Final Report
NASA Land Cover Land Use Change Program:

Social drivers of land cover change around African transboundary Peace Parks

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Statement of Work

Project activities:

During its final stage, the project activities focused on characterization of change in the spatial structure of settlements with accumulation of wealth over time. In this analytical component we combined the results of field surveys, conducted during the 2014 season, and mapping amount, quality, and spatial distribution of housing structures and corrals from very high resolution imagery. Our major findings indicate that inhabitants of the village within out study, which was identified as aspirationally empowered during the first year of the project development, have accumulated a substantial amount of wealth since the establishment of the Great Limpopo Transfrontier Park (GLTP), especially when compared to their less aspirationally empowered neighbors within the GLTP boundary. However, the improved economic status of population is achieved at the expense of the park's primary objective – wildlife conservation. Contrary to the predictions of the dominant economic theory, inhabitants of villages in our study did not benefit from the tourism and broader economic development associated with the park's existence. Our field surveys indicate that their substantial new-found wealth is most likely the result of extensive poaching activities. Our village-scale results are supported by the Associated Press reporting that rampant poaching has severely threatened wildlife in GLTP including complete elimination of black rhinos which were reintroduced into the Mozambican part of the GLTP only after the park's establishments in 2002 (http://www.nydailynews.com/news/world/mozambique-rhinos-extinct-experts-article-1.1333267). Our findings suggest that a new framework should be developed to combine species conservation priorities with improving economic well-being of population to achieve desired outcomes for both economic development and biodiversity.

Structural changes in settled areas within the GLTP boundary between 2004 and 2012

Prior to the beginning of this study we hypothesized that the signs of enrichment of population driven by the economic benefits from the park will be manifested in structural changes to the villages. Specifically, we expected to see change in housing conditions and livestock areas, associated with better economic standing of individuals, as well as community-level improvements in infrastructure and public services (including schools, medical facilities, etc.). We have conducted a study of changes to village structure using very high resolution multi-spectral imagery from 2004 (Ikonos) and 2012 (WorldView2). The differences in spectral band positions and spatial resolution of the two instruments preclude mapping changes using direct change detection approach. Instead we focused on mapping village components at two different time steps and quantifying the observed changes over time using the resultant maps.

A major challenge in mapping very poor rural settlements in Mozambique, as in many African countries, is presented by the scale of the mapping objects and the type of building materials. Individual houses of very poor villages are frequently as small as a single Ikonos multispectral image pixel (4m) which effectively precludes successful mapping of those dwelling especially if the view from above is obstructed by the overhanging vegetation. The limited range of multispectral observations (4 bands: blue – NIR) and relatively coarse (4 m) spatial resolution of Ikonos imagery compared to the (8 bands: blue – NIR) and finer (~2m) spatial resolution of WorldView2 necessitated development of slightly different approaches to image classification from imagery acquired by the two instruments. The general approach to mapping village structure presents a combination of spectral classification and identification of the 3-D object structure. The typical object-oriented approaches to mapping buildings in poor rural settlements are not effective because the near-identical spectral signature of building materials and surrounding background does not allow for edge definition as there is virtually no spectral contrast between the buildings (made of local wood, mud, and thatch) and the surrounding bare and sparsely vegetated land surface within the village boundary. Zinc (metal) roofs on dwelling of comparatively more affluent inhabitants allow for easy and consistent spectral identification and successful mapping from both Ikonos and WorldView2 imagery even at a single pixel size (for Ikonos). Therefore, in our general approach to image classification we first mapped zinc roofs of buildings, photosynthetically active vegetation, livestock corrals (corrals actually have a spectrally distinct signature most likely associated with some presence of wet mud and tree shadowing), and non-photosynthetically active surface components. We subsequently mapped locations of shadows associated with 3-D structure of landscape components (including buildings, trees, shrubs, and fences) and used a post-processing object oriented techniques to link the mapped shadow with either "non-photosynthetically active surface" classes based on the solar geometry and expected direction and size of the shadow (Fig. 1). While this is a viable and successful mapping method for rural dwellings, it suffers particularly strongly from the influence of trees and shrubs near the buildings (which occurs commonly in African villages) which impact both detection of buildings and mapping of building size and configuration as parts of the same building can be mapped as separate units because they are visually separated by an overhanging tree crown. For accuracy assessment, we generated 8 random points within a village, delineated a "block" based on the nearest intersections of major pathways through the village identifiable in the imagery and delineated every building and corral within the identified block. We subsequently compared our classification with the manually mapped objects and counted the number of correctly mapped objects (or portions of objects – we did not compare their extent between maps), objects that we mapped that were not identified manually (commission error), and objects that were not mapped in our approach but were picked up manually. As expected Ikonos results were less accurate than those obtained from the WorldView2 image but even with those we were able to map 59% of building and 80% of corrals accurately ($n_{buidling}$ = 112, n_{corral} = 10). Neither class had commission errors but the omission error of the building class was 41% with

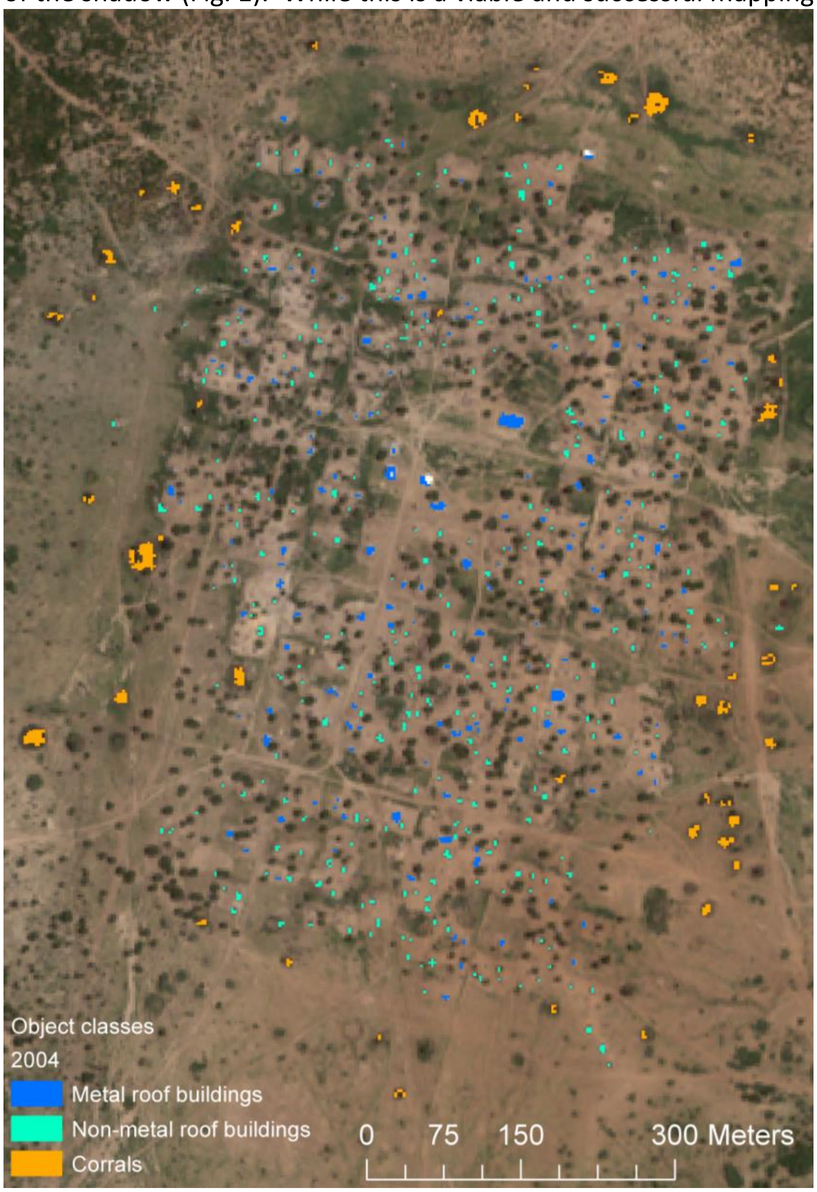

Figure 1. 2004 Ikonos-based map of village objects.

contribution primarily from small thatched roof buildings. Our method was overall successful for more spatially cohesive villages with well-defined boundaries and few patches of vegetation within the village (fig. 1). A more economically disadvantaged village within our study area, however, presented even greater challenges to mapping as the mapping objects are spread continuously throughout the area with large patches on trees and shrubs between various portions of the village (fig. 2). In those conditions, no reliable method for automated mapping of thatched roof buildings was produced and we heavily relied on extracting those using manual detection. The higher resolution of 2012 image and the actual structural changes that we observed take place by the time of image acquisition (including greater proliferation of metal roofing and an increase in the size of houses) required substantially less post-processing to achieve the 15% commission and 19% omission classification rates for buildings with the overall accuracy at 92% and Kappa > 0.8. It is important to note that a large number of buildings were under construction in in the imagery and there locations were indicated as piles of bricks roughly outlining the perimeter of the future building creating a complex and not readily interpretable objects in the image. We were able to identify these objects and verify the date of house construction during the field campaign. These results indicate that with the continuous improvement of the VHR mapping instruments (particularly as it relates to spatial resolution and availability of multispectral data) and the structural changes to the village composition are likely to support satellite mapping of poor rural settlements across the African continent as a whole with a high level of precision.

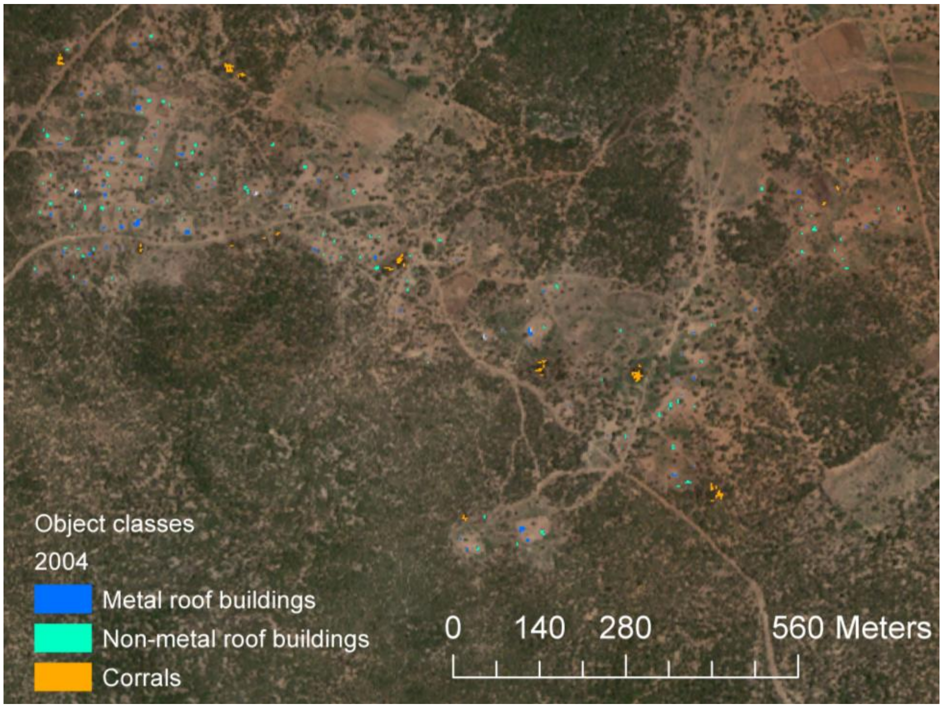

Figure 2. Ikonos-based map of village 2 in the study area.

The 2004 and 2012 village maps were subsequently used to investigate the changes in village structure over the time-period of the study and link the observed changes with the field survey results (fig.3). Considering the inherent uncertainty of inferring the exact location and size of an object from the position of its shadow in the image, we undertook as very labor-intensive analyst-driven analysis where we visually verified all classification results and matched all buildings across the 2004 – 2012 span to be able to identify the changes in the village with a high degree of confidence. The results show an extensive expansion of housing and other buildings in both villages. A comparatively small number of objects remained unchanged over the 8-year period. Both buildings and corrals were added and removed in both villages. Our field surveys verified that a removed object was most likely replaced with a new one in a nearby location and in most cases with considerable improvements. In village 2, we were able to track with a high degree of confidence only buildings with metal roofs and corrals. Over the 8-

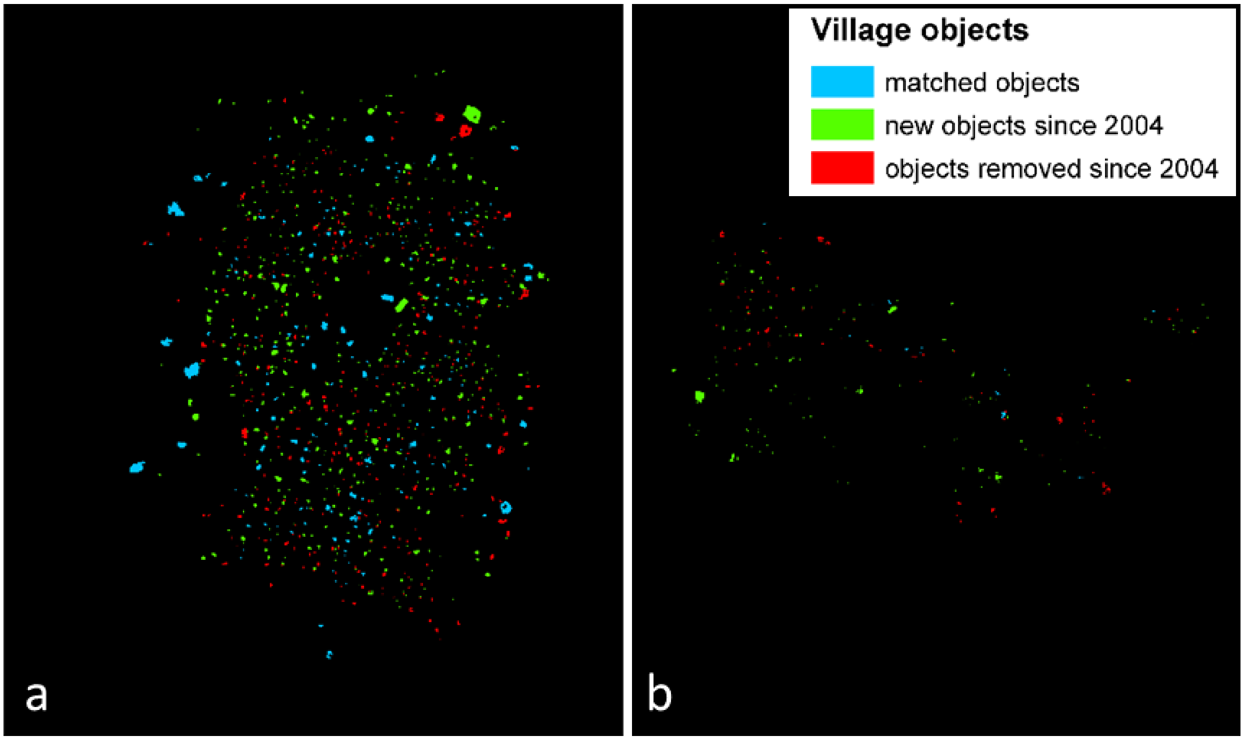

Figure 3. Structural changes detected in (a) village 1 and (b) village 2 between 2004 and 2012.

year period, the number of houses with metal roofs in village 2 grew to over 300% of the 2004 value. The number of building with both metal and thatched roofs increased in village 1 as well but at a slower rate (~54% for metal roofs and ~5% for thatched roofs). The area of the corrals also grew in both villages by 37% and 30% for villages 1 and 2, respectively.

Table 1. Changes in the number (for buildings) and extent (for corrals) of village structural objects between 2004 and 2012.

Objects	Village 1	Village 2
Corral area in 2004 (m^2)	3561	1117
Corral area 2012 (m^2)	4895	1449
Metal roof (count 2004)	177	65
Metal roof (count 2012)	273	208
Metal roof (added)	199	199
Metal roof (removed)	100	57
Metal roof (matched)	73	9
Thatched roof (count 2004)	328	-
Thatched roof (count 2012)	343	-
Thatched roof (added)	262	-
Thatched roof (removed)	247	-
Thatched roof (matched)	80	-

Overall out results show a large turn over in village composition and structure between 2004 and 2012 for both villages within the park boundaries. The majority of the changes also suggest an overall increase in the wealth of the inhabitants. Specifically, the area of the corrals has grown by ~1/3 in both villages indicating an increase in the number of livestock owned. The number of metal roofs in both villages has grown substantially as well. We did not observe any notable change in infrastructure of either village and were not able to verify that any change in the infrastructure of substantial communal building improvement has taken place through our field surveys.

Field survey analysis

The findings of this study illustrate dramatically different levels of forest clearing taking place among the case study communities between 2000 and 2010. In two communities, we find that residents have reduced the amount of area of land being converted from forest to agricultural uses. In the third village (outside the GLTP), land clearing for agricultural purposes has accelerated over the same time period. Our evidence indicates that land remains available for agricultural clearing in all three villages and that population growth has been comparable. No clear relationship between socio-economic conditions and differential rates of agricultural land expansion emerges from the 2009 survey data. Given that these villages share many similar characteristics, including poverty levels, livelihood strategies, and ethnic affiliations, our study indicates that socio-economic conditions alone cannot account for the differential rates of deforestation. Differences due to park management regulations also fail to adequately explain the variation in land clearing, since one community located within the boundaries of the park has lower rates of agricultural land expansion while another has considerably more. Moreover, respondents within the park expressed no concerns about land tenure or resettlement, which could potentially prompt clearing.

Turing to the findings of the qualitative analysis of interview data, our study indicates a relationship between lower levels of aspirational capacity and higher deforestation rates since the establishment of the GLTP. Despite evidence indicating a heavy reliance on crop farming as a primary livelihood activity in all case study sites, our findings reveal that the majority respondents in all villages do not aspire to remaining crop farmers. This is reflected in how people repeatedly describe dissatisfaction with farming as a primary livelihood and express a desire to attain formal employment. The negative views towards crop farming comport with lower rates of agricultural land conversion in two of our case study sites. However, the widespread dissatisfaction with crop farming in Machaule appears in conflict with the disproportionally high rates of agricultural land conversion that has taken place since the establishment of the park. In Machaule we find evidence of what Coomes et al. (2011) refer to as a land-use poverty trap. When assessing differences in aspirational capacity and perceived empowerment, we find that Machaule respondents expressed a more limited capacity to envision and plan for achieving alternative livelihoods, or translate possible opportunities into actions to bring about a higher quality of life.

Several factors appear to contribute to the lower capacity to aspire in Machaule. Household heads have statistically significant lower levels of education, which has been linked to more limited abilities to envision and plan to bring about desired future goals. Our findings lend support to those of Czaika and Vothknecht (2012) who find that individuals with limited or no education have reduced aspirations over both short- and long-term time frames of their lives. In relation to the other villages, Machaule respondents place more emphasis on the need for external intervention (e.g., god, the government) to bring about changes that could improve their quality of life. These findings indicate low levels of perceived agency of among Machaule residents to bring about desired change themselves or through collective action with other community members. These qualitative findings align with those of our quantitative analysis of survey data, where Machaule residents reported significantly lower levels of empowerment, including the freedom to participate in community decision making. Our findings comport with those of Bernard et al.'s (2011) study of Ethiopia, where individuals who exhibited an external locus of control were more likely to have weaker aspirational capacity. Our findings also suggest that the aspirational windows of Machaule respondents differ in scope from those of the other two communities. In the other two villages, more respondents speak more about learning from neighbors or gaining experiences in off-farm employment as ways to envision, plan, and carry out new activities. In Machaule, people explicitly noted the lack of role models for alternative, off-farm livelihoods. Given that only three kilometers separates Machaule from Chibotane, these results suggest that aspirational windows rely on who live next to, not necessary what you know others to be doing.

The various constraints on aspirational capacity not only contribute to on-going poverty in Machaule, they also seem to be a major factor in higher levels of deforestation and less uptake of admittedly dangerous alternatives such as rhino poaching to overcome poverty. Thus our results also indicate a potential downside to high aspirational capacity. We find higher levels of personal empowerment and capacity to aspiration in the context of few formal employment opportunities can potentially lead to negative conservation outcomes other than land clearing. In our case study analysis, we find that less deforestation takes place in villages where residents have become increasing engaged in the rhino poaching economy since 2009. Yet the causality between less deforestation and higher participation in rhino hunting must be interpreted with caution. Chibotane and Canhane exhibited lower rates of land clearing for agricultural expansion prior to the surge in rhino poaching within Kruger National Park, suggesting that other factors made residents in these villages limit agricultural expansion and, later, embark on alternative livelihoods as they became available. Greater demonstrated capacities to aspire for alternative livelihoods may well shape community engagement in the rhino poaching economy, although a full examination of this relationship lies outside the scope of our study. Ultimately our findings demonstrate the need for more research on the individual and social determinates of aspirational capacity, the conditions under which desires for alternative futures become translated into action in communities located in or near protected areas, and the potential consequences for conservation outcomes.

New elements of living space emerging as a result in changing activities and mythology

Between 2008, when the case study villages were selected as part of an NSF-funded study, and the 2014 NASA-funded field campaign, numerous new structures had been built in Canhane and Chibotane. Field observations, surveys, and interview data indicate that some residents of both communities participate in rhino poaching. Evidence indicates that income earned via poaching activities is being used to construct new houses made of conventional building materials (fig. 4). These new houses often had one or more smaller structures located on the perimeters of the household's living area (fig. 5). Key informants called these structures either 'veneration huts' or 'demon houses,' the latter term being more

Figure 4. House with water catchment system constructed in 2011 using conventional building materials, glass windows, and wood door.

commonly used by informants who identified as Christian. The motivation for building these structures was explained as being a way for individuals to honor their ancestors who had protected them during illegal hunting excursions in South Africa's portion of the GLTP (Kruger National Park). Given the high risks associated with rhino poaching, people who successfully participated in the activity were said to owe a debt to their deceased ancestors. These structures were round and lower than standard dwellings. Although the materials to construct these structures varied, the entrances were always blocked. Alters and offerings were often visible inside these structures.

Figure 5. Example of structures referred to as 'demon houses' and constructed to honor ancestors.

Conclusions

Taken together, our research has identified a new theoretical underpinning of human drivers of LCLUC in rural high poverty areas which accounts for the aspirations and goals of local residents. We find that a more limited capacity to aspire for a better future is associated with more forest clearing for agricultural purposes. People who feel they have no choice other than crop farming become locked into multidimensional poverty and potentially unsustainable land use patterns. This dynamic takes place even in the context of a relatively well-financed transboundary conservation effort. While stronger capacity to aspire is associated with less forest clearing in our study, we find that less deforestation may mask other undesirable conservation outcomes such as species endangerment or potential extinction. Moreover, the desire for change could place people in the position of making what Nussbaum (2010) refers to as tragic choices in their efforts to achieve their goals. The risks of participating in the poaching economy are extremely high, including death when rangers find people illegally inside Kruger National Park. Higher levels of aspirations coupled with limited livelihood alternatives, particularly formal employment, also leaves an imprint on both physical and social landscapes.

Project presentations and publications

Presentations

Loboda, T.V., Silva, J.A., Moulden A., Strong, M., Dodson, Z. (2014). Linking perceptions of well-being to land cover change: Lessons from the Great Limpopo Transfrontier Park, Mozambique. *Poster presentation* at the LCLUC Spring Science Team Meeting 2014, Rockville, MD (April 23-25, 2014).

Silva, J.A. and Loboda, T.V. (2015) Aspiration's Imprint on the Mozambican Landscape: Examining Regional Development and Land-Cover Change Using a Capabilities Approach. Department of Geography, University of Kansas, Lawrence, KS, February 2015.

Silva, J.A. and Loboda, T.V. (2015) Aspiration's Imprint on the Mozambican Landscape: Examining Regional Development and Land-Cover Change Using a Capabilities Approach. National Socio-Environmental Synthesis Center (SESYNC) Seminar, Annapolis, MD, March 2015.

Loboda, T.V., Silva, J.A., Cockerham, A., Strong, M., Dodson, Z. (2015) Global governance and land use decisions in Mozambique. NASA Carbon Cycle and Ecosystems Joint Science Workshop, Washington DC (April 20-24, 2015) (oral presentation).

Silva, J.A. and C. Meque (2015). Parques Nacionais e os Meios de Substistência Rurais: Histórias de Moçambique. Universidade Pedaógica – Delegação de Tete, Tete, Mozambique, June 2015.

Publications

Considering the potentially high impact of our findings, we have intentionally held back on submitting the manuscripts to allow for additional verification of our findings and strengthening the development of the theoretical framework for these results.

Silva, J.A., Loboda, T.V., Strong, M., Moulden, A., Dodson, Z., (in prep). Examining Aspiration's Imprint on the Landscape: Lessons from the Great Limpopo Transfrontier Park, Mozambique. Prepared for *PloS One* (expected submission April 2017).

Loboda, T.V., Chen, D., Silva, J.A. (in prep). Mapping structural changes in village composition as a reflection of economic growth in rural Mozambique. Prepared for *Remote Sensing* (expected submission July 2017).

Silva, J.A. and Loboda, T.V. (in prep). Spices conservation vs human economic well-being in rural Mozambique: the loss of black Rhino. Prepared for the *Proceedings of the National Academy of Sciences (PNAS)* (expected submission August – November 2017).

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