicles being denied passage, threats to burn the camp and demands for the operator's eviction[32]. In Sinya's case, the high costs created by strict enforcement of revenue sharing and restrictions on land use have been exacerbated by a lack of investor accountability to the village. Although Sinya is notable, it is not unique, with ongoing conflicts also well-documented in two villages in Burunge WMA[35,37,38].

Taken together, our results suggest important heterogeneity in the effects of WMAs, linked to the balance of benefits and costs that they bring. The two WMAs we studied whose management regimes of rules and regulations have been fully implemented - Enduimet and Burunge - appear to have negatively affected household wealth because the costs of the restrictions and benefit-sharing models they impose are not offset by the benefits that even these well-situated WMAs provide[36]. Conversely, WMAs whose management regimes have not yet been fully established may have little direct effect on household wealth. By contrast, although the only statistically significant effect was positive we do not find clear evidence in support of any positive effects on household wealth that can be unambiguously attributed to WMA activities. This suggests that the current WMA policy – if successfully implemented – fails to promote, and may ultimately restrict, the economic development of member village residents, supporting earlier qualitative research that has questioned the promises of WMAs pertaining to rural development[34,35]. To become a catalyst for positive economic development, a WMA would have to tackle several policy challenges and power relations. Key amongst these are: the revenue sharing formula, which currently imposes a high level of taxation on village revenues and penalises villages which contribute more to conservation; the rules and regulations that impose stringent restrictions on local land and resource access; the process of implementation that lacks transparency and accountability; the limited power of communities to renegotiate the terms of WMA membership or to leave the WMA if they are dissatisfied; and the resource investment priorities that currently tend to privilege wildlife conservation over crop protection or compensation for crop damage and livestock losses[38,43,44].

Improving evaluations of large conservation interventions

The international community is committed to further increasing the area of land under conservation management[45], so the need for research that evaluates the impacts of different conservation governance regimes as they unfold over time is greater than ever. Most previous evaluations of the social impacts of protected areas have relied on household survey data[46]. These data are time-consuming and expensive to collect[47], particularly for the measurement of complex constructs within quasi-experimental designs. By focusing on quantities that can be elicited via focus group discussions at the village-level our approach offers a cost-effective model for large-scale participatory data collection (e.g. our detailed survey of a sample of ~40 households per village required approximately five to ten times as many person-hours as carrying out a complete village wealth ranking). This approach to measuring wealth is not new and has previously been shown to provide an accurate measure of relative wealth in other settings[e.g. 48]. Comparison with our detailed household survey data likewise shows that the wealth ranking captures meaningful differences (e.g. in livestock ownership, land use and positions of leadership[29]; Supplementary Table 1). Despite this we are not aware of previous applications to impact evaluation in conservation.

Our approach allows the definitions of the wealth-categories used in data collection to vary at the village-level.This permits more locally-meaningful measures of impact, but imposes additional technical challenges for analysis. We address this by extending cumulative logit models to include village-varying parameters for each group of cut-points. Standard cumulative-logit models for response variables with three or more ordered outcome categories are closely related to binomial or Bernouilli logit models for responses with two possible outcome categories, but include additional intercept parameters which serve as cut-points dividing an underlying latent variable into discrete categories (i.e. here they translate an assumed continuous measure of wealth into the four observed wealth categories)[49]. Rather than model each village separately or average outcomes across villages, we use all of the available data within a single model that allows these ordinal cut-point parameters to vary by village. The parameters corresponding to the same cutoff (e.g. the boundary between "Very poor" and "Poor") share a common hierarchical prior distribution, partially-pooling information to increase precision. Although the use of varying intercepts within multilevel models is a long-standing, well-established and widely-used technique[e.g. 22], we are not aware of other examples where this principle has been extended to allow all of the cut-points within a multilevel cumulative logit model to vary by a grouping factor. Thus, our modelling approach provides an example of how flexible multilevel models could be used more widely in conservation to enrich the set of analytical tools available for impact evaluation[22].

Within this study, these new contributions to the impact evaluation toolkit were used while adopting other elements of existing best-practice in quantitative impact evaluation: collecting data within a robust, quasi-experimental design[13], using statistical matching techniques to ensure that non-WMA "control" villages are closely comparable to WMA villages[25] and carrying out post-matching regression-adjustment to reduce the potential bias from any residual differences[23,25]. Despite these efforts, some aspects of real-world complexity are not well-captured by our quantitative analyses. For example, the cases of Mbarang'andu, Enduimet and Burunge WMAs show how site-specific circumstances drive differentiation in the impacts of otherwise similar conservation interventions. Understanding the outcomes of large-scale conservation interventions, therefore, requires detailed, contextual knowledge of (i) the functionality of the interventions themselves and (ii) other factors that coincide geographically and temporally, even within the most carefully designed evaluations[12,27]. Mixed-methods studies incorporating quantitative and qualitative approaches are already widely

used to understand the social impacts of conservation[46], but continued efforts are needed to ensure that this becomes the norm and to further expand the range of evidence that is used to learn about conservation's effects.

Conclusions

The ongoing expansion of large, area-based conservation interventions, and the development of new approaches to their governance, challenges conservationists to monitor their effectiveness in delivering desirable social and environmental outcomes. Meaningful policy guidance requires detailed understanding of how interventions differentially impact specific areas or groups of people. The approach described here offers both a cost-effective way to collect locally-meaningful measures of locally-variable outcomes and demonstrates how these complex data can be successfully incorporated into robust, comparative analyses. Ultimately, however, the value of increasingly sophisticated ways to quantify the outcomes of conservation depends on the extent to which they are supported by detailed qualitative understanding of local realities that requires longer-term, on-the-ground researcher presence and engagement.

Methods

Study system and context

Tanzania's WMAs constitute a nationwide "community-based" natural resource management programme which was co-designed by the Tanzanian state and international conservation NGOs and shaped by international donor funding. The WMA programme was rooted in Tanzania's first Poverty Reduction Strategy Paper Mkukuta[50], and its commitment to community-based natural resource management (CBNRM) as a pathway to socially and environmentally sustainable development, The first WMAs were formally registered in 2006[28] and by 2014-2015, at the time of data collection, 18 WMAs existed, encompassing several hundreds of thousands of villagers. A planned total of up to 38 WMAs has been proposed to eventually cover some 14-15% of Tanzania's land area, directly and indirectly affecting several million people[28,51]. Tanzania's WMAs were modelled on similar initiatives elsewhere in Africa (e.g. Namibia[52–54]), and were ostensibly designed to bring about poverty reduction through sustainable use of natural resources. However, they have been critiqued from the start for deep-rooted flaws in their design and implementation[35,55,56].

As prescribed by the state, WMAs require a number of villages to come together and set aside a substantial proportion of their pooled village lands for wildlife conservation purposes. The regulations vary but may forbid access, through-passage and use for activities such as livestock grazing, collection of water or non-timber forest products (NTFPs; e.g. firewood, thatch, poles, honey or medicinal plants), except under permit. Agriculture is always forbidden in WMAs. WMAs are supposed to attract tourist game viewing or trophy hunting entrepreneurs to bid for operating contracts. Any revenues received are divided into roughly equal parts, with approximately and notionally one-third each going to the state, the Authorised Association, and the governments of the participating villages. Income from investors is paid to the state, which keeps approximately one-third to one-half[43]. The rest is returned to the Authorised Association (AA) operating the WMA. The AA takes around half of this for administrative purposes, to pay for training and employment of village game scouts monitoring and enforcing WMA rules and regulations, and other conservation initiatives. On average around one-third of the WMA's original earnings are left[43]. These remaining funds are divided equally between governments of participating villages who can use this money for community projects (e.g. schoolroom, clinic or road construction; educational or health care bursaries). WMAs are thus meant inter alia to enable local communities and individual households to derive benefits from wildlife resources[28].

In common with many other community-based conservation initiatives in Africa[57], the existing evidence for the social impacts of Tanzania's WMAs is inconclusive and of mixed quality. Tanzanian scholars have documented and analysed individual cases in depth[30,33,40,58], with consideration of patterns of politics and conflicts more salient than livelihoods change[34,38,56]. Existing larger-scale studies emphasizing livelihoods have used pre-existing datasets that may be poorly suited for the purpose, or unmatched comparisons. They have produced mixed and often contradictory results. For example, one study, based on successive panel samples collected for Tanzanian national statistics, has suggested community-based natural resource management interventions including WMAs enhance food security[59]. A second, based on single-round unmatched comparison of WMA and non-WMA villages in Northern Tanzania, suggest WMAs reduce food security[60]. This confused picture fuels intense debate. State, bilateral and multilateral donors, NGOs, and civil society organisations, all emphasise the need to establish the extent to which WMAs are working, for whom, and whether they can be made more effective.

Study design

This research forms part of a larger project which evaluated the impacts of six WMAs in Northern and Southern Tanzania. The project focused on local people's governance[31,33,38], livelihoods and resource use (analyses underway), and women's wellbeing[61] as well as on biodiversity and other ecosystem services[62]. We provide an outline of the overarching study design here, accompanied by: (1) detailed descriptions of the participatory exercises used to define and categorise household wealth and (2) our analytical approach, which are of specific relevance here. Full details of the study area, sampling strategy, matching approach and survey instrument design are reported in Buwstein et al.[29]. Approval for the research was given by the University College London Anthropology Departmental Ethics Committee (reference No. Z6364106 of UCL Data Protection Registration) and a research permit (2014-49-NA-2013-154) was obtained from Tanzania Commission for Science and Technology (COSTECH).

Our overall approach to identifying the effects of WMAs on household-level wealth is based upon the logic of a quasi-experimental, Before-After Control-Impact design[63]. We therefore set out to examine how reported changes in wealth over time have differed between villages that have joined WMAs and villages that are otherwise similar in their observable characteristics, but are not part of an existing WMA. We focused on six of the earliest-established WMAs: Enduimet, Burunge and Makame in the north, and Liwale, Mbarang'andu and Tunduru in the south of Tanzania (Supplementary Table 1). For each WMA we sampled four member villages and selected three or four non-member villages, giving a total of 42 study villages. Non-WMA villages were selected using nearest neighbour matching with replacement, based on Mahalanobis distance from other villages within the same district. The variables used to create the Mahalanobis distance metric were: distances from the centroid of the village to the nearest major town, major road, wildlife corridor and major protected area respectively; the total annual precipitation; the mean slope and elevation; whether the village overlaps with the species ranges of elephants and lions respectively; the human population density; and the proportions of the village area covered by forest, woodland and shrubs, and grassland and crops respectively[29].

Wealth categorisation and data collection

In order to gather data on wealth that is both locally meaningful and comparable across multiple sites, we carried out participatory wealth ranking exercises separately in each of our study villages. Initial trials with separate female and male focus groups returned minimal differences, and subsequently a single focus group was carried out in each village. Focus groups comprised 2-4 knowledgeable people who had lived in the community for a long period of time. Focus group participants were often sub-village chairpersons and often but not always middle-aged or older and male. The focus groups were first asked to agree upon a set of criteria that could be used to distinguish between four categories of household in their area: very poor, poor, normal and rich. Focus group discussions were locally led, with the research team prompting where necessary, with questions such as "*In your village, what would a typical very poor/ poor/ normal/ wealthy household spend money on, or spend additional money on if it becomes available?*", "*What would a typical very poor/ poor/ normal/ wealthy household be able to access in terms of: food / number of meals per day / ability to send children to school, to pay back debt, to repair the house, to improve agricultural land, to increase herd count, or to acquire more land? / indicators of housing quality (iron sheet roof, cement floor, electricity…) / assets (clothes, radio, mobile phones, furniture, bicycles, domestic animals, farm land, agricultural implements, bee hives, small scale businesses, shop….) / access to services (protected water pump, health care, veterinary assistance, primary and secondary school….)*

/ access to opportunities (non-farm employment, pension, micro loans, bursaries…)?". These prompts were used to initiate discussion and were based on a detailed understanding of varying patterns of local livelihoods from prior research[e.g. 64]. Focus group facilitators were trained to ensure that criteria that were not directly referenced in the prompts but arose naturally as part of the discussions were given due prominence. While some anchoring of discussions around the concepts of wealth implied by the prompts may be inevitable, we are confident that each focus group was able to arrive independently at an appropriate set of criteria. This belief is corroborated by the fact that the criteria chosen to define wealth categories differed significantly from village to village and made sense given what is known of local livelihoods. For example, villages in the north give greater prominence to the importance of cattle, reflecting their well-established cultural and economic importance, while some villages in the south did not refer to cattle at all in their wealth rank definitions. The full set of criteria chosen by focus groups to define wealth ranks in each village are presented as Supplementary Data and the associated codelist is provided as Supplementary Table 2.

Focus groups were next asked to assist in augmenting existing household registers for their own villages to ensure they were updated and complete. They were then asked to place each household into one of these four categories (a) at the time of the discussion (2014-2015) and also, (b) by recall, for 2007 to provide an estimate of the baseline conditions that existed before the first WMAs were formally implemented. The results were recorded onto village register templates, and transcribed into Microsoft Excel. The full dataset therefore included wealth rank both at the time of the 2014-15 survey and by recall for 2007 for 13,573 households across 42 villages. Of these, 8,499 households belonged to 24 villages from the 6 WMAs, while the remaining 5,074 households belonged to the 18 statistically matched non-WMA villages.

Use of recall data

As is frequently the case for impact evaluations of large, long-standing conservation programmes, there were no consistent baseline data on household-level wealth available across our study sites from the period before WMA establishment. White[65] advocates the use of recall data where there are no baseline data but cautions against the biases involved, particularly over longer time-periods (see also[47,66]). By focusing on highly-salient, locally-relevant and easily quantifiable household assets in the wealth rank definitions, our approach helps to limit the extent of potential bias. However, since we required recall of circumstances in 2007, around the time of implementation of the relevant WMAs but 7-8 years before this study, we also included description of a prominent event in our survey instrument to act as an anchor to facilitate accurate recollection. In the north this event was the eruption of Ol Doinyo Lengai, a volcano sacred to the Maasai ethnic group. In the south, people were asked to recall President Kikwete's 2005 election and then to work forwards to 2007 using local and personal events as markers. To validate the effectiveness of these precautions we re-surveyed a separate sample of 220 North heads of household in 2015-6, for whom pre-existing data had been collected during 2002-4, to assess the accuracy of their long-term recall of household assets and income (see Supplementary Information for detail).

Analysis and presentation

We analysed the data using a series of Bayesian multilevel cumulative logit models fitted in R version 3.5.2[67] and Stan using the Rstan interface[68]. In each case, the response was our household-level wealth categorisation, coded as a four-level ordinal variable (Very poor < Poor < Normal < Rich). Within our modelling framework the wealth categories observed within our data are conceptualised

as being crude measures of a continuous underlying latent wealth state and results are discussed in terms of this unobserved state. Thus, it is meaningful to talk about the estimated probability that a rich household would have increased in wealth despite there being no higher category of wealth in our observed response variable. To reflect differences in locally-defined wealth categories while allowing data from multiple villages to be combined within the same model, we estimated village-specific wealth cut-points. Each batch of parameters corresponding to the equivalent cut-point across different villages was given a hierarchical Normal prior (see Supplementary Information).

We fitted three different versions of this model in total, using different combinations of predictor variables (Supplementary Table 3). All three models estimated varying intercepts for households, villages and pairs of matched WMA and non-WMA villages to account for the grouping structure of the data. Each batch of intercepts was given its own hierarchical Normal prior with mean zero and standard deviation estimated from the data using a weakly-informative half-Cauchy hyperprior (location = 0, scale = 2.5). The half-Cauchy distribution has the majority of its probability density close to zero but has fatter-tails than, for example, a half-Normal distribution, reflecting our prior belief that large variation within batches of intercept terms was unlikely but could not be firmly discounted[69]. All models also included terms for the time period (before or after WMA establishment), whether a given village was a WMA member or not, the name of the specific WMA to which a village belonged or was matched, and their two- and three-way interactions. Our estimates of individual WMA effects are derived from the difference in changes in wealth over time between WMA and matched non-WMA villages, akin to a difference in differences estimator. They are estimated within our models as the interaction between WMA-membership, WMA name and the change from 2007 to 2014. Our overall estimate of WMA impact is calculated as the arithmetic mean of the individual WMA effects.

The second model incorporated an additional six predictors which represented village-level variables measured before WMA establishment and which were used in the matching process to select non-WMA villages. Only those matching covariates where the absolute standardised mean difference in values between WMA and non-WMA villages remained higher than 0.1 after matching were included (Supplementary Figure 6) – population density, distance to the nearest town, distance to the nearest large road, distance to the boundary of the nearest national park or game reserve, distance to the nearest wildlife corridor, and proportion of village land under forest – along with their interactions with the change from 2007 to 2014. These variables were each centred on their mean and scaled by two standard deviations[70]. A comparison of models 1 and 2 provides a check on the extent to which our findings are robust to this aspect of imperfect matching (Supplementary Figure 4).

The third model adds a further three household-level predictors and a variable for region indicating whether the village was in the northern part of our study area (i.e. either a member of one of Enduimet, Burunge or Makame WMAs, or one of their matched non-WMA villages) or the southern part (i.e. a member of Liwale, Mbarang'andu or Tunduru WMA or a matched non-WMA village). These variables allow us to examine how household characteristics are linked to the uptake of WMA-related opportunities, how they moderate WMA effects, and whether these effects differ by region. Household characteristics are represented by terms indicating whether or not the household was female-headed, had a member who obtained a WMA-related leadership position (defined as becoming a member of the community-based organisation or authorised association), or had a member who obtained a position as a village game scout, and their interactions with region, WMA-membership and the change from 2007 to 2014.

Posterior distributions were explored using Hamiltonian Monte-Carlo sampling with the No-U-Turn Sampler in Stan[68]. Four Markov chains were run in parallel for 2000 iterations each, with the first 1000 iterations discarded. Convergence of the models was checked by consulting the Gelman-Rubin statistic (with values <1.01 taken to indicate convergence) and visual examination of trace-plots. Posterior predictive checks were carried out to assess the adequacy of the fitted models.

To facilitate interpretation, our model-based results (including estimates of WMA effects) are presented as mean predicted changes in wealth rank and their associated 95% and 80% credible intervals (CIs), and we interpret estimates whose 80% CIs do not overlap zero as statistically meaningful. We calculated these mean predicted changes by first generating predictions from the model for each WMA separately for the following set of scenarios: (a) setting the year to 2007 and assuming no WMA membership, (b) setting the year to 2014 and assuming no WMA membership, (c) setting the year to 2007 and assuming WMA membership, and (d) setting the year to 2014 and assuming WMA membership. Following the logic of a difference-in-differences estimator, we calculated overall WMA effects as (d - c) - (b - a). To produce regression-adjusted estimates from our second and third models, we set the value of the six village-level matching variables to zero prior to generating predictions for the four scenarios (i.e. we fixed the values to the mean within the dataset since the variables had been scaled and centred). Finally, to estimate the effect of household-level covariates on WMA effects we followed the same strategy, first generating predictions for the set of scenarios above with the additional assumption that a given characteristic was present (i.e. assuming all households were female-headed) and then for the same set of scenarios under the assumption that the characteristic was not present (i.e. assuming all households were male-headed), in order to calculate the difference in the estimated WMA effects in each case.

Data availability

The datasets analysed during the current study are available in the UK Data Service ReShare repository, https://dx.doi.org/10.5255/UKDA-SN-852960, and are fully described in a data descriptor paper: Bluwstein, J. et al. (2018). A quasi-experimental study of impacts of Tanzania's wildlife management areas on rural livelihoods and wealth. Scientific Data, 5, 180087, https://doi.org/10.1038/sdata.2018.87.

Code availability

Computer code used in this analysis is available from the authors upon reasonable request.

Supplementary information

See attached file.

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Author contributions

All authors contributed to the conceptualisation of the project and the development of the survey and sampling procedures. J.B. led data collection in the field. A.K. analysed the data. A.K. lead the writing of the manuscript, with all authors contributing sections of text, comments and review.

Correspondence and requests for materials should be directed to A.K.

Competing interests

The authors declare no competing interests

Materials and correspondence

Correspondence and requests for materials should be addressed to AK (aidan.keane@ed.ac.uk)

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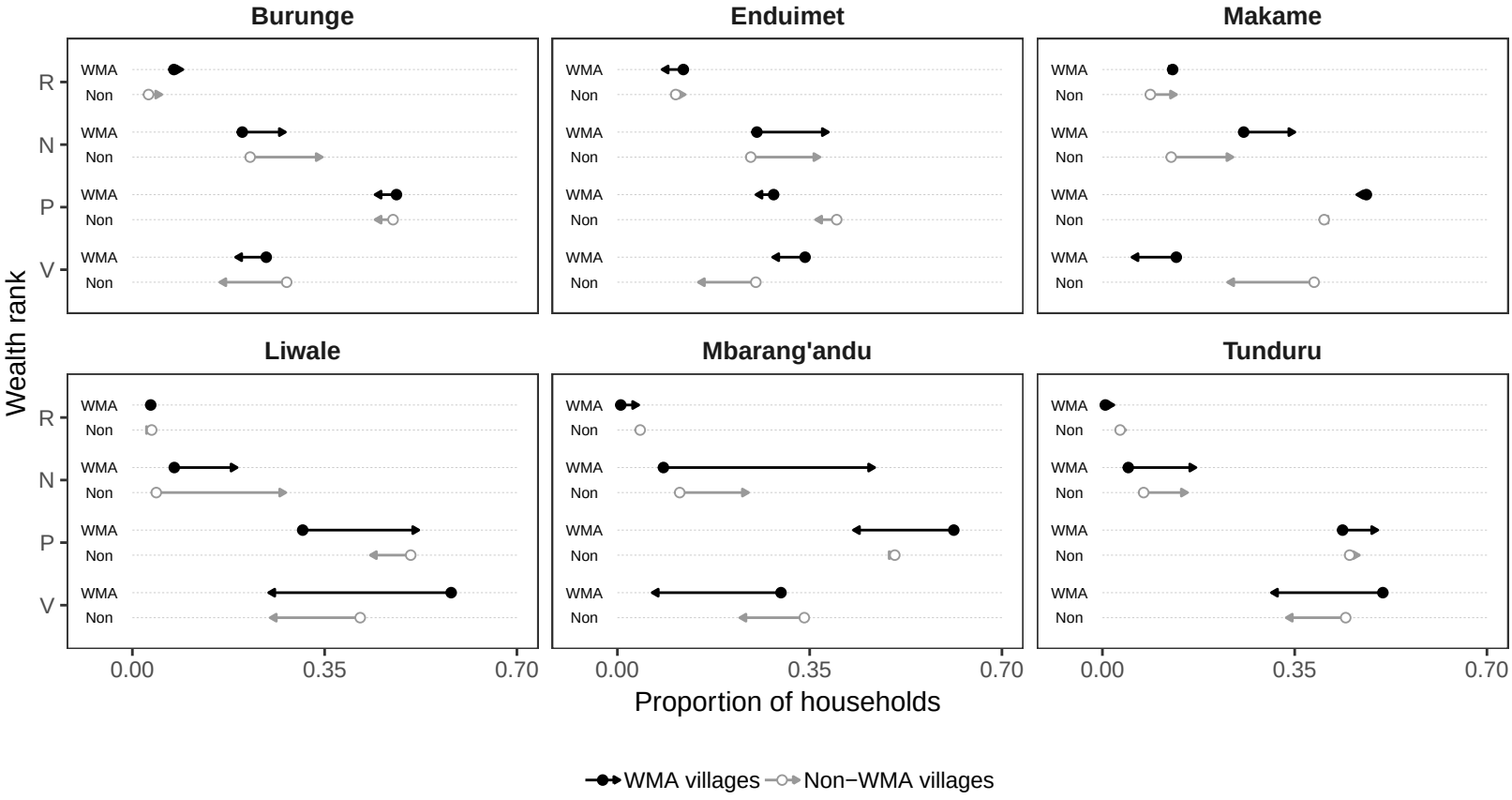
Figure Legends

Figure 1 | Changes in household wealth from 2007 to 2014/15. These summaries are derived from community focus group wealth rankings and compare villages in each of the six WMAs to their matched non-WMA villages. Each panel displays data for villages which are members of a single WMA or are matched to those member villages. Open circles represent the proportion of households within the WMA and non-WMA villages that were classified as "Rich" (R), "Normal" (N), "Poor" (P) or "Very Poor" (V) in 2007. Arrows show the change in proportion with the tip of the arrow representing the value in 2014/15.

Figure 2 | Mean differences-in-differences between trends in household wealth from 2007 to 2014/15 associated with each of the six WMAs. Symbols indicate the mean difference-in-difference associated with WMA membership, thick lines show the 80% credible intervals and thin lines show the 95% credible intervals around these means. Positive values mean that increases in wealth since 2007 were more likely in a WMA household than in an otherwise equivalent non-WMA household, while negative values mean that increases in wealth were less likely relative to non-WMA households, with zero corresponding to no difference.

Figure 3 | Differences in wealth and WMA impacts associated with household characteristics. Panel A shows differences in wealth rank in 2007. Panel B shows differences-in-differences associated with membership of a WMA. Results are presented for female-headed households, households with one or more members who obtained a WMA leadership position, and households with one or more members who are employed as village game scouts. The results are also differentiated by region. In each case, the differences are expressed relative to a baseline household which is male-headed, and whose members do not include a member of the community-based organisation or a village-game scout. Symbols indicate the mean effects. Thick lines show the 80% credible intervals and thin lines show the 95% credible intervals around these mean values.


Burunge
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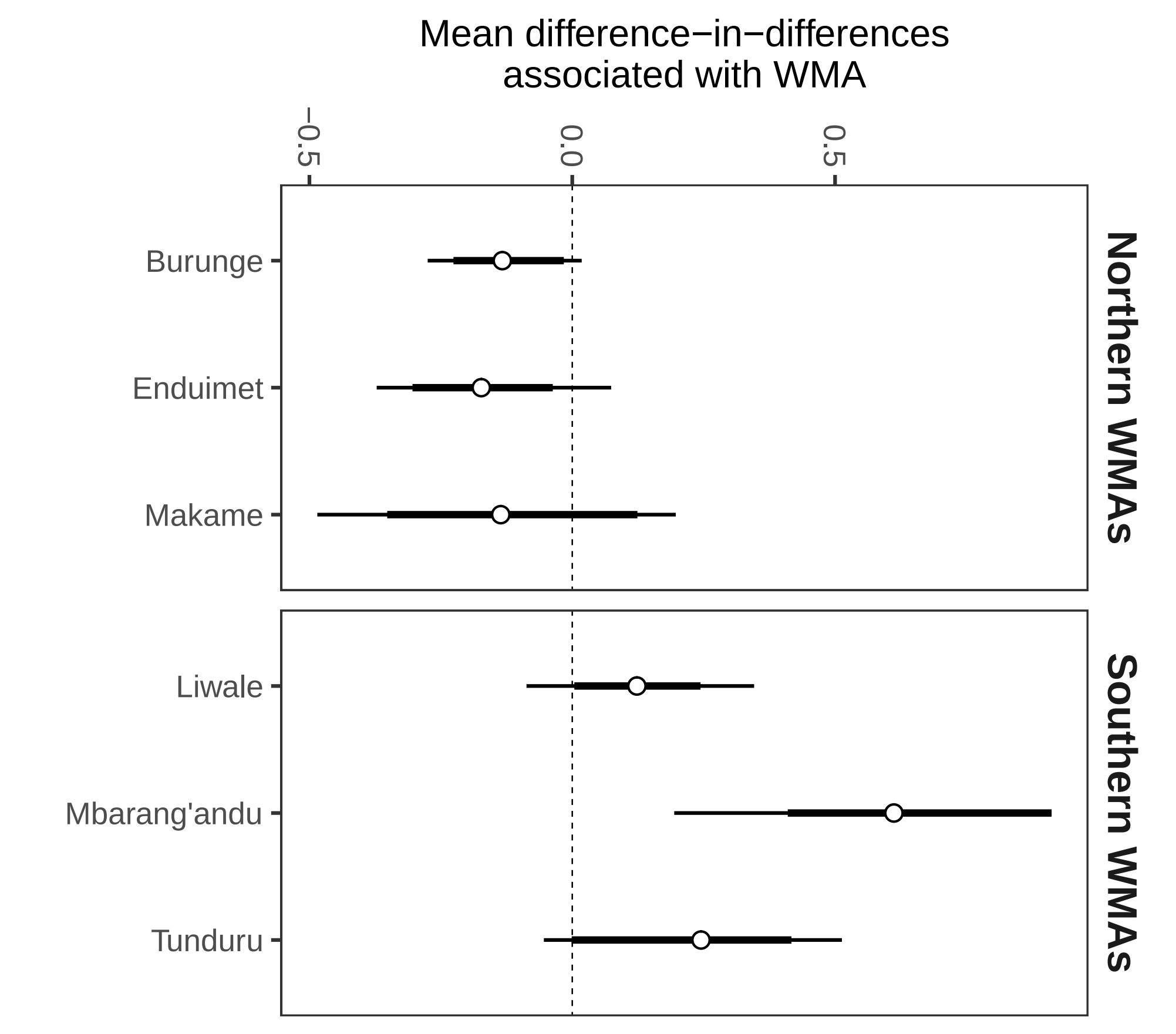
Proportion of households
WMA villages
Non−WMA villages


Mean difference−in−differences
associated with WMA
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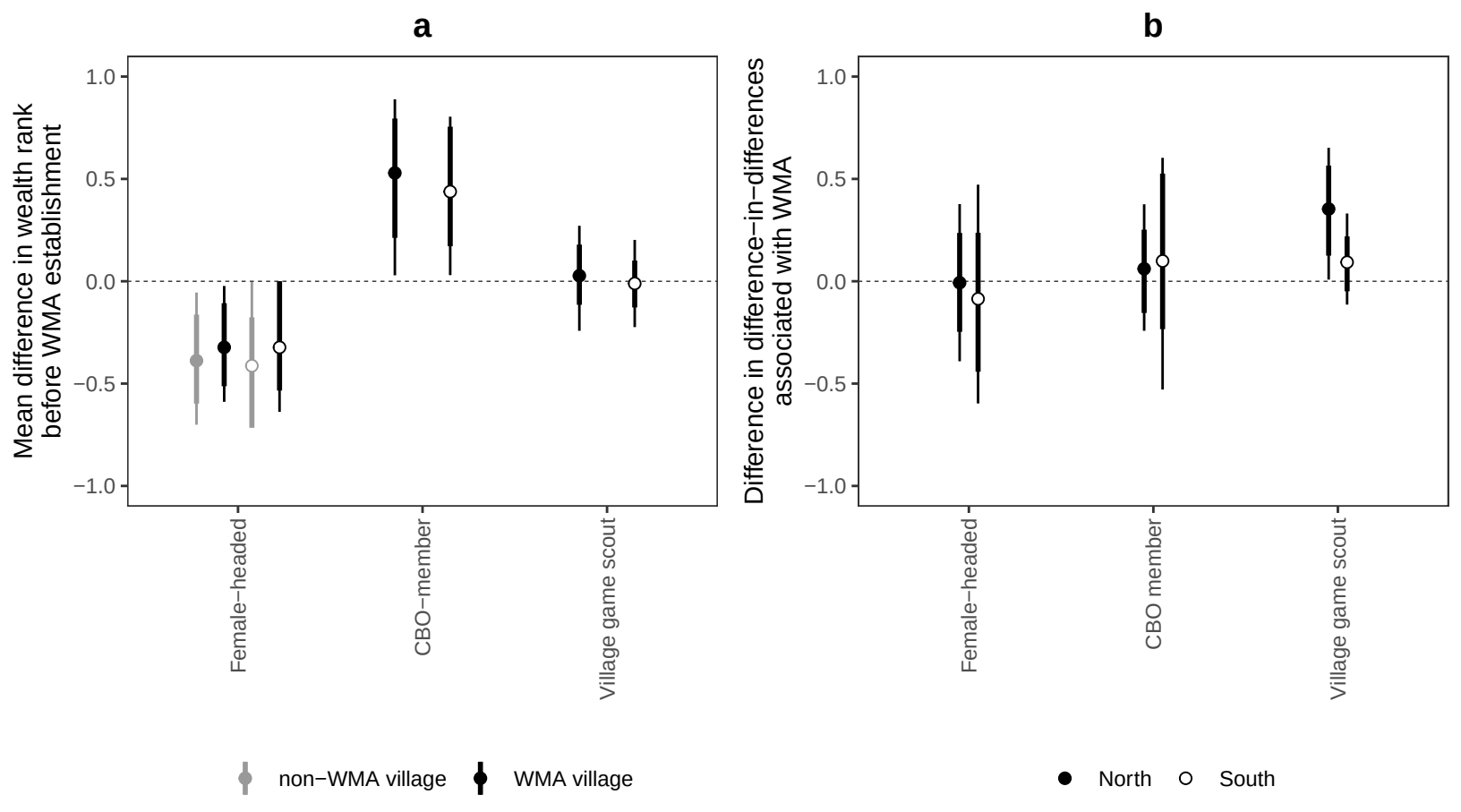
Northern WMAs
Liwale
Mbarang'andu
Tunduru
Southern WMAs


a
b
Mean difference in wealth rank before WMA establishment
Difference in difference−in−differences associated with WMA
1.0
0.5
0.0
−0.5
−1.0
Female−headed
CBO−member
Village game scout
CBO member
non−WMA village
WMA village
North
South