Applied Geography 125 (2020) 102326

Contents lists available at ScienceDirect

Applied Geography

journal homepage: http://www.elsevier.com/locate/apgeog

Mapping natural resource collection areas from household survey data in Southern Africa

Karen M. Bailey [a,*], Michael D. Drake [a], Jon Salerno [b], Lin Cassidy [c], Andrea E. Gaughan [d], Forrest R. Stevens [d], Narcisa G. Pricope [e], Kyle D. Woodward [e], Henry Maseka Luwaya [f], Joel Hartter [a]

[a] Environmental Studies Program, Sustainability, Energy and Environment Community, University of Colorado Boulder, 4001 Discovery Drive, Boulder, CO, 80303, USA
[b] Department of Human Dimensions of Natural Resources, Graduate Degree Program in Ecology, Colorado State University, Campus Box 1480, Fort Collins, CO 80523-1480, USA
[c] Okavango Research Institute, University of Botswana, P/Bag 285, Maun, Botswana
[d] Department of Geography and Geosciences, Lutz Hall, University of Louisville, Louisville, KY, 40292, USA
[e] Department of Earth and Ocean Sciences, University of North Carolina Wilmington, 601 South College Road, Wilmington, NC, 28403, USA
[f] Department of National Park and Wildlife, Private Bag 1, Kafue Road, Chilanga, Zambia

A R T I C L E I N F O

Keywords:
Resource mapping
Transfrontier conservation area
Southern Africa
Fuelwood
Participatory mapping
Human livelihoods

A B S T R A C T

As conservation landscapes are threatened by global change, there is a growing need to understand relationships between human livelihoods and environmental processes. This often involves integrating multiple data sources capturing different scales of measurement. Participatory methods have emerged as a means to accomplish this, but are hampered by a wide range of challenges associated with data collection and translation. Here, we present a novel methodology for mapping human use of natural resources that overcomes many of the difficulties faced in participatory mapping. Based in the world's largest terrestrial transfrontier conservation area, we couple household surveys with in-situ fine-scale mapping to identify key resource areas that support local livelihoods. This allows for a spatially referenced human use 'footprint' that can be combined with remotely-sensed data measuring environmental impact. This methodology is applicable across contexts and has implications for landscape management and conservation.

1. Introduction

Southern Africa continues to experience unprecedented anthropogenic change impacting human livelihoods, wildlife, and environmental processes. Rural and subsistence livelihoods in this region are highly dependent on natural resources and vulnerable to global shocks and stresses (Challinor, Wheeler, Garforth, Craufurd, & Kassam, 2007; Connolly-Boutin & Smit, 2016; Jones & Thornton, 2009). As a result, there is a growing need to understand how global environmental changes impact people and their use of land and resources (Conway et al., 2015; Gaur & Squires, 2018; Wilbanks & Kates, 1999), and to identify feedbacks between environmental processes and human activities (Coetzer-Hanack, Witkowski, & Erasmus, 2016; Nagendra, Munroe, & Southworth, 2004). This is particularly true in arid and semi-arid landscapes of low and middle income countries, where complex relationships with the land are complicated by ongoing anthropogenic change (Gaur & Squires, 2018). The need to understand these feedbacks is often encompassed in the call to connect "people to pixels" (Liverman, Moran, Rindfuss, & Stern, 1998). Global-scale, remotely sensed data is a powerful resource for quantifying and monitoring complex dynamics and change over time (Agutu et al., 2017; Townshend, Justice, Li, Gurney, & McManus, 1991; Turner et al., 2003; Vågen, Winowiecki, Tondoh, Desta, & Gumbricht, 2016). However, these data are at different spatial and temporal scales than the activities of people on the landscape, and many challenges (i.e. matching levels of accuracy with other data sets, generalizing methods across different land-cover types) exist in integrating remotely-sensed data and data on human activities (Liverman et al., 1998; Dubovyk, 2017; Wardrop et al., 2011). In order to understand social-ecological systems dynamics - a critical step toward adaptation under global climate change - it is imperative that we overcome these challenges and find new ways to link people to pixels.

We explore the use of participatory mapping as a means to connect remotely-sensed data to human use of the landscape. Participatory mapping incorporates local knowledge on a wide range of landscape

* Corresponding author.
E-mail address: karen.bailey@colorado.edu (K.M. Bailey).

https://doi.org/10.1016/j.apgeog.2020.102326
Received 12 July 2019; Received in revised form 11 August 2020; Accepted 8 September 2020
Available online 24 September 2020

features (natural resources, population, land tenure, etc.) in a spatially explicit framework to better understand local needs, activities, perspectives, and threats (Chambers, 1994; Cornwall & Jewkes, 1995; Brown et al., 2014). Participatory methods vary widely in their application and use. For example, participatory maps have leveraged local knowledge to identify ecosystem services and areas of conservation priority and support delineation of land tenure rights and sense of place (Klain & Chan, 2012; Ramirez-Gomez, Brown, Verweij, & Boot, 2016). Participatory mapping has also been used to assess potential resource conflicts, inform adaptive management, measure value derived and threats perceived from local protected areas, and to create a bottom-up understanding of land use (Brown & Raymond, 2014; Kalibo & Medley, 2007; Palomo, Martín-López, Potschin, Haines-Young, & Montes, 2013). More recently, participatory GIS (geographic information systems) has informed policy for regional landscape planning to preserve cultural landscapes, incorporate indigenous knowledge in development, and garner public support for landscape management (Engen et al., 2018; Ramirez-Gomez et al., 2016; Siswa Sulistyawan et al., 2018).

Despite the advancements and wide use of participatory methods, there are limitations and challenges that remain in both creating participatory maps and in linking participatory-based data to other sources (Chambers, 1994; Ernst, Biβ, Shamon, Schumann, & Heinrichs, 2018; Ramirez-Gomez, Brown, & Fat, 2013). Participatory mapping methods are often contingent on communities possessing knowledge informative to researchers, as well as methods sufficient to elicit this knowledge; both steps include sources of error. In particular, conceptualizations of space and the integration of externally-sourced maps can prove challenging in participatory mapping and may require extensive preliminary training (Roth, 2009; Koskinen et al., 2019). Participants must employ a significant, and perhaps unfamiliar, level of abstraction to situate themselves on externally-sourced maps, which may be a difficult new experience (Nackoney, Rybock, Dupain, & Facheux, 2013). This challenge of abstracting a participant's daily activities to a visual representation can be compounded within homogenous landscapes that offer few points of reference useful in identifying landscape features (Cadag & Gaillard, 2012).

The applicability of participatory maps is further complicated by participant and researcher ability (e.g. locally relevant experience, mapping expertise, logistical constraints) and integration with external data may prove challenging (Brown, 2017; Rambaldi, Kyem, Mccall, & Weiner, 2006). Participatory maps that are not properly rendered at scale or georeferenced have limited applicability beyond the group that created it, and are less likely to be integrated by governments, researchers, or policy makers into future research or management plans (Cadag & Gaillard, 2012). Further, the accuracy, precision, and applicability of participatory maps is heavily influenced by who participates in the process, making it challenging to distinguish landscape variation from participant group variation (Brown, 2017; Mapedza, Wright, & Fawcett, 2003; Rambaldi et al., 2006). As such, there is still a need for methods that overcome sampling bias, evenly represent different groups (e.g., women, immigrants, elders, ethnic groups) within the community, efficiently and effectively integrate local knowledge and remotely-sensed data, and balance tradeoffs between the different data types (Selgrath, Roelfsema, Gergel, & Vincent, 2016; Zaehringer, Llopis, Latthachack, Tun Thein, & Heinimann, 2018).

Here we present a new approach to mapping natural resource collection on the landscape, which we term *livelihood-resource mapping,* readily implemented in conjunction with household survey methodologies, and as a link to remotely-sensed analyses at multiple spatial scales. We developed this method to overcome challenges associated with sourcing community-level data and accurately combining satellite imagery for community or household use. It explicitly considers community- and household-level variation in natural resource use and aims to map human resource use areas onto the landscape. Rather than elicit the qualitative resource mapping information typically associated with participatory rural appraisal approaches (Chambers, 1994; Cornwall & Jewkes, 1995), we match household data on resource use and resource place names to areas in the landscape that can be mapped using satellite imagery. We pioneer this method as part of a larger study in southern Africa where livelihoods are heavily dependent on natural resources and where wildlife conservation is a regional priority. Our primary research objectives were to (1) use local knowledge to create a map of important natural resource collection and use areas and (2) assess spatial variation in natural resource use across communities.

2. Methods

2.1. Contextual background

The approach outlined in this paper was integrated with a research project aimed at understanding how climate variability and socio-ecological conditions interact with and affect household vulnerability in a conservation landscape (Gaughan et al., 2019, Salerno et al., 2020). We implemented this method in community-based conservation areas (CBCs), where local communities have agency to dictate local land management. The long-term goal of the CBC structure is to promote both human livelihoods and environmental conservation, making CBCs ideal locations to investigate the interplay between humans and the environment. CBCs often neighbor other types of protected areas in the conservation landscape and overlap with regions that are relied on by both humans and wildlife (Cumming, Andersson, deGarine-Wichatitsky, Dzingirai, & Giller, 2013). To better understand how human activities and reliance on the surrounding natural resources may affect environmental conservation or degradation, we sought to find a way to link individual households and their resource use with natural resource collection areas.

We initially piloted a more traditional participatory mapping technique (e.g. Chambers, 2006; Slocum, Wichart, Rocheleau, & Thomas-Slayter, 1995) in our study area. We recruited participants with the help of a local conservancy, with the goal of representing men and women and participants from different villages of different ages. We separated participants randomly into two groups. We presented one group with satellite (Google Earth) imagery of the landscape and asked them to identify areas where they collected natural resources. We asked the other group to draw their village and surrounding area, and then identify places where resources were collected. We soon learned that the homogenous aerial view of the landscape (lacking major roads, topographical variation, obvious ecological gradients, etc.) made it challenging for participants to confidently locate boundaries of resource extraction areas at a spatial resolution needed for linking to remotely-sensed data. Generally, participants were knowledgeable about broad areas for specific land use activities (e.g. farming, wildlife areas, settlement), but the degree of specificity was not high enough to identify the resource collection areas. Further, many of these areas did not have hard boundaries. However, participants could confidently denote the local name and relative distance to resource collection areas, and these pilots confirmed that collecting resource use and resource place name information during the household survey would provide the necessary data for describing areas on the landscape. Due to these challenges, we sought to create a novel methodology that would allow for the spatial delineation of natural resource areas without the use of satellite imagery. In this new methodology, we could then travel to these areas with a community key informant (KI) to verify their location and to collect GPS points for linking to satellite imagery, thus mapping resource use both quantitatively, and in a novel, precise and in-depth way. Not only does this methodology allow for the identification of resource areas, but may also provide data that could facilitate future identification of resource areas through traditional remote sensing.

2.2. Study sites

We implemented livelihood-resource mapping in villages in three

CBCs within the Kavango-Zambezi Transfrontier Conservation Area (KAZA, Fig. 1). KAZA is the largest terrestrial transfrontier conservation area in Africa and an important international tourism destination for its member nations: Angola, Botswana, Namibia, Zambia, and Zimbabwe (Lindsay, Chase, Landen, & Nowak, 2017). The KAZA landscape is composed of semi-arid forests and savannas interspersed with extensive wetlands and shrublands (Schultz, Shapiro, Clevers, Beech, & Herold, 2018). This landscape has highly variable dry and wet seasons and water security is dependent on annual rains, making local people vulnerable to seasonal flooding and drought (Gaughan & Waylen, 2012). However, these regional climatic and rainfall cycles, and thereby the crop yields and human livelihoods dependent on them, are likely to be altered by global climate change (New et al., 2006; Nkemelang, New, & Zaroug, 2018). People in this landscape depend on rainfed agriculture for their livelihoods and collect natural resources to buffer against low agricultural yields due to marginal farming conditions and extensive crop raiding by elephants (Andersson, Garine-Wichatitsky, Cumming, Dzingirai, & Giller, 2017; Metcalfe & Kepe, 2008; Salerno et al., 2018).

The social-ecological system in KAZA comprises a complex landscape of multiple land use types, which present different benefits and challenges to the maintenance of rural livelihoods. The KAZA landscape connects 36 protected areas that are embedded within a mosaic of privately, publicly, and communally owned land. Within communally managed lands, common pool resources are accessed by local communities who rely heavily on subsistence crop and livestock farming as well as natural resource harvesting (Chingombe, Pedzisai, Manatsa, Mukwada, & Taru, 2015). KAZA's land uses range from relatively undisturbed parks to urban areas, and the area is therefore subject to high variation in human impacts (Munthali, Smart, Siamudaala, Mtsambiwa, & Harvie, 2018). Within KAZA's national parks, most natural resource collection and human activities beyond tourism are illegal, with exceptions for some communities (Hitchcock, Sapignoli, & Babchuk, 2011; Thondhlana, Shackleton, & Muchapondwa, 2011). Outside of the communal lands, which limit human uses within their boundaries, human impacts range from resource extraction and farming to ecotourism (Metcalfe & Kepe, 2008). We investigated livelihood-resource collection in 3 CBCs; Lower West Zambezi Game Management Area (LWZ GMA) in Zambia, Chobe Enclave in Botswana, and Mashi Conservancy (Mashi) in Namibia; and the (Fig. 1). All three study sites are adjacent to national parks and are comprised of a mixture of floodplains and forested, dryland areas.

Zambia's LWZ GMA is the largest CBC area in our study at 19,300 km^2 and a population of 70,157 people (Department of National Parks and Wildlife & Ministry of Tourism and Arts, 2016). LWZ follows the Zambezi River and is bounded by Namibia to the south, Angola to the west, the Upper West Zambezi GMA to the north, and unprotected lands across the Zambezi River to the east. We limited our study to five communities within the Sesheke West Community Resources Board, one of the LWZ GMA's two administrative units. The area of the Sesheke West Community Resource Board is more comparable in size to our other study sites and is administered by a single body, making it an apt comparison with the other CBCs. Three of these communities (Kaale, Lusu, Kalobolelwa) were located on the banks of the Zambezi river and the remaining two communities (Kapau, Makanda) border Sioma Ngwezi National Park.

Chobe Enclave is located in Northern Botswana and encompasses 2990 km^2 with a human population of 4108 based on latest Census data (Central Statistics Office & United Nations, 2011; Stone, 2015). The conservancy is bounded by the Chobe River and Namibian border to the north, Chobe National Park to the southwest, and the Chobe Forest Reserve to the southwest. Three communities within Chobe Enclave (Kachikau, Kavimba, Muchenje-Mabele) occur on the sandy southern

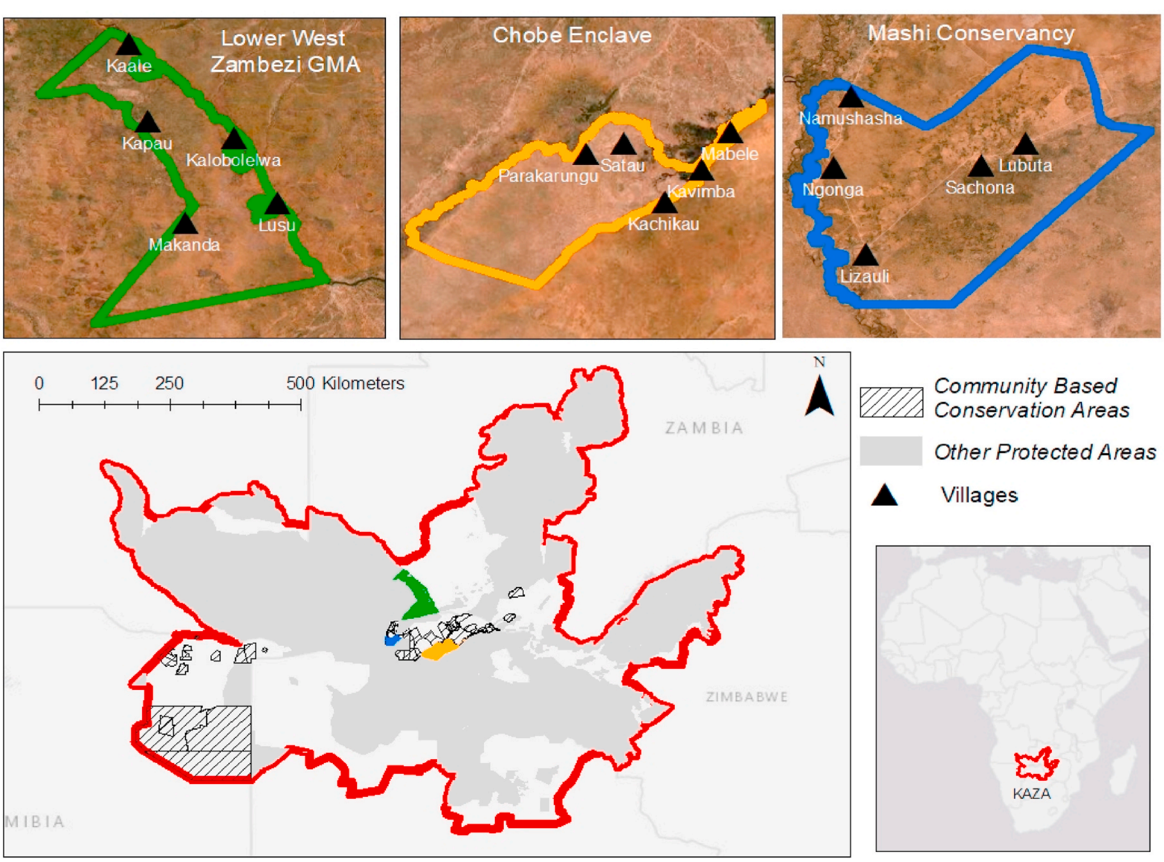

Fig. 1. Study area highlighting the KAZA boundary and protected areas, (A) Lower West Zambezi game management area, (B) Chobe Enclave, and (c) Mashi conservancy.

dryland escarpment that borders the Chobe Forest Reserve and two more (Parakurungu, Satau) occur within the Enclave's extensive central floodplain zone.

Mashi is a 297 km^2 conservancy in the Eastern Zambezi Region (formerly known as the Caprivi Strip) of Namibia that was established in 2003 (Fig. 1). Mashi is bounded by the Kwando River to the west and the conservancy abuts two national parks (Bwabwata and Mudumu), the Botswana border, and the Mayuni conservancy. Five village areas, with a total human population of approximately 2,200, occur within the conservancy, three of which lay close to the Kwando river floodplain (Lizauli, Namushasha, Ngonga) while two are located in upland forests (Sachona, Lubuta; Kanapaux & Child, 2011).

2.3. Ecological landscape

KAZA is a dynamic matrix of shrub and tree-dominated savanna, complex river systems, wetlands, and grasslands. As such, many important natural resources in the region are not evenly distributed across the landscape. For example, grapple, also known as devil's claw (*Harpagophytum* spp.), is a medicinal plant used locally and

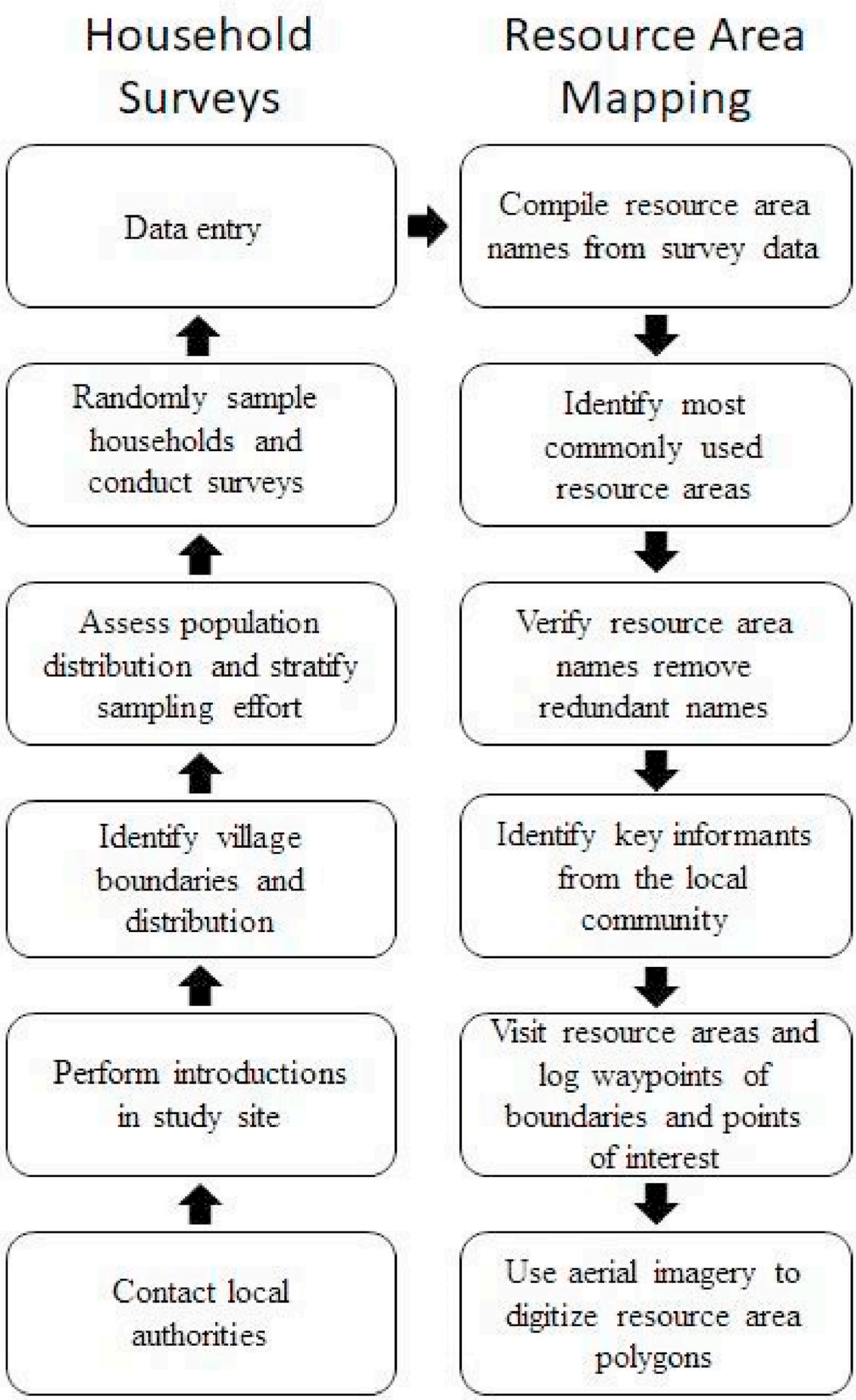

Fig. 2. Flowchart of the main steps taken during data collection for household surveys and livelihood-resource area mapping.

commercially for treatment of a wide range of diseases (Stewart & Cole, 2005). While widely distributed across the KAZA region, locally, it has a clumped, patchy distribution driven by competition with grasses and response to heavy grazing (Hachfeld & Schippmann, 2002; Stewart & Cole, 2005). Similarly, wetland-dependent resources, such as reeds, are only available to households in some communities because of their limited distribution. Beyond the ecological factors that influence resource distribution, anthropogenic activities, such as farming and landscape fragmentation, and the large elephant populations that call KAZA home, have significant impacts on the availability and distribution of vegetation and natural resources (Fullman & Bunting, 2014; Reid et al., 2000; van Aarde & Jackson, 2007). Understanding variation in resource distribution and availability across the study area provides important context for understanding how communities use the landscape for resource collection.

2.4. Household surveys

Before engaging in any research, protocols were approved following recognized codes of conduct by both community and traditional authorities (Fig. 2) (Bernard, 2006; Ibbett & Brittain, 2019). All human data collection adhered to ethical standards that were reviewed and approved by the University of Colorado Institutional Review Board (#16–0126). Protocols included gaining verbal informed consent from all participants prior to research activities. Participants were assured anonymity. Researchers introduced the project and gained permission to conduct activities at higher levels of authority (e.g., national research councils, KAZA Secretariat, Traditional Authorities, Council Chiefs) as well as from local authorities in each community. We conducted all field work (household surveys along with the subsequent resource mapping) between May and July, in the dry seasons of 2017 and 2018.

Additionally, members of the traditional authority performed introductions of our project and personnel in each community to increase local acceptance of our project. We consulted with conservancy land managers, traditional authorities, village leaders, and sub-village representatives to ensure the relevance of our survey instrument and to identify suitable research assistants. We conducted household surveys to measure livelihood capitals (economic, human, natural, physical, social), demographics, food security, and health as part of an integrated human-biophysical framework to quantify vulnerability and change. While conducting household surveys, we incorporated livelihood-resource mapping to provide fine-scale data on local natural resource use.

We sampled the five villages in the Sesheke West portion of the LWZ GMA and all five villages within Chobe Enclave and Mashi. These villages were roughly evenly divided between floodplain and dryland areas within each CBC. Villages had social boundaries based on traditional authority structures and we consulted with the village headman (*induna/kgosi*) to determine approximate village boundaries before setting our sampling protocol (Fig. 2). We defined households within a village as a single house or a cluster of buildings that utilized a single cooking fire and were often enclosed by a thatch fence (lapa). Using estimates of village populations obtained from the induna/kgosi or census data when available, we created a stratified area sample frame for each village. Most villages were centered around a densely populated core area with less dense clusters of households radiating from the village center. We stratified our sampling effort in proportion to the number of households in the core area versus in satellite regions to minimize potential bias associated with spatial clustering in the households. To ensure that 48 surveys were conducted in each village area, we surveyed every *nth* household, depending on the total number of households provided to us by village leaders. Beginning in the center of the village area, we followed arterial roads or paths extending outward and surveyed every *nth* household after selecting the first surveyed house on the basis of a random number between 1 and *n*. If an adult representative was unavailable, enumerators revisited the household twice more before surveying an adjacent household instead. Research assistants recruited from within each respective conservancy administered the surveys orally in the primary language spoken within the household (Silozi, Subiya, Tswana, Thimbukushu or Fwe). Research assistants all possessed a secondary education and did not conduct surveys in their home village.

The survey instrument contained questions about food security, household livelihoods, household demographics, employment, and human-wildlife conflict. Specifically, it included a detailed section relating to a wide range of natural resources, with amounts collected, travel time, mode of travel and place names, as follows:

- "Did you collect any of the following natural resources during the wet/dry season in the past 3 years?" Listed resources were firewood, thatching grass, building poles, fish, reeds, palm leaves, medicinal plants, and fruits and vegetables.
- "[What is the] Name of the main area where you usually collected [the resource] in the wet/dry season in the past 3 years?"
- "How do you usually travel there (walk, cart, canoe, etc.)?"
- "Time taken to get to the area"
- "Total quantity gathered during the wet/dry season since this time last year"

Respondents reported the quantity of resources that they collected in units familiar to them, such as bowls or wagon loads. These units are common and relatively standard across communities and were later converted into kilograms using conversions provided by key informants. Estimates of mass were not collected for the quantity of grass grazed by livestock or water collected.

2.5. Resource area mapping

After completion, household survey responses were entered into a database. We aggregated and post-coded all resource area names and associated resource types reported by respondents from each village area. To reduce errors of omission and commission, we consulted with survey enumerators to confirm the existence of resource areas names provided and removed redundancies of resource names. We counted the number of times each resource area was mentioned in the surveys and ranked the areas by these numbers to prioritize mapping of the most frequently used areas. At this stage, we also filtered out any reported areas that referred to overly general areas or locations around the household (e.g. 'in the bush' or 'in the village'). We then cross-referenced these area lists with an area induna/kgosi or KI familiar with the resource areas to confirm that no important resource areas had been omitted. Next, accompanied by the KI, we traveled to each named resource area to collect GPS waypoints along all accessible boundaries of the area (Fig. 2). We also opportunistically mapped resource areas that were not listed in household surveys that KI's identified as important for community resource collection. Within the resource area, we also collected waypoints at points of interest, such as water pans or sites of obvious natural resource harvesting (e.g. felled trees, etc.). Where resource areas were too large (e.g., >10,000 ha) or impassible to vehicles (e.g. extensively flooded areas or dense bush), we logged multiple reference points - noting the distance, bearing, and proximity to physical features of the boundary - so that we could later triangulate the area's boundary using satellite imagery. If our KI was unfamiliar with a resource area, we identified a second KI within the community to assist in the mapping of that resource area. Note that we mapped all accessible resource areas that were reported, regardless of location (e.g. within or beyond the established boundaries of CBCs or communal lands).

We digitized resource area boundaries in ArcMap 10.5 (ESRI, 2011). For each resource area, we first identified any unvisited borders using field notes and reference waypoints. We then delineated resource area polygons by connecting existing border waypoints with the newly identified, unvisited borders. When constructing these polygons, we attempted to follow natural features in land-cover, such as forest edges, roads, or drainages, where these were more obvious. In instances when notes about boundaries did not obviously align with physical features, we constructed resource area polygons to incorporate the minimum area that satisfied all other recorded notes and waypoints (Fig. 3).

Following completion of the household survey data entry and resource area mapping, we recorded the number of individual households that reported visiting a resource area. We combined and summarized household survey data to create metrics of use for each identified resource area including:

- Number of households utilizing each resource area
- Number of resource areas utilized by each household
- Type and amount (in kg) of resource extracted in the wet and dry season

3. Results

3.1. Livelihood resource areas

We mapped a total 214 resource areas across 3 countries derived from 726 household surveys; 77 in Zambia, 53 in Botswana, and 84 in Namibia (Table 1, Fig. 4). The total area of all resource areas is 1117 km^2; 789 km^2 in Zambia, 231 km^2 in Botswana, and 97 km^2 in Namibia. In Zambia, the resource areas ranged in size from 0.046 km^2 to 174 km^2 (the largest resource area we mapped, referred to as "Tiki"). In Botswana, they ranged in size from 0.007 km^2 to 63.8 km^2. In Namibia, they ranged in size from 0.002 km^2 to 17.3 km^2. Resource area size can be explained by a number of factors. First, homogeneity of the landscape requires larger extents in order for rare resources to be found in sufficient quantities, or for a greater diversity of resources to be found. In Botswana and Namibia, savanna woodlands, floodplains and river systems are much closer together than in Zambia. At the same time, population densities and the land available to the communities are also factors.

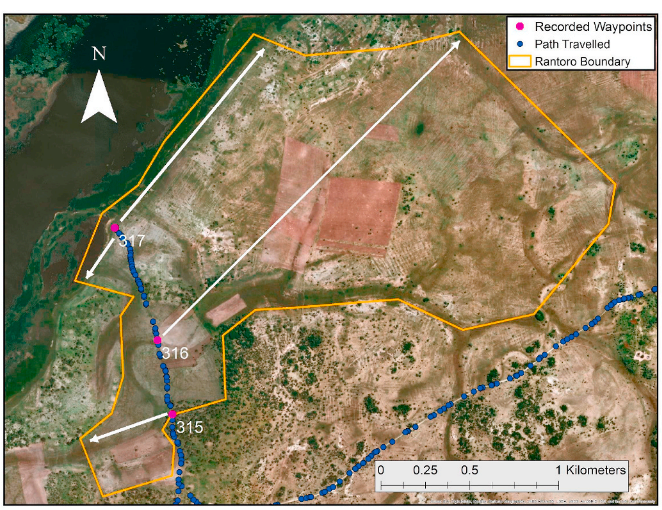

Fig. 3. Sample resource area digitization. We recorded three waypoints while mapping the Rontoro resource area in Botswana; the southern area edge bounded by trees at a heading of 260° at waypoint 315, the northeastern resource area edge bounded by palm trees ~3 km away at 45° at waypoint 316, and the northwestern resource area boundary at the river at waypoint 317. The northwestern and southern boundaries of Rontoro were created using these notes (bearings from each point visualized by white arrow). The eastern boundary was formed by tracing the visible drainage that most directly connected the points where we had recorded notes or waypoints. Notably, estimated distances were almost always significant overestimates when compared to aerial imagery.

Botswana has the greatest average number of households using each resource area and the greatest average number of resource areas accessed per household (Table 1). The resource area with the greatest number of households reporting use (38) is also in Botswana, representing use by 16% of households surveyed. Zambia, in contrast, has the highest average resource collection at the resource area and household level, with an average of 9033 kg collected per resource area and 2117 kg collected per household (Table 1). On average, people spend the greatest amount of time traveling to resource areas in Botswana (79 min) and the least amount of time in Zambia (52 min).

3.2. Resource collection

The resource areas represent collection of fourteen resource types; timber poles, firewood, edible and medicinal plants, fish, birds and mammals, grapple, livestock grazing, livestock watering, mud, palm leaves, reeds, thatching grass, and water lily bulbs. On average, households collect 3 or 4 different types of resources. The most commonly collected resources are firewood (97% of households), thatching grass (63% of households), and edible plants (43% of households). All resource areas but one are used by households in two or fewer communities. The exception is one resource area in Botswana used for collection of reeds by households in four communities.

4. Discussion

By mapping natural resource areas in conjunction with household surveys, we developed a systematic method for leveraging local perspectives to create a map of community use of the landscape. The maps and associated data helped us visualize differences in resource areas across the three studied communities/countries in KAZA. We found that natural resource extraction, as measured by total amount gathered per resources area and per household, was highest in Zambia, which also had the most resource areas. This may reflect Zambia's above average natural resource dependence and population density when compared to other countries in the region (Bwalya, 2011; Gylfason & Zoega, 2006; Sachs & Warner, 2001). Conversely, Botswana had the highest average household use per resource area, providing another indicator of extraction pressure. This may be the result of a history of government management and privatization of natural areas and exclusion of local communities (Blaikie, 2006). In Namibia, communities used the smallest resource areas and collected intermediate amounts of natural resources. It is worth noting that the averages and standard deviations we present demonstrate the great variability in resource collection at the household level. In Zambia, for example, there is both high average resource collection and a large standard deviation; some households collected 1–2 kg while others collected over 10,000 kg. Households that gather large amounts of resources each year may mask the overall measure of natural resource dependence at the community or country level. Further work is necessary to identify the spatial footprint of these super-collectors relative to average households. Such spatially-explicit data on community- and country-level variation in natural resource use is valuable for understanding regional-scale trends and informing policy and management decisions in KAZA in the future (Andersson, deGarine-Wichatitsky, Cumming, Dzingirai, & Giller, 2017).

We are also able to begin to make inferences about why communities use the landscape in the ways they do. Future integration with land-cover and land-use maps will allow us to explain both the "where" and the "why" of landscape use. For example, for resources with constrained distribution (e.g. fish, water lilies), many households reported collection in the same resource areas. This information can be used by communities to identify which specific aquatic regions are most important for supporting livelihoods and has implications for sustainable management of natural resources (Sandström et al., 2003; Skidmore, Bijker, Schmidt, & Kumar, 1998). Further, by utilizing socio-economic household data, we can investigate which household-

Table 1
Summary statistics for all resource areas and households by country. Average values (standard deviation) are displayed where applicable.

Region	Resource Areas	Average Perimeter (km)	Average Area (km^2)	Households/ Resource Area	Resource Areas/ Household	Average Collected/ Resource Area (kg)	Average Collected/ Household (kg)
Zambia	77	11.2 (9.7)	10.2 (23.2)	3.2 (7.4)	2.2 (1.0)	9033 (25,162)	2117 (9658)
Botswana	53	7.3 (8.1)	4.4 (10.1)	5.8 (8.5)	2.6 (1.4)	907 (1351)	180 (370)
Namibia	84	3.6 (4.5)	1.2 (3.0)	3.3 (5.2)	2.5 (1.2)	2145 (5084)	354 (1080)
Total	214	7.3 (8.3)	5.22 (15.3)	3.8 (7)	2.4 (1.2)	4095 (15,213)	907 (5772)

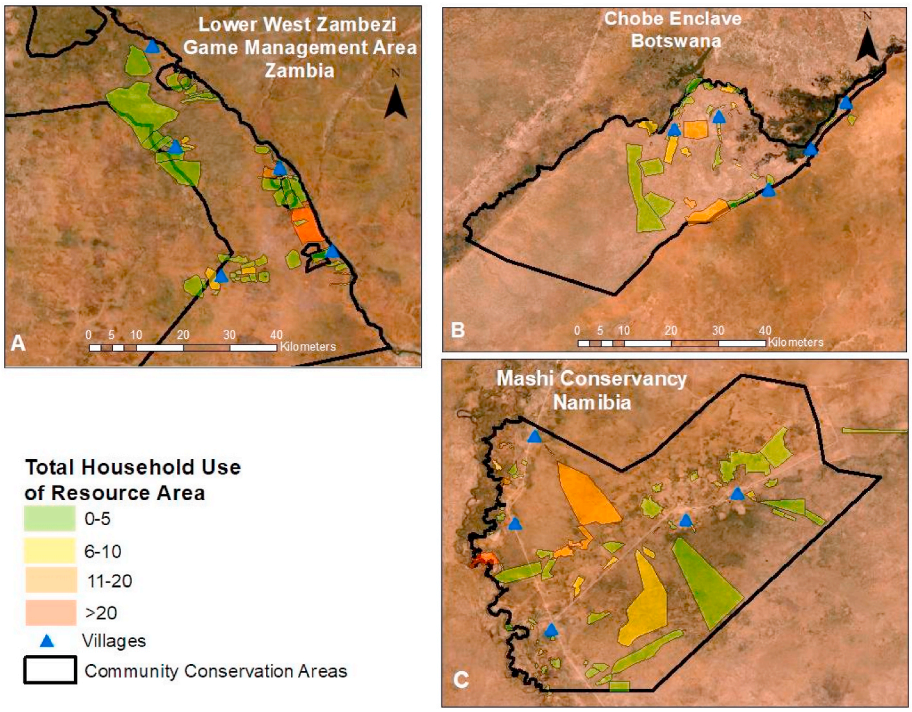

Fig. 4. Livelihood resource areas mapped in (A) Zambia, (B) Botswana, and (C) Namibia and the number of households that reported using each area. Resource areas with zero households were those mapped opportunistically.

and community-level factors influence fine-scale resource use and which households are most likely to be vulnerable to perturbations in the landscape. The pairing of resource collection and household data may inform a broader understanding of the KAZA social-ecological system and could be used to explore how natural resource usage impacts community livelihoods (Cadag & Gaillard, 2012; Folke, 2006).

Despite the value of the data gathered through this method, we faced several challenges that bear discussion. This method of resource mapping is labor-intensive and requires the ability to quickly move between households, communities, and various resource areas. In some instances, we couldn't successfully map resource areas due to flooding and road blocks, or the absence of roads for resource areas typically accessed by communities solely on foot. For those resource areas we did access, identifying and validating the boundaries was often difficult. Estimating distance in the field proved challenging, even for individuals very familiar with the area, and distance estimates often did not match aerial imagery. However, these inaccuracies in distance estimations only reinforce the benefit of physically visiting resource area boundaries. Additionally, the distant border of a resource area may be unknown to most households that access it or variable depending on environmental conditions. More commonly, resource areas do not always have finite boundaries and have different shapes in different people's minds. It begs the broader question, should these resource areas be envisioned as sharply bounded polygons? Perhaps future resource mapping and participatory mapping efforts can borrow from other fields to yield a more dynamic interpretation of a resource area. For example, ecologists use a variety of methods to estimate the "home range" of individuals, relying on data associated with presence, absence, intensity of use, and other factors (Boitani & Fuller, 2000; Worton, 1987). These data allow the delineation of regions with core areas of use, and relative probability of use and could potentially be applied to this method through incorporation of resource collection data. Such a method would allow us to distinguish between areas of high and low use while creating a more fuzzy boundary of the resource area itself.

More broadly, this method serves only as a foundation for identifying and delineating patterns of resource use across the landscape. We did not explicitly measure resource availability and quality (which may explain some of the patterns observed) within resource areas and how it may vary across CBCs or countries. Additionally, converting the amount of resources gathered to mass enabled us to compare collection effort between households, but may be less meaningful when comparing across different resource types. However, using the products derived from this research, we can further investigate natural resource use and extraction pressure in the context of ecological and environmental dynamics.

While these challenges and limitations should be taken into consideration when applying this method elsewhere, our household-level research design enabled us to effectively and efficiently map local resource areas throughout KAZA. These data will be incorporated into multi-scalar analysis of livelihoods, climate, and land systems dynamics that will identify interactions of biophysical and social conditions associated with household vulnerability and environmental change.

4.1. Methodological experiences and comparison to other participatory mapping

To summarize our mapping process, we have identified several key advantages of our methodology:

Accessing spatially explicit community level knowledge: Because the conservancy boundaries are a management tool established at governance levels higher than the communities, it is not surprising that most households do not access the entire area of the conservancy landscape. These landscapes are vast and hard to access, particularly since most households lack transport. Instead, households tend to focus on just those areas closer to their homesteads or where ecosystem conditions favor specific resources of interest (e.g., reeds on floodplains). However, the pooled spatial knowledge from hundreds of household survey responses allows for a broader and more complete picture of resource interests and use. Importantly, traditional participatory mapping efforts are often bounded with researchers/experts defining the area to be mapped, or regions of interest/priority (Basupi, Quinn, & Dougill, 2017; Brown, 2017; Levine & Feinholz, 2015). In contrast, beyond the previously identified households and communities, we mapped any and all accessible sites identified by participants. Using this method, we did not constrain our measures of resource use to *a priori* areas of interest, and allowed resource users to directly define areas of relevance. This method provides a more explicit spatial representation of human activities on the landscape and generates a more realistic footprint for human use and reliance on surrounding natural resources than might be obtained from focus groups or key informants alone or by limiting research to a single portion of the landscape.

Quantitative evaluation of landscape use: Our method quantitatively evaluates landscape use. Often, particularly in rural and low- and middle-income country contexts, participatory mapping focuses on assessment of generalized use and perceived value of areas on a landscape. Participants are asked what parts of the landscape are used, how they are used, and if and how they are important in terms of ecosystem services, including food provisioning, recreation, aesthetics, etc. (Bijker & Sijtsma, 2017; Blake, Augé, & Sherren, 2017; Weyer, Bezerra, & De Vos, 2019). It is less common for participants to explicitly quantify use, behavior, or extraction patterns, as our research has. This quantitative data enables a more accurate integration of household data, land-cover and land-use change data, and ecological and environmental data.

Integration of multiple data types: By incorporating survey research into our methodology, we were able to leverage a large sample size for our study, as is typical of other, quantitative participatory GIS (PGIS) studies (Brown et al., 2014). However, by decoupling mapping from our household surveys, we were able to maintain a large sample size without sacrificing the accuracy of our mapping effort. Perceptions of the boundaries of an area can vary greatly within a community and are not always accurate, requiring multiple community members to map an area before a consensus on boundaries is achieved (Chingombe, Pedzisai, Manatsa, Mukwada, & Taru, 2015). Brown and Pullar (2012) recommend using at least 25 respondents to achieve reliable convergence when mapping polygons. However, each resource area in our study was only identified by ~4 households, which would likely have resulted in poor agreement between community members had they attempted to identify resource area boundaries on a map. As such, traditional PGIS mapping methodologies would have produced poor results in our system. By pairing survey research and on-the-ground mapping, our methodology circumvents these issues and allows for the efficient sourcing of community knowledge and the accurate mapping of resource locations.

Additionally, utilizing high resolution satellite imagery during the mapping process allowed for the creation of polygons without having to walk the entire resource area boundary. As many polygon boundaries were physically inaccessible, leveraging this imagery provided a practical way to combine recorded waypoints and identified place names into polygons. Though this stage of data integration likely introduced some uncertainty into our final polygons, it proved to be an effective way to produce polygons for inaccessible resource areas. Through the combination of household place names, in-person visits, and remotely-sensed imagery, we were able to compensate for the deficiencies in each data type alone, namely the linking of local names to satellite imagery, the inability to identify resource areas from satellite imagery, and the difficulty of visiting all boundaries on the ground.

Identification of resource area boundaries: The integration of resource location and distance information in the survey provided triangulating evidence that increased our confidence in the spatial extent of areas on the landscape used for resource extraction. While we acknowledge that exact boundary lines for these resource areas may appear somewhat arbitrary, it is also likely that boundaries are fuzzy, and that formal and fixed lines do not exist. That is, from a householder perspective, the boundaries are related to ecological features and resource presence or absence and not geographic coordinates, and the former may shift from time to time. This method allows for the estimation of resource area boundaries, despite their shifting nature, which are necessary for spatial analyses of natural resource use across scales. Additionally, boundaries are critical for establishing management policy (eg. limiting resource extraction, establishing buffers around protected areas, prioritizing fire management regimes). Combining resource information in household surveys with on-the-ground field visits to resource areas provides a much more robust spatial representation of land-use within a CBC area. In addition, even with a degree of uncertainty, the identification of resource use areas provides a vital link for remotely-sensing analyses, at a variety of potential spatial scales, to household level metrics from the surveys.

Generalizability: This methodological framework is easily applicable to different habitats, resource types, and communities. We successfully implemented it in three countries and believe that it would be an effective methodology to extend to rural mapping projects globally, allowing for quantitative landscape use mapping in regions where it is less commonly done. This robust methodology allows for replication across regions and produces data that allows local-scale features to be linked with broader-scale spatial datasets (e.g. satellite derived imagery, climate metrics). Indeed, the genesis of this methodology was to link satellite data (e.g. CHIRPS, TARCAT, LANDSAT) to households and to identify leverage points where climate and environmental vulnerability could be addressed at local scales.

A supplement to traditional participatory mapping: While participatory mapping is typically conducted to understand resources and landscape values from different perspectives in the community, our approach sought to promote a more holistic and unbiased overview of the distribution of resources across the landscape, as well as the ability of households to access those resources. By combining our data with the outputs from the initial participatory mapping exercises, we were able to develop a sense of the landscape that is both broad and in-depth. By supplementing traditional mapping approaches, we were able to delineate a much larger, more clearly defined portion of the landscape than by using traditional participatory mapping methods alone.

5. Conclusions

In our ongoing efforts to link people and pixels, we integrated methodologies in a novel way to map local resource use in a threatened conservation landscape. With the help of community members and by eliciting readily available knowledge, we created a method that pushes beyond traditional participatory methods to explicitly highlight the extended footprint of people's use of resources in a landscape. Our method supplements standard participatory mapping by creating accurate results that can be readily integrated with remotely-sensed data and draws upon knowledge representative of the community. Livelihood-resource mapping provides a systematic method for linking on-the ground expertise with global-scale data and has potential applications for communities across the world.

CRediT authorship contribution statement

Karen M. Bailey: Writing - original draft, Writing - review & editing, Data curation, Visualization, Formal analysis. **Michael D. Drake:** Methodology, Investigation, Writing - original draft, Writing - review & editing, Data curation, Visualization, Formal analysis. **Jon Salerno:** Conceptualization, Funding acquisition, Methodology, Investigation, Writing - original draft, Writing - review & editing, Data curation, Visualization, Formal analysis. **Lin Cassidy:** Conceptualization, Funding acquisition, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Andrea E. Gaughan:** Conceptualization, Funding acquisition, Methodology, Investigation, Writing - original draft, Writing - review & editing, Data curation, Visualization, Formal analysis. **Forrest R. Stevens:** Conceptualization, Funding acquisition, Methodology, Investigation, Writing - original draft, Writing - review & editing, Data curation, Visualization, Formal analysis. **Narcisa G. Pricope:** Conceptualization, Funding acquisition, Methodology, Investigation, Writing - original draft, Writing - review & editing, Data curation, Visualization, Formal analysis. **Kyle D. Woodward:** Methodology, Investigation, Writing - original draft, Writing - review & editing, Data curation, Visualization, Formal analysis. **Henry Maseka Luwaya:** Methodology, Investigation, Writing - review & editing. **Joel Hartter:** Conceptualization, Funding acquisition, Methodology, Investigation, Writing - original draft, Writing - review & editing.

Acknowledgements

Support for this research was provided by the United States National Science Foundation (NSF) (#1560700). Research permissions were provided by the governments of Zambia, Botswana, and Namibia, as well as the traditional authorities. We appreciate the collaboration and support of KAZA-TFCA Secretariat, the University of Namibia, the Integrated Rural Development and Nature Conservation, the Department of National Parks and Wildlife in Zambia, and Dr. Patricia Mupeta-Muyamwa. We would like to acknowledge our many research assistants and collaborators in Zambia, Namibia, and Botswana, in particular: Eric Mabuta, Moses Maele, Lubasi Imbula, Alfred Manyuka, Chukwu Iwanga, and Lawrence Sitaboho. We would also like to thank Ariel Weaver (U of Louisville) and Steele Olsen (UNCW) for their assistance in the field. We extend special thanks to our long-term collaborator, Dr. Lukas Rutina, at the University of Namibia Katima Mulilo campus, who graciously supported our efforts to secure a research permit in Botswana.

References

van Aarde, R. J., & Jackson, T. P. (2007). Megaparks for metapopulations: Addressing the causes of locally high elephant numbers in southern Africa. *Biological Conservation, 134*(3), 289–297. https://doi.org/10.1016/j.biocon.2006.08.027.

Agutu, N. O., Awange, J. L., Zerihun, A., Ndehedehe, C. E., Kuhn, M., & Fukuda, Y. (2017). Assessing multi-satellite remote sensing, reanalysis, and land surface models' products in characterizing agricultural drought in East Africa. *Remote Sensing of Environment, 194*, 287–302. https://doi.org/10.1016/j.rse.2017.03.041.

Andersson, J., de Garine-Wichatitsky, M., Cumming, D., Dzingirai, V., & Giller, K. (2017). *Transfrontier conservation areas: People living on the edge*. Taylor & Francis.

Basupi, L. V., Quinn, C. H., & Dougill, A. J. (2017). Using participatory mapping and a participatory geographic information system in pastoral land use investigation: Impacts of rangeland policy in Botswana. *Land Use Policy, 64*, 363–373. https://doi.org/10.1016/j.landusepol.2017.03.007.

Bernard, H. R. (2006). *Research methods in anthropology: Qualitative and quantitative approaches* (4th ed.). AltaMira Press.

Bijker, R. A., & Sijtsma, F. J. (2017). A portfolio of natural places: Using a participatory GIS tool to compare the appreciation and use of green spaces inside and outside urban areas by urban residents. *Landscape and Urban Planning, 158*, 155–165. https://doi.org/10.1016/j.landurbplan.2016.10.004.

Blake, D., Augé, A. A., & Sherren, K. (2017). Participatory mapping to elicit cultural coastal values for Marine Spatial Planning in a remote archipelago. *Ocean & Coastal Management, 148*, 195–203. https://doi.org/10.1016/j.ocecoaman.2017.08.010.

Boitani, L., & Fuller, T. (2000). *Research techniques in animal ecology: Controversies and consequences*. Columbia University Press.

Brown, G. (2017). A review of sampling effects and response bias in internet participatory mapping (PPGIS/PGIS/VGI). *Transactions in GIS, 21*(1), 39–56. https://doi.org/10.1111/tgis.12207.

Brown, G., Donovan, S., Pullar, D., Pocewicz, A., Toohey, R., & Ballesteros-Lopez, R. (2014). An empirical evaluation of workshop versus survey PPGIS methods. *Applied Geography, 48*, 42–51. https://doi.org/10.1016/j.apgeog.2014.01.008.

Brown, G. G., & Pullar, D. V. (2012). An evaluation of the use of points versus polygons in public participation geographic information systems using quasi-experimental design and Monte Carlo simulation. *International Journal of Geographical Information Science, 26*(2), 231–246. https://doi.org/10.1080/13658816.2011.585139.

Brown, G., & Raymond, C. M. (2014). Methods for identifying land use conflict potential using participatory mapping. *Landscape and Urban Planning, 122*, 196–208. https://doi.org/10.1016/j.landurbplan.2013.11.007.

Bwalya, S. M. (2011). Household dependence on forest income in rural Zambia. http://www.saipar.org:8080/eprc/handle/123456789/89.

Cadag, J. R. D., & Gaillard, J. C. (2012). Integrating knowledge and actions in disaster risk reduction: The contribution of participatory mapping. *Area, 44*(1), 100–109. https://doi.org/10.1111/j.1475-4762.2011.01065.x.

Central Statistics Office, & United Nations. (2011). 2011 population and housing census. https://unstats.un.org/unsd/demographic/sources/census/wphc/Botswana/census%20project.pdf.

Challinor, A., Wheeler, T., Garforth, C., Craufurd, P., & Kassam, A. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic Change, 83*(3), 381–399. https://doi.org/10.1007/s10584-007-9249-0.

Chambers, R. (1994). Participatory rural appraisal (PRA): Challenges, potentials and paradigm. *World Development, 22*(10), 1437–1454. https://doi.org/10.1016/0305-750X(94)90030-2.

Chambers, R. (2006). Participatory mapping and geographic information systems: Whose map? Who is empowered and who disempowered? Who gains and who loses? *The Electronic Journal on Information Systems in Developing Countries, 25*(1), 1–11. https://doi.org/10.1002/j.1681-4835.2006.tb00163.x.

Chingombe, W., Pedzisai, E., Manatsa, D., Mukwada, G., & Taru, P. (2015). A participatory approach in GIS data collection for flood risk management, Muzarabani district, Zimbabwe. *Arabian Journal of Geosciences, 2*(8), 1029–1040. https://doi.org/10.1007/s12517-014-1265-6.

Coetzer-Hanack, K. L., Witkowski, E. T. F., & Erasmus, B. F. N. (2016). Thresholds of change in a multi-use conservation landscape of South Africa: Historical land-cover, future transformation and consequences for environmental decision-making. *Environmental Conservation, 43*(3), 253–262. https://doi.org/10.1017/S0376892916000084.

Connolly-Boutin, L., & Smit, B. (2016). Climate change, food security, and livelihoods in sub-Saharan Africa. *Regional Environmental Change, 16*(2), 385–399. https://doi.org/10.1007/s10113-015-0761-x.

Conway, D., van Garderen, E. A., Deryng, D., Dorling, S., Krueger, T., Landman, W., et al. (2015). Climate and southern Africa's water–energy–food nexus. *Nature Climate Change, 5*(9), 837–846. https://doi.org/10.1038/nclimate2735.

Cornwall, A., & Jewkes, R. (1995). What is participatory research? *Social Science & Medicine, 41*(12), 1667–1676. https://doi.org/10.1016/0277-9536(95)00127-S.

Cumming, D. H. M., Andersson, J. A., de Garine-Wichatitsky, M., Dzingirai, V., & Giller, K. E. (2013). Whither TFCAs and people on the edge in southern Africa?. In *Transfrontier conservation areas people living on the edge* (1st ed., p. 240). Routledge https://www.taylorfrancis.com/books/e/9781315147376/chapters/10.4324/9781315147376-10.

Department of National Parks and Wildlife, & Ministry of Tourism and Arts. (2016). *General management plan for Lower West Zambezi game management area*.

Dubovyk, O. (2017). The role of remote sensing in land degradation assessments: Opportunities and challenges. *European Journal of Remote Sensing, 50*(1), 601–613. https://doi.org/10.1080/22797254.2017.1378926.

Engen, S., Runge, C., Brown, G., Fauchald, P., Nilsen, L., & Hausner, V. (2018). Assessing local acceptance of protected area management using public participation GIS (PPGIS). *Journal for Nature Conservation, 43*, 27–34. https://doi.org/10.1016/J.JNC.2017.12.002.

Ernst, A., Biß, K. H., Shamon, H., Schumann, D., & Heinrichs, H. U. (2018). Benefits and challenges of participatory methods in qualitative energy scenario development. *Technological Forecasting and Social Change, 127*(October 2017), 245–257. https://doi.org/10.1016/j.techfore.2017.09.026.

Esri, R. (2011). *ArcGIS desktop: Release 10*. CA: Environmental Systems Research Institute.

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change, 16*(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002.

Fullman, T. J., & Bunting, E. L. (2014). Analyzing vegetation change in an elephant-impacted landscape using the moving standard deviation index. *Land, 3*(1), 74–104. https://doi.org/10.3390/land3010074.

Gaughan, A. E., Stevens, F. R., Pricope, N. G., Hartter, J., Cassidy, L., & Salerno, J. (2019). Operationalizing vulnerability: Land system dynamics in a transfrontier conservation area. *Land, 8*(7), 111. https://doi.org/10.3390/land8070111.

Gaughan, A. E., & Waylen, P. R. (2012). Spatial and temporal precipitation variability in the Okavango–Kwando–Zambezi catchment, southern Africa. *Journal of Arid Environments, 82*, 19–30. https://doi.org/10.1016/j.jaridenv.2012.02.007.

Gaur, M. K., & Squires, V. R. (2018). *Climate variability impacts on land use and livelihoods in drylands*. New York: Springer.

Gylfason, T., & Zoega, G. (2006). Natural resources and economic growth: The role of investment. *The World Economy, 29*(8), 1091–1115. https://doi.org/10.1111/j.1467-9701.2006.00807.x.

Hachfeld, B., & Schippmann, U. (2002). Occurrence and density of Harpagophytum procumbens in Namibia and South Africa. *Proceedings of the Regional Devil's Claw Conference*, 26–28.

Hitchcock, R. K., Sapignoli, M., & Babchuk, W. A. (2011). What about our rights? Settlements, subsistence and livelihood security among central kalahari san and bakgalagadi. *The International Journal of Human Rights, 15*(1), 62–88. https://doi.org/10.1080/13642987.2011.529689.

Ibbett, H., & Brittain, S. (2019). *Conservation publications and their provisions to protect research participants*. John Wiley & Sons, Ltd. https://doi.org/10.1111/cobi.13337.

Jones, P. G., & Thornton, P. K. (2009). Croppers to livestock keepers: Livelihood transitions to 2050 in Africa due to climate change. *Environmental Science & Policy, 12*(4), 427–437. https://doi.org/10.1016/j.envsci.2008.08.006.

Kalibo, H. W., & Medley, K. E. (2007). Participatory resource mapping for adaptive collaborative management at Mt. Kasigau, Kenya. *Landscape and Urban Planning, 82* (3), 145–158. https://doi.org/10.1016/J.LANDURBPLAN.2007.02.005.

Kanapaux, W., & Child, B. (2011). Livelihood activities in a Namibian wildlife conservancy: A case study of variation within a cbnrm programme. *Oryx, 45*(3), 365–372. https://doi.org/10.1017/S0030605310000815.

Klain, S. C., & Chan, K. M. A. (2012). Navigating coastal values: Participatory mapping of ecosystem services for spatial planning. *Ecological Economics, 82*, 104–113. https://doi.org/10.1016/j.ecolecon.2012.07.008.

Levine, A. S., & Feinholz, C. L. (2015). Participatory GIS to inform coral reef ecosystem management: Mapping human coastal and ocean uses in Hawaii. *Applied Geography, 59*, 60–69. https://doi.org/10.1016/j.apgeog.2014.12.004.

Lindsay, K., Chase, M., Landen, K., & Nowak, K. (2017). The shared nature of Africa's elephants. *Biological Conservation, 215*, 260–267. https://doi.org/10.1016/j.biocon.2017.08.021.

Liverman, Diana M., Moran, Emilio F., Rindfuss, Ronald R., & Stern, Paul C. (1998). *People and pixels: Linking remote sensing and social science*. Washington: National Academy Press.

Mapedza, E., Wright, J., & Fawcett, R. (2003). An investigation of land cover change in Mafungautsi Forest, Zimbabwe, using GIS and participatory mapping. *Applied Geography, 23*(1), 1–21. https://doi.org/10.1016/S0143-6228(02)00070-X.

Metcalfe, S., & Kepe, T. (2008). "Your elephant on our land": The struggle to manage wildlife mobility on Zambian communal land in the kavango-zambezi transfrontier conservation area. *The Journal of Environment & Development, 17*(2), 99–117. https://doi.org/10.1177/1070496508315733.

Munthali, S. M., Smart, N., Siamudaala, V., Mtsambiwa, M., & Harvie, E. (2018). Integration of ecological and socioeconomic factors in securing wildlife dispersal corridors in the kavango-zambezi transfrontier conservation area, southern Africa. Selected studies in biodiversity. https://doi.org/10.5772/intechopen.70443.

Nackoney, J., Rybock, D., Dupain, J., & Facheux, C. (2013). Coupling participatory mapping and GIS to inform village-level agricultural zoning in the Democratic Republic of the Congo. *Landscape and Urban Planning, 110*(1), 164–174. https://doi.org/10.1016/j.landurbplan.2012.11.004.

Nagendra, H., Munroe, D. K., & Southworth, J. (2004). From pattern to process: Landscape fragmentation and the analysis of land use/land cover change. *Agriculture, Ecosystems & Environment, 101*(2), 111–115. https://doi.org/10.1016/j.agee.2003.09.003.

New, M., Hewitson, B., Stephenson, D. B., Tsiga, A., Kruger, A., Manhique, A., et al. (2006). Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research: Atmosphere, 111*(D14). https://doi.org/10.1029/2005JD006289.

Nkemelang, T., New, M., & Zaroug, M. (2018). Temperature and precipitation extremes under current, 1.5\hspace0.167em°C and 2.0\hspace0.167em°C global warming above pre-industrial levels over Botswana, and implications for climate change vulnerability. *Environmental Research Letters, 13*(6), Article 065016. https://doi.org/10.1088/1748-9326/aac2f8.

Palomo, I., Martín-López, B., Potschin, M., Haines-Young, R., & Montes, C. (2013). National Parks, buffer zones and surrounding lands: Mapping ecosystem service flows. *Ecosystem Services, 4*, 104–116. https://doi.org/10.1016/j.ecoser.2012.09.001.

Rambaldi, G., Kyem, P. A. K., Mccall, M., & Weiner, D. (2006). Participatory spatial information management and communicationcommunication IN developing countries. http://www.ejisdc.org, 1, 1-9.

Ramirez-Gomez, S. O. I., Brown, G., & Fat, A. T. S. (2013). Participatory mapping with indigenous communities for conservation: Challenges and lessons from Suriname. *The Electronic Journal on Information Systems in Developing Countries, 58*(1). https://doi.org/10.1002/j.1681-4835.2013.tb00409.x.

Ramirez-Gomez, S. O. I., Brown, G., Verweij, P. A., & Boot, R. (2016). Participatory mapping to identify indigenous community use zones: Implications for conservation planning in southern Suriname. *Journal for Nature Conservation, 29*, 69–78. https://doi.org/10.1016/j.jnc.2015.11.004.

Reid, R. S., Kruska, R. L., Muthui, N., Taye, A., Wotton, S., Wilson, C. J., et al. (2000). Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: The case of southwestern Ethiopia. *Landscape Ecology, 15*(4), 339–355. https://doi.org/10.1023/A:1008177712995.

Roth, R. (2009). The challenges of mapping complex indigenous spatiality : From abstract space to dwelling space. *Cultural Geographies, 16*, 207–227. https://doi.org/10.1177/1474474008101517.

Sachs, J. D., & Warner, A. M. (2001). The curse of natural resources. *European Economic Review, 45*(4–6), 827–838. https://doi.org/10.1016/S0014-2921(01)00125-8.

Salerno, J., Chapman, C. A., Diem, J. E., Dowhaniuk, N., Goldman, A., MacKenzie, C. A., et al. (2018). Park isolation in anthropogenic landscapes: Land change and livelihoods at park boundaries in the african albertine rift. *Regional Environmental Change, 18*(3), 913–928. https://doi.org/10.1007/s10113-017-1250-1.

Sandström, P., Pahlén, T. G., Edenius, L., Tømmervik, H., Hagner, O., Hemberg, L., et al. (2003). Conflict resolution by participatory management: Remote sensing and GIS as tools for communicating land-use needs for reindeer herding in northern Sweden. *Ambio, 32*(8), 557–567.

Schultz, M., Shapiro, A., Clevers, J. G. P. W., Beech, C., & Herold, M. (2018). Forest cover and vegetation degradation detection in the Kavango Zambezi Transfrontier Conservation area using BFAST monitor. *Remote Sensing, 10*(11), 1850. https://doi.org/10.3390/rs10111850.

Selgrath, J. C., Roelfsema, C., Gergel, S. E., & Vincent, A. C. J. (2016). Mapping for coral reef conservation: Comparing the value of participatory and remote sensing approaches. *Ecosphere, 7*(5). https://doi.org/10.1002/ecs2.1325. e01325–e01325.

Siswa Sulistyawan, B., Verweij, P. A., Boot, R. G., Purwanti, B., Rumbiak, W., Wattimena, M. C., et al. (2018). Integrating participatory GIS into spatial planning regulation the case of Merauke. *Source: International Journal of the Commons, 12*(1), 26–59. https://doi.org/10.18352/ijc.759.

Skidmore, A. K., Bijker, W., Schmidt, K., & Kumar, L. (1998). *Use of remote sensing and GIS for sustainable land management*.

Slocum, R., Wichart, L., Rocheleau, D., & Thomas-Slayter, B. (Eds.). (1995). *Power, process and participation: Tools for change*. Practical Action.

Stewart, K. M., & Cole, D. (2005). The commercial harvest of devil's claw (Harpagophytum spp.) in southern Africa: The devil's in the details. *Journal of Ethnopharmacology, 100*(3), 225–236. https://doi.org/10.1016/j.jep.2005.07.004.

Stone, M. T. (2015). Community empowerment through community-based tourism: The case of Chobe Enclave conservation trust in Botswana. In R. van der Duim, M. Lamers, & J. van Wijk (Eds.), *Institutional arrangements for conservation, development and tourism in eastern and southern Africa: A dynamic perspective* (pp. 81–100). Springer Netherlands. https://doi.org/10.1007/978-94-017-9529-6_5.

Thondhlana, G., Shackleton, S., & Muchapondwa, E. (2011). Kgalagadi transfrontier park and its land claimants: A pre- and post-land claim conservation and development history. *Environmental Research Letters, 6*(2), Article 024009. https://doi.org/10.1088/1748-9326/6/2/024009.

Townshend, J., Justice, C., Li, W., Gurney, C., & McManus, J. (1991). Global land cover classification by remote sensing: Present capabilities and future possibilities. *Remote Sensing of Environment, 35*(2–3), 243–255. https://doi.org/10.1016/0034-4257(91)90016-Y.

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., & Steininger, M. (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution, 18*(6), 306–314. https://doi.org/10.1016/S0169-5347(03)00070-3.

Vågen, T.-G., Winowiecki, L. A., Tondoh, J. E., Desta, L. T., & Gumbricht, T. (2016). Mapping of soil properties and land degradation risk in Africa using MODIS reflectance. *Geoderma, 263*, 216–225. https://doi.org/10.1016/j.geoderma.2015.06.023.

Wardrop, D. H., Glasmeier, A. K., Peterson-Smith, J., Eckles, D., Ingram, H., & Brooks, R. P. (2011). Wetland ecosystem services and coupled socioeconomic benefits through conservation practices in the Appalachian Region. *Ecological Applications, 21*(sp1), S93–S115. https://doi.org/10.1890/09-2292.1.

Weyer, D., Bezerra, J. C., & De Vos, A. (2019). Participatory mapping in a developing country context: Lessons from South Africa. *Land, 8*(9), 134. https://doi.org/10.3390/land8090134.

Wilbanks, T. J., & Kates, R. W. (1999). Global change in local places: How scale matters. *Climatic Change, 43*(3), 601–628. https://doi.org/10.1023/A:1005418924748.

Worton, B. J. (1987). A review of models of home range for animal movement. *Ecological Modelling, 38*(3), 277–298. https://doi.org/10.1016/0304-3800(87)90101-3.

Zaehringer, J. G., Llopis, J. C., Latthachack, P., Tun Thein, T., & Heinimann, A. (2018). A novel participatory and remote-sensing-based approach to mapping annual land use change on forest frontiers in Laos, Myanmar, and Madagascar View supplementary material. *Journal of Land Use Science, 13*, 1–2. https://doi.org/10.1080/1747423X.2018.1447033.