Research Paper

Spatial distribution and perceived drivers of provisioning service values across an East African montane forest landscape

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HIGHLIGHTS

- Informants readily associate 'benefits from the land' with provisioning services.
- Values of provisioning services in the West Mau Forest are spatially explicit.
- Legal, economic, social, and biophysical factors shape provisioning service values.
- Perceived drivers of value influence provisioning services and locations differently.
- Mixed methods can enable socially and locally informed landscape service planning.

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ABSTRACT

Increasingly, resource managers and planners seek to manage forested landscapes for the value of the services they provide. This is especially true in the Mau Forest of Kenya, a montane area that harbors some of Kenya's most important headwaters but has lost a quarter of its forest cover since 1999. While managing for the Mau Forest's landscape services is a priority, it is critical to understand why and how people value these services differently. Otherwise, land management policies risk exacerbating rather than alleviating conservation and environmental justice problems. This is particularly true of provisioning services, a category of landscape services on which communities directly depend. This research combines participatory mapping and semi-structured interviews to understand how socio-cultural values of provisioning services are distributed across two sites within the Western Mau Forest and analyze linkages between mapped values, their locations, and influencing factors. In total, 55 informants were interviewed. Frequently listed provisioning services were water, firewood, cultivation, grazing, timber, and medicine. Results indicate that four main factors influence the location from where these services were derived: historical and legal arrangements, social relations, economic conditions, and biophysical conditions. How these factors influence where people value provisioning services differ based on the service and community in question. This study demonstrates that communities can use and value provisioning services differently and that the distributions of these services are influenced by the factors mentioned above. Understanding this heterogeneity can enable managers and policy makers to create local land use plans that account for spatially-explicit values.

1. Introduction

Increasingly, resource managers and policy makers seek to manage landscapes for the services they provide (Egoh et al., 2012; Kenya Forest Service, 2018; National Ecosystem Services Partnership, 2014; Schaefer et al., 2015). These "landscape services" are derived from the structure, ecological processes, and functions of ecosystems (Termorshuizen & Opdam, 2009). But not all resource-dependent people value these landscape services in the same way, even in the same community (Fagerholm et al., 2012). To adequately address human needs for these

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services, and plan accordingly, decision makers need to understand why landscape services are valued differently in different places. Such an understanding of place-based social values is important for managing provisioning services, a category of landscape services, particularly in rural natural resource-dependent communities (Abram et al., 2014; Egoh et al., 2012; Ramirez-Gomez et al., 2015). Previous analyses have described and mapped socio-cultural values of provisioning services (Brown et al., 2020; Brown & Fagerholm, 2015; Paudyal et al., 2015; van Riper et al., 2012), studied the drivers of landscape service value (Iniesta-Arandia et al., 2014; van Riper & Kyle, 2014), and assessed the linkages between distributions of landscape value and underlying social and environmental conditions or characteristics using spatial statistics (Brown et al., 2015; Meacham et al., 2016). However, few studies have assessed the socially perceived linkages between underlying conditions and spatial distributions of provisioning service values (Ericksen et al., 2011; Plieninger et al., 2013; Scholte et al., 2015). In other words, the question remains: why do people perceive some places as being more valuable for provisioning services than others? This study aims to fill that gap using a case study from a montane forest ecosystem in Kenya and provide empirical evidence for resource managers regarding the key underlying conditions that influence local value of provisioning services among subsistence peoples in Kenya. Furthermore, this study demonstrates the value of a mixed methodology approach in understanding local values of provisioning services in a landscape. By combining both quantitative and qualitative data and rendering such data in a spatially explicit manner, the approach enables researchers to acquire nuanced and context-dependent data.

This study employs the concept of landscape services, as developed by Termorshuizen and Opdam (2009) to understand land and forest-derived benefits. Past landscape services studies have grouped services into categories such as provisioning, cultural, and recreation (Fagerholm et al., 2012; Ramirez-Gomez et al., 2013). This study specifically assesses provisioning services, within the framework of landscape services (Fagerholm et al., 2012; Termorshuizen & Opdam, 2009).

Studies have shown that individuals can value a landscape for multiple services, that a landscape can be valued for different services by different people, and that methods for quantifying or qualifying value differ across scientific disciplines (Brown et al., 2015; Clements & Cumming, 2017; Díaz et al., 2018; S. Jacobs et al., 2016; Ramirez-Gomez et al., 2015). Individuals hold or assign socio-cultural values which describe the principles and preferences expressed by people towards landscape services (Pascual et al., 2017; Walz et al., 2019). Studies that explore how and why people hold socio-cultural values of landscape services have increased in number and importance in the last decade (Cheng et al., 2019; Milcu et al., 2013; Scholte et al., 2015). This trend can be seen in language from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which has emphasized value pluralism and social valuation (Pascual et al., 2017). The IPBES and other researchers have also highlighted the need for local knowledge of ecosystem services and a review of ecosystem service studies in Africa has emphasized the need for local information to support landscape-level decision-making. (Díaz et al., 2018; McElwee et al., 2020; Turnhout et al., 2012; Wangai et al., 2016).

Understanding how and why people perceive and value services differently across a landscape, in addition to biophysical assessments of the environment, is critical for crafting landscape service-based management plans. Past research has found that conservation and land use initiatives that do not adequately address local understandings of and constraints to natural resource access can lack legitimacy in the eyes of resource users and increase conflict over said resources (Brechin et al., 2002; Chepngeno, 2014; Scoones et al., 1997). Local perceptions can affect whether communities will support or undermine conservation initiatives and understanding such perceptions can help tailor activities and management planning to increase the legitimacy and effectiveness of activities (Bennett, 2016). One component of local perspective that is often overlooked in research and practice is how and why people value landscape services where they do (Chan et al., 2012; de Groot

et al., 2010). Understanding how people assign value to these sites and the factors that influence that value would enable the creation of more adaptive and locally-appropriate spatial forest and land use plans (Cowling et al., 2008; Plieninger et al., 2013).

This study aims to further the science on the assigned socio-cultural values, perceived linkages between value and underlying conditions, and geography of provisioning services in an East African montane landscape by mapping and analyzing community values of said services. This focus on provisioning services reflects local management and research priorities. A review by Egoh and colleagues (2012) discusses the particular dependence rural people in many countries in Africa have on provisioning services. Past forest management planning processes in the area have assessed and developed actions for managing provisioning services such as water, firewood, and fodder for livestock among others (Kenya Forest Service, 2015a, 2018).

This research offers empirical evidence of the relationship between socio-cultural values of provisioning services and underlying conditions from two locations within the Western Mau Forest, which is part of the Mau Forest Complex (MFC), of Kenya. We selected the Mau Forest Complex (MFC) because the area is currently a hotbed of issues that intersect with topics high on the international forest and land agenda: deforestation, the tension between indigenous rights and vested interests, payment for ecosystem services, and community-based forest management. The MFC lost a quarter of its entire forest cover between 1973 and 2013 (Swart, 2016). Furthermore, 42.4% of the Western Mau Forest had been disturbed between 2010 and 2016 (Brandt et al., 2018)

While the MFC historically has been the home to the Ogiek people, the last century has seen a marked increase in forest clearing and new settlements by other social groups (Owino, 2009). Deforestation patterns and processes have changed over time but a common driver of deforestation has been patronage politics (Klopp & Sang, 2011). Politicians have used forest resources as means of securing support and funding campaigns (Ibid.). These types of campaigns can incite a scramble for resources as availability decreases, causing more deforestation (Klopp, 2012). Other explanations for the degradation of the forest include migration from urban areas to forests because of increasing population and decreasing land availability, higher poverty levels that lead to the need for firewood and charcoal for home energy, the increasing value of tree products, and the inadequacy of strong tenure and conservation policies (Government of Kenya, 2005; Kweyu, 2015; Owino, 2009).

Deforestation and degradation in the MFC is a pressing issue for many reasons but one significant concern is its impact on Kenya's watersheds (Chrisphine et al., 2016; S. R. Jacobs et al., 2017). The MFC is often referred to as Kenya's most important 'water tower'—a term used to describe montane forests from which water is captured and then flows to downstream communities (Chrisphine et al., 2016). The forest harbors the main water sources for 12 rivers that feed into Lake Victoria, Natron, and Turkana while providing water for up to six million people in surrounding communities and urban centers (Olang & Kundu, 2011).

Attempts to curb deforestation in the MFC have been instituted over the last decade by government, the private sector, international development agencies, and local communities. In 2005, the national government passed the Kenya Forests Act, which decentralized forest management authority to Community Forest Associations (CFA). But in order to transfer management rights, CFAs need to create Participatory Forest Management (PFM) plans in coordination with the Kenya Forest Service (KFS) (Oddi, 2007). In 2018, the Government of Kenya released a report urging the joint implementation of PFMs by KFS and CFAs across the country (Ministry of Environment and Forestry, 2018). Creating and implementing PFMs involves eight steps as set forth by KFS (Kenya Forest Service, 2015b). Step three of this process is 'Assessing the Forest Area and Communities' and calls for participatory resource assessments that document all locally-important products and services and assess the value local people attach to these products and services (Kenya Forest Service, 2015b).

This study employs an exploratory design, in which qualitative data is used to explain and elaborate on quantitative results (Creswell, 2014).
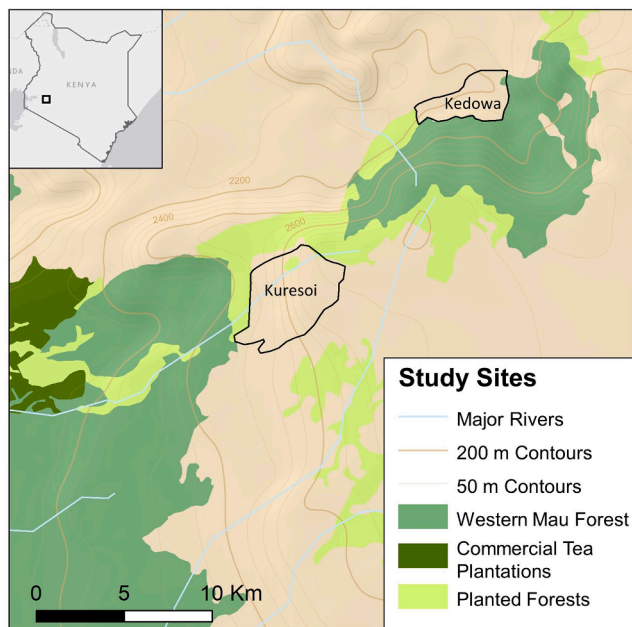
Fig. 1. Map of study site. The extent of the surveyed area within each Location is demarcated by black lines and represents the outer boundaries of the surveyed villages. The Western Mau Forest symbology depicts forests with closed canopy (greater than 70% tree canopy cover) and planted forests depict timber plantations of eucalyptus (*Eucalyptus* spp.), pines (*Pinus* spp.), and cypress (*Cupressus* spp.). *GIS Data Source:* World Resources Institute et al., 2007.

Through participatory mapping and ranking exercises of social values (produces quantitative data, rendered spatially explicit) and semi-structured interviews (produces qualitative data), local perceptions of provisioning services were mapped, valued, and analyzed for linkages to underlying conditions. The resultant maps developed in this research visualize social values of the participants interviewed and are used to inform and aid in the interpretation of qualitative data. They clearly communicate the distributions of social values of those interviewed, enabling a greater depth of qualitative analysis. They do not serve to communicate generalizable results for a larger population beyond those sampled.

The research adds to the literature in two ways: 1) It investigates the linkages between social values of provisioning services, and their locations, and underlying conditions through semi-structured interviews. This method enables a deeper understanding of how social and cultural context influences where and why people value services than purely quantitative approaches provide (Scholte et al., 2015). 2) This study is the first of its kind in an East African montane forest and adds on the minimal literature on social values and geography of landscape services in Africa (Wangai et al., 2016).

Furthermore, there is a gap between the scale, objectives, and results of many participatory mapping-oriented ecosystem service studies and the information needed for their application to management (Brown & Fagerholm, 2015; Wangai et al., 2016). The results and subsequent discussion in this paper can inform and be used in ongoing participatory forest management processes in Kenya to address underlying conditions that influence how and where people value provisioning services in the Mau Forest and beyond.

2. Methods

2.1. Study area

The study was conducted in two Locations within the Mau Forest Complex (Fig. 1). A Location is an administrative unit in Kenya, smaller than Division, Sub-county, and County. The Mau Forest covers roughly approximately 24,000 km² in the Rift Valley of Kenya and is the largest closed canopy forest in East Africa (Swart, 2016).

The Mau Forest Complex is a montane landscape dominated by escarpments, hills, and rolling land. Located between 1,800 and 2,932 m above sea level, the Mau Forest experiences above average annual rainfall (1988 ± 328 mm) and below average annual temperatures for Kenya (17-20° C) (S. R. Jacobs et al., 2017; Olang & Kundu, 2011). There is a bimodal distribution of rain in the area, with heavy rains April to July and a shorter rain season October to December (Jacobs et al., 2017). Presently, the MFC, is dominated by smallholder agriculture (50.7%), rangeland (23.7%), and natural forest (17.7%) (Swart, 2016). This paper refers to 'forests' as areas of tree height greater than two meters and crown coverage over 30% and refers to timber plantations and 'planted forests' as areas of planted eucalyptus (*Eucalyptus* spp.), pines (*Pinus* spp.), and cypress (*Cupressus* spp.) which are often managed and harvested for timber.

A common land use in the area is the Plantation Establishment Livelihood Improvement Scheme (PELIS), which was formerly named the 'shamba system' (Agevi et al., 2016; Oduol, 1986). In these schemes, communities grow crops on allocated plots within the Kenya Forest Service's timber plantations when the timber trees are young. Once the tree canopy closes, community members have to vacate the plots (Agevi et al., 2016). Villagers in our study area still refer to this system as 'shamba' so we use the same terminology in this paper.

The two study areas were within Kedowa and Kuresoi administrative Locations. Within Kedowa, we interviewed informants within Ewat, Chebewor, Burgei, Kondamet, Emitiot, Simotwet, and Tach Asis villages. Within Kuresoi we interviewed informants within Kio, Githima, Kipkewa, Mwarangania, Chorwa, and Ogilgei villages. These villages were chosen, as there were other villages we did not work with in Kedowa and Kuresoi, because they are adjacent to the Western Mau Forest and community members in all villages rely on the forest (personal communication). The extents of the sampling areas, which encompass the villages we sampled within each Location, were 1006 ha in Kedowa and 2,283 ha in Kuresoi. Additionally, even though the town centers of each Location are only 12 km away from each other, they vary in altitude and precipitation. Kedowa is located at 2100 m and receives an average annual rainfall of 1,221 mm (World Resources Institute et al., 2007) while Kuresoi is located at a higher elevation on the escarpment, at 2,600 m, and receives an average annual rainfall of 1,738 mm (S. R. Jacobs, Timbe, et al., 2018). The Western Mau Forest of the MFC is more degraded than other areas, which signifies more intensive use and reliance on forest resources (Brandt et al., 2018).

These two sites were both accessible during field work and were selected to avoid other Locations and villages that had been the subject of previous research and development initiatives. Kedowa has a Community Forest Association (CFA) but has not engaged in the PFM process yet. Kuresoi also has a CFA and, at the time of the study, was beginning to engage in the PFM process. At the start of the study, the research team met with Kenya Forest Service staff at the Kuresoi Forest Station, whose jurisdiction covers Kuresoi Location, and Londiani Forest Station, whose jurisdiction covers Kedowa Location. Both stations expressed interest in understanding how to integrate participatory mapping into the PFM process and saw a direct link between the methods of this study and future PFM work. This study could inform future PFM processes and potentially shape ongoing PFM work, but not directly input to current PFM plans. Care was taken in conversations with informants to set honest expectations about how the results would be used, and which results would not be used, by Kenya Forest Service and the research team.

2.2. Sampling

Combining both purposive and stratified random sampling techniques, we selected fifty-five individuals for interviewing, 27 in Kedowa and 28 in Kuresoi. Based on purposive sampling strategy, interviewees were selected to provide depth of qualitative content and the number of interviewees was determined to be an adequate number of interviewees to capture the variability in potential interview responses (Devers & Frankel, 2000). The results from these interviewees are not expected to be generalized to a wider population, though the methodology and

Table 1
Overview of number of semi-structured interview participants by community, disaggregated by gender and age.

Overview of semi-structured interview participants		Kedowa	Kuresoi
	Total	27	28
By Gender	Males	14	14
	Females	13	14
By Age	15 to 40 years old	13	14
	above 40 years old	14	14

findings from this case study can be transferred to and compared with other contexts. For this reason, we were not concerned about achieving a statistically representative sample.

We focused our interviews on individuals within households within 5 km of the forest edge to increase the likelihood that the respondents actively used the forest for resources and ecosystem services. This was an important criterion because we hope this research can inform work with other forest-dependent communities in the MFC. The villages that we sampled (see section 2.1) had roughly 848 households in Kedowa and 808 households in Kuresoi in total. These estimates are from communications with local leaders, but we only received household estimates for three of the six Kuresoi villages, so we multiplied the average of those three by six to get the total estimate for Kuresoi. The seven studied villages in Kedowa and the six studied villages in Kuresoi had on average 121 households and 269 households, respectively. These averages are slightly higher than the surrounding villages; unpublished data from a related project finds between 70 and 120 households per village in the surrounding area.

To ensure geographic diversity, the households were systematically sampled across the five kilometer forest edge buffer zone using an ArcGIS Online imagery basemap (Esri et al., 2009) and fishnet grid in ArcGIS (Esri, Redlands, CA) overlaid on each sampling area (Kedowa and Kuresoi). The Kedowa grid had 10 rows and 11 columns of cells with dimensions 450 m × 260 m and the Kuresoi grid had 10 rows and 8 columns of cells with dimensions 615 m × 500 m. These dimensions were chosen to cover the entirety of each sampling area, include multiple locations in each village, and generate a practically-feasible number of geographically-dispersed respondents—which based on available resources we estimated to be no more than 30 in either Location.

Interviewees were selected from households within the grid cells to ensure even gender and age balance, disaggregating age by those 15–40 years old and people 40 years old or older (see Table 1), with the intention of alternating between interviewing men and women and age classes in the field. This division of ages was based on local definitions of "youth" vs. "adults" (personal communication). The 2019 Kenya Population and Housing Census shows that of the 9,105 residents of Kedowa Location, 49.6% are male and 50.4% are female (KNBS, 2019). The same survey shows that of the 17,825 residents of Kuresoi Location, 49.8% are male and 50.2% are female (KNBS, 2019). As such, each sample's gender ratio is representative of the respective Locations. We could not find secondary data on ethnicity nor on age distribution in either Location, though would expect the populations to skew younger, per Kenya national statistics (CIA, 2020). We purposively sampled those above 15 years old as these individuals are more likely to be involved in future PFM processes and be more involved in household decision-making around provisioning services.

In the end, it cannot be argued that this sample of 55 individuals is fully representative of the broader region. However, we have confidence in this data for two reasons. First, through the combination of purposively ensuring geographic distribution of households and stratifying the sample by both age and gender, we ensured a more representative sample of interviewees. Second, by the end of the interview process we reached a level of data saturation in which themes and responses to interview questions were repeated and no new insights were generated, indicating we had adequately captured most of the variability in potential interview responses.

Once the locations of desired houses were selected on the basemap, we had to further refine the sampling in the field. Based on the desire to alternate the gender of respondents spatially, to avoid clusters of genders such as having only men interviewed along the forest edge, we sometimes had to use snowball sampling in the village. Snowball sampling was employed with the help of a village elder in places where the desired informant or gender (based on the earlier systematic grid) was unavailable. In these instances, we approached neighbors and relied on suggestions to identify alternative informants. Because we often relied on neighbors and the village elder to identify alternative informants, there is a chance that individuals might have been identified based on personal relationships. However, we do not expect those biases to significantly alter our results. Many households in this area are clustered by extended family, with relatives living in a compound or nearby. In these cases, we treated each house as a separate household but did not interview more than one person from an extended family or compound. Due to the practicalities of translation, we interviewed people who could speak Swahili—we only had to turn away 3 potential informants for language reasons. The predominant languages spoken in the area are Kipsigis and Swahili.

2.3. Interview protocol

Semi-structured interviews included discussions on demographics, provisioning services, and linkages between place-based values and underlying conditions. Each semi-structured interview (1–1.5 h, see Supplementary Material) began with an introduction to the topic and collection of background information (i.e., age, ethnicity, main income sources, land tenure) followed by a discussion on provisioning services ("benefits from the forest and land" was used to signify this concept) (Fagerholm et al., 2012). The provisioning services discussed were ones that the informants listed as being important for their livelihoods. While other studies have approached informants with lists of services to discuss (Sherrouse et al., 2011; Zoderer et al., 2019), this study elicited an open-ended typology to ensure that responses were not biased by the researcher's knowledge and to illuminate the services that are most important to informants. Once an informant finished listing services, we would ask about additional provisioning services—which we knew other people in the area acquired. We did not ask informants about other types of services (i.e., regulating, cultural, supporting) as we sought to explicitly understand the socio-cultural values, and factors that influence such value, of provisioning services in this study.

During the interview, once the landscape services had been categorized by the informants, participatory mapping was used to locate, describe, and facilitate analysis of places where informants obtained each service. Informants were presented with an A0 color aerial image (Google & CNES/Airbus, 2017) of their community (map scale in Kedowa was 1:12,114 and in Kuresoi was 1:7,974). The scale was chosen to capture the extent of each town, and it was assumed that this difference in scale was not large enough to alter map interpretation. After locating their home and prominent locations on the map, the informants were given 10 beans and were asked to distribute them to denote the locations ("service locations") and importance ("location weight") of where they obtain an individual service. We used 10 beans as informants mapped on average two locations per service, thus distributing 10 beans was sufficient to capture the difference in importance. Informants placed more beans in locations that were more important (Klain & Chan, 2012). This process was repeated for each individual service. To ensure respondents understood the map and the service locations, we discussed the locations in reference to other identifiable features on the map—for example timber plantations, trails, and streams.

Each service location was complemented with further interview questions, such as how often the location is accessed, how much of the service is used based on locally-relevant units (e.g., bundles of firewood, cans of water) and how use changes during the dry season *versus* the wet season. These questions allowed the research team to calibrate our understanding of the service and identify any discrepancies between how informants described the same service. The research team then asked what factors drive people to value some service locations more than others

(Bryan et al., 2010). This last point was assessed by asking informants, "why is this location important to you for this service" and "why did you rank this service location [i.e., stream for water] as more important than another service location [i.e., well for water]?" (see questions 6c and 6d in Supplementary Material). We asked follow-up questions on this point if needed, to understand why informants ranked sites differently in importance. The answers to these questions were later analyzed (method in section 2.5) to produce the results in section 3.4. If a location was outside of the map, the bean was placed on the edge of the map, a note was made, and only the descriptive information was collected.

Each location was given a unique identifier to designate the service it represented, and the weight attached to the location, and to distinguish it from other locations of the same service. These identifiers, as well as the home location, were manually color-copied on a black and white A3 paper sheet copy of the aerial image and photographed for verification (Fagerholm et al., 2012). Once the information was recorded, the beans were removed from the A0 map and the process began again for the next listed landscape service. All interview answers were recorded, and key notes were transcribed on a piece of paper during the interview.

We also conducted observational walks with officials from Kenya Forest Service (KFS) and community members to triangulate interview responses and calibrate the results of the mapping exercise. We visited a shamba system with KFS officials, a commonly mentioned sawmill, streams used for water collection, and other notable sites in town that people had mapped. During these walks we verified the locations of these sites and gained more context surrounding uses of these locations.

2.4. Data analysis

The A3 maps were then digitized using a flatbed scanner and georeferenced in ArcGIS 10.5 (Esri, Redlands, CA) software. Each bean location was digitized as a point feature. Shapefiles were created for each community that recorded each service location as a separate attribute and included variables for informant ID, service weight, location weight, age, ethnicity, and gender. Using these shapefiles, density surfaces ("hotspot maps") were generated using a quadratic Kernel function, as has been performed in similar studies (Fagerholm et al., 2012). The Kernel function allowed us to weight each point by the location weight ascribed to the point by the informant. We set the cell size for the Kernel function equal to 24.56 m (in line with the default cell size for the smaller scale map) and set the search radius, a parameter of the Kernel function, based on a subjective assessment of how spatially 'diffuse' values are for different services. For example, grazing cattle is a more spatially expansive ("diffuse") behavior than collecting water. The search radii used for the different services can be seen in Appendix Table A.1.

The result of a Kernel function is a GIS layer where each cell represents the density of point features, which in our case are weighted by importance, around the cell. Thus, each cell has a quantitative representation of that location's importance for a given service. However, we are less concerned with these quantitative results as we use the hotspot maps to aid and inform the interpretation of the interview responses. Therefore, using ArcGIS, we assign the highest density value from Kedowa, for each service, the same color as the highest density value from Kuresoi, and same with the lowest value. The result is that any one density value may be visualized by a different color in Kedowa as in Kuresoi, but relative values (e.g., lowest value, 25% value, highest value) in each town will have the same color. This allows us to visually compare the most (and least) important sites from each town.

Interviews were transcribed and analyzed using NVivo 11 (QSR International, Victoria, Australia). Using principles of grounded theory, a high-level theory emerged inductively from the interview data (Corbin & Strauss, 2008), shedding light on why Kenyan subsistence peoples in Kedowa and Kuresoi value landscape services where they do. First, we developed initial, literal codes that are based directly on participants' language regarding why certain service locations were more important to them than other locations (Saldana, 2016). Secondly, we integrated

Table 2
Summary of ethnic and socio-economic characteristics of informants from both communities.

Number of respondents by ethnicity	KedowaKedowa	Kuresoi
Kalenjin	27	22
Kikuyu	0	2
Kisii	0	2
Luhya	0	1
Maasai	0	1
Average tenure	16 years	22.5 years
Average size of owned agricultural land	0.4 ha	0.8 ha
Average number of income sources	3	4
Average number of stated provisioning services	5	6

related codes into intermediate categories that incorporate a level of abstraction. Lastly, the intermediate categories were grouped into related high-level themes that allow for more transferrable conclusions, which categorize the underlying conditions that influence how and why people value service locations differently. The range of intermediate categories and illustrative initial codes are shown in Appendix Fig. A.1 and intermediate categories and high-level themes are in Appendix Fig. A.2. Through this process, we created 413 initial codes, 16 intermediate categories, and four high-level themes. The high-level themes make up the general theory presented in section 3.4. Codes were also created to indicate where informants obtained services (e.g., forest, well, stream, home farm). These codes enabled us to explore the connections between underlying conditions and locations of value, by performing queries of overlapping location and condition-related codes in the NVivo software. The results from the qualitative analysis are discussed in section 3.4.

3. Results

3.1. Community profile

In Kedowa, all the informants were of Kalenjin ethnicity while in Kuresoi, the informants represented five different ethnic groups: Kalenjin, Kikuyu, Kisii, Luhya, and Maasai (Table 2). The ethnic diversity in Kuresoi may be partly due to the fact that, in the past, the government has resettled people to the area as part of campaign promises (personal communication). The average length of land ownership of the informants was, rounded to the nearest half year, 16 years in Kedowa and 22.5 years in Kuresoi. The average size of owned agricultural land was 0.4 ha in Kedowa and 0.8 ha in Kuresoi.

From the 55 interviews across both communities, a total of 22 different sources of income were listed by informants, 12 of which were listed by respondents in Kedowa and 20 of which were listed by respondents in Kuresoi (see Table A.2 in Appendix). Eight income-generating activities were practiced in Kuresoi that were not practiced at all in Kedowa.

Informants in Kedowa state that, on average, they have three main income sources, though these sources can vary by individual. The main sources of income in Kedowa are selling maize (practiced by 81% of informants), selling beans (44%), and employment for salary (which includes casual labor) (37%). All informants in Kedowa say that they engage in some amount of farming for subsistence. In Kuresoi, respondents, on average, state that they derive income from four sources. The most commonly cited sources of income in Kuresoi are selling potatoes (practiced by 86% of informants), selling tea leaves (61%), selling milk (39%), and employment for salary (32%). Again, all informants practice subsistence agriculture, mainly growing maize for food. A full list of all stated income sources can be found in the Appendix (Table A.2).

3.2. Provisioning services classification

A total of 10 different provisioning services, following the typology of ecosystem services developed by work of the global initiative, The
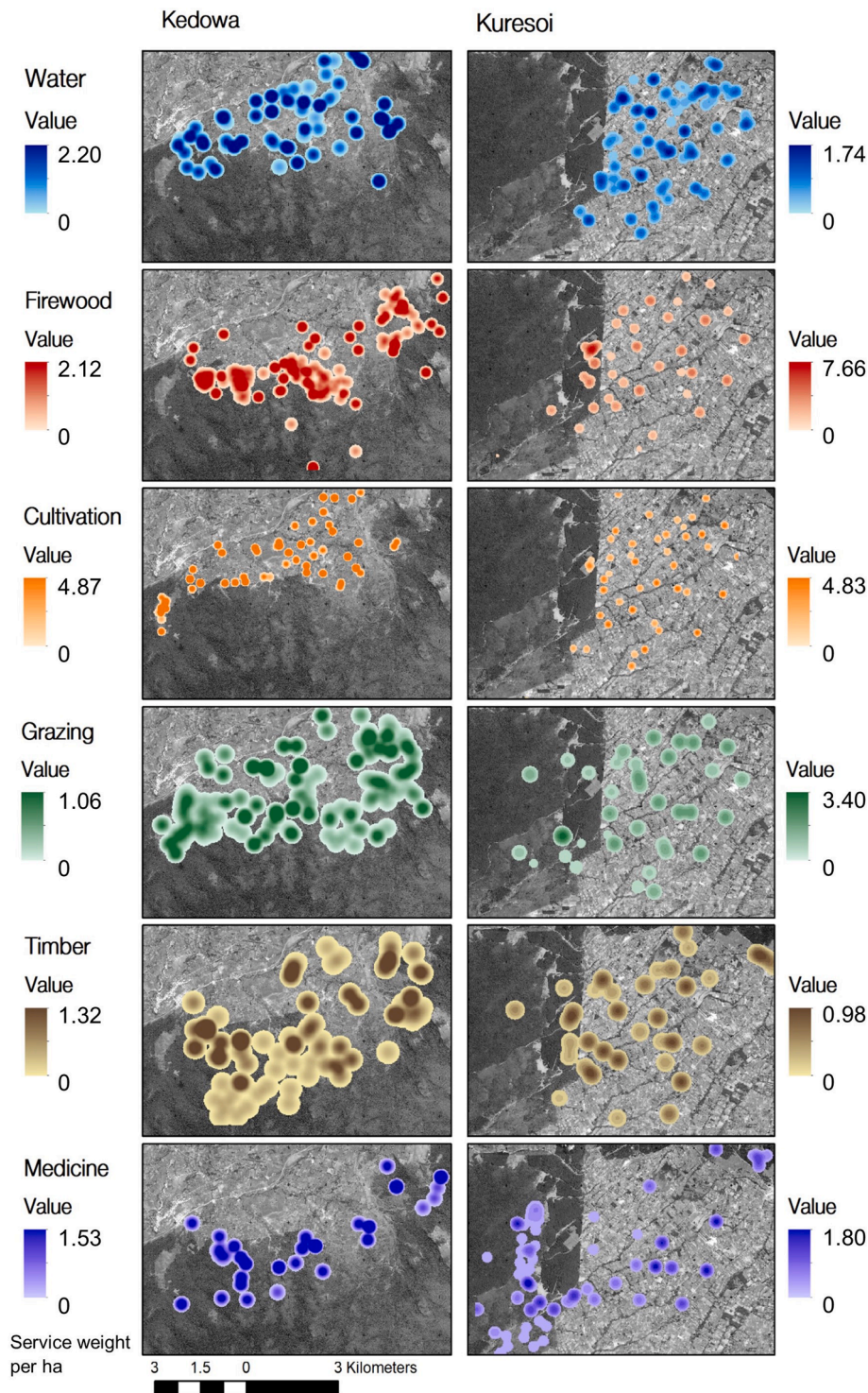
Fig. 2. Hotspots of value for the six most commonly listed provisioning services (listed by row) in Kedowa (left column maps) and in Kuresoi (right column maps). The dark grey areas in the satellite image, along the bottom of the Kedowa image and along the left of the Kuresoi image, is the Mau Forest and the light grey areas are smallholder farms, residential areas, and rural infrastructure. These maps are presented at the same scale and extent as were used during fieldwork.

Economics of Ecosystems and Biodiversity (TEEB), were listed by informants, 9 of which were listed in both Kuresoi and Kedowa (each community listed one service that the other did not) (see TEEB, 2010). One listed service, "Milk", was removed from the analysis as it can be a derivative of a more-commonly listed service: "Grazing for cattle". All listed provisioning services are presented in the Appendix (Table A.3).

Respondents in Kedowa reported between three and nine

provisioning services while those in Kuresoi reported between four and eight (range). In both Kedowa and Kuresoi, respondents most frequently stated that they obtained six provisioning services (mode). The six most commonly stated services in both communities, in order, were water, firewood, food production off-farm, grazing, timber, and medicine (see Table A.3 for full list).
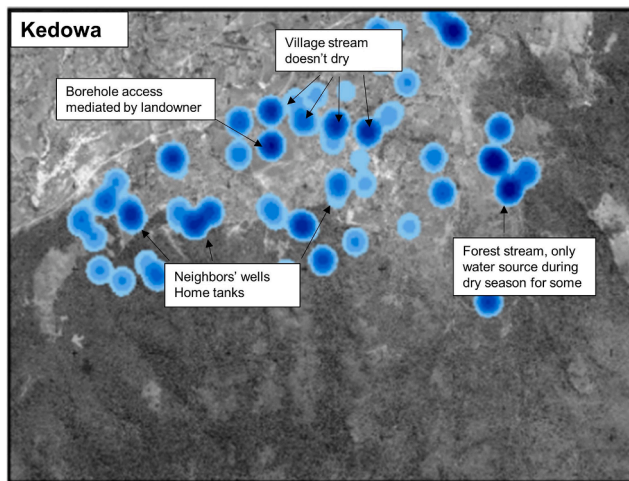
Fig. 3. Annotated map contextualizing hotspot maps with interview data to generate a more detailed understanding of provisioning service values.

3.3. Spatial patterns of service value

3.3.1. Spatial distributions of values

The resulting maps represent hotspots of value that emerged after analyzing 27 responses in Kedowa and 28 responses in Kuresoi, as outlined in Section 2.6 (Fig. 2). Areas of darker colors are areas that were weighted highly by an informant or areas where multiple informants indicated value. Based on the search radii used (Table A.1), each service has a different spatial threshold (the radius of a circle) for grouping and representing hotspots. Maps that have wider circles around individual points are those with a larger search radius. Clusters of color represent areas where multiple individuals indicated value or areas where an informant distributed beans across the map rather than place them in one discrete location.

Judging from Fig. 2, there are some places that hold high value for multiple, overlapping services. For example, areas along rivers, especially in Kuresoi, were noted as being important for medicine, water, and grazing.

To assist interpretation of Fig. 2, and to enable the research team to visualize interview data, we annotated the density maps for each provisioning service with explanatory qualitative interview data. Fig. 3 below provides an example of such an annotated map of hotspots of water values in Kedowa.

3.3.2. Spatial patterns omitted from the hotspot maps

In addition to identifying the locations of value, the participatory mapping exercise also revealed controversial services. Charcoal production is only legally permitted under a lengthy set of conditions and if managed by licensed members of a CFA-organized charcoal producers group (The Forests Act, 2005; Annex 4: The Forests (Charcoal) Regulations, 2009; Mutune et al., 2017). Furthermore, charcoal production is stigmatized in the area (personal communication) and is a commonly-cited source of forest degradation by researchers, the government, and the public media (Bewernick, 2016; Mbaria, 2004; Olang & Kundu, 2011; Owino, 2009). While villagers were willing to discuss charcoal and map where they produced it (often at home), very few mapped where they obtained the wood. One informant abruptly ended the conversation about charcoal when we got to the mapping exercise. Since the resulting maps would identify peoples' homes (based on where people placed their beans) and given the illegal nature of charcoal production, we have decided to omit the maps from this publication. This interaction highlights the value of using a mixed methodology as we would not have known the sensitivity of locating wood sources for charcoal if we had not combined the mapping process with the interviews.

Additionally, certain locations of value were located outside of the map extent and, thus, could not be visualized. One such recurring location was a sawmill just north of Kuresoi where many people in Kuresoi purchase timber. We focused our analysis on locations where people obtain value directly from the forest or the land. Many people obtain services such as timber and medicine from sawmills or markets. Sawmills and markets were not mapped because we wanted to represent the original source of the service.

3.4. Thematic analysis of linkages between mapped values and underlying conditions

The qualitative analysis of interviews produced (following the method described in section 2.5) four high-level analytical categories that warrant further discussion: historical and legal arrangements, social relations, economic conditions, and biophysical conditions. These four categories represent the key underlying conditions that informants perceive to influence mapped values. These categories were found to influence each of the six major provisioning services analyzed: water, firewood, cultivation, grazing, timber, and medicine. Sections 3.4.1 through 3.4.4 review semi-structured interview data and field observations that illustrate the connections between interview responses, the high-level categories of underlying conditions, and the provisioning services they influence.

3.4.1. Historical and legal arrangements

When asked why certain locations are important for different provisioning services, informants frequently described factors that we categorize as historical and legal arrangements. Embedded within this category are issues such as environmental history, political history, land ownership, state regulations, and the enforcement of said regulations. While historical and legal arrangements were described in reference to all services, we highlight their influence on cultivation and firewood in the discussion below.

For both communities, land title and tenure security (herein classified as a legal arrangement) were described as influencing how valuable different locations are for cultivation. One informant in Kuresoi remarked about why an area that he rented from a neighbor was not as valuable as land at home, "*I have title [to the rented land] to farm, but technically it is officially forest. Trees were cut in 1975 then land was given to the people by the government. I can't use this for a loan because the bank is afraid the government will take it back, so it's not as important.*" One person in Kedowa, when asked why they had marked their home as being the most important place for farming, said, "*Home is more important because I can make my own decisions about what I grow. I own the land. I interplant crops that I can't plant in the shamba.*" These responses were characteristic of many informants with whom we spoke in both Kedowa and Kuresoi. Interestingly, these locations of value were not necessarily tied to the size of land or amount of production—some people had more land in the shamba but still said land at home was more important because it was more secure. In brief, quality or quantity were not always the prime driver of why people perceive some landscapes as more valuable than others.

Regulations and enforcement also influenced where people value firewood. We learned that firewood is generally a permit-based resource, governed by KFS. One person, when explaining why the KFS plantations were less important for firewood collection than the home (though the plantations were still used by many people), said "*We go to the shamba when KFS cuts the trees but KFS can stop you so it's less important.*" Others remarked that they get more firewood from home or from neighbors' houses because the process to obtain a legal permit for firewood is long, cumbersome, and costs money. While we did not quantify socioeconomic standing for informants, it is likely that individuals who spoke about skirting the permitting process because of costs were also the poorer households.

3.4.2. Social relations

Social relations, defined here as direct and indirect interpersonal relations (relationships between individual people at a local level) and the power dynamics that surround such relations, were perceived to influence all services. In this section we highlight how they impact values for water and cultivation land. In Kedowa, few people interviewed rely on their own wells but 11 out of 27 informants draw water from neighbors' wells. Multiple people rely on one landowner whose family historically owned a large portion of the village before the land was divided. In Kedowa, access to these wells is mediated by neighborly

relationships as people do not pay one another for access. Conversely, in Kuresoi, almost all informants have their own wells. Those who do not, again, obtain water from neighbors' wells. In Kuresoi, those who do not have wells cite financial concerns as the primary hindrance.

Interpersonal relations were also reported as playing a role in shaping where people farm, particularly in Kedowa. In both communities, people list their own homes, rented land, or the shamba system as sites of cultivation. Across Kenya, plots in the shamba system are allocated by Community Forest Associations (CFA) to those who pay for CFA membership. One informant, who only farms at home, stated, "*I paid for the CFA registration, but the CFA is not giving me land. They promised to give me land in the shamba but they're not giving it.*" While informants were unclear why this was happening, a recent report found the process of allocating shamba plots to be guided, unfairly, by social and political relationships (Ministry of Environment and Forestry, 2018). Since all access to the shamba system is mediated by the CFA, it is important to investigate the relationship between prospective farmers and the CFA further.

3.4.3. Economic conditions

In our study, the category of economic conditions includes intermediate categories surrounding market opportunities, cost, and efficiency. Efficiency includes questions of time and access to resources. Many informants listed provisioning service locations as being more important because they were either closer, required less energy to access, or faster to acquire. We understand, through an analysis of interviewee's own words, these responses to ultimately indicate a consideration of personal resources in valuing service locations, mainly time and energy. One provisioning service value that was uniquely said to be affected by economic considerations was that of timber. In Kedowa, no informant stated getting income from selling timber and nobody valued their land at home for timber. Instead, it is all collected or purchased. In Kuresoi, however, almost everyone who values timber places highest importance or second-highest importance on their home for this service. When asked why people planted timber trees at their home many people gave similar responses to the following informant, "*I plant trees so I can sell them to the nearby sawmill. I use the money to pay for school fees.*" Kuresoi has multiple sawmills in town and an informal furniture industry (from personal observation) to which people can sell their timber for cash, which provides a market opportunity that incentivizes the growing of on-farm trees for timber .

3.4.4. Biophysical conditions

Biophysical conditions were said to prominently influence all provisioning service locations, as might be expected. In Kedowa, 20 out of 27 informants listed the native forest or clearings within the forest as the most important places for grazing. When asked why, informants responded, "*This area is most important because it has lots of water in streams and grass. I go here specifically because the fire burned here, and grass is coming back.*" Others remarked, "*I take them further during drought, to where there are more trees, because the grass dies closer.*" In Kuresoi, people have fewer cattle and do not take them as far (see Supplementary Material). Instead, many people list their home as the most important place and say, "*This land at home is enough. I grow terraces of Napier grass, so I don't need to take it to the forest.*" From these responses, we infer that home is more important to Kuresoi people for grazing than it is to Kedowa people because, among other reasons, they tend to have fewer cattle and many grow Napier grass (*Pennisetum purpureum* Schumach.).

When asked they people valued certain locations for medicine, informants only listed biophysical conditions. In this area, bark, roots, and leaves of indigenous plants are used to cure toothaches, chest pains, and most other ailments. However, these plants are only found in native forests. One person in Kuresoi stated, "*I go to the indigenous forest because the medicine plants only grow here. They grow along the river. During the wet season I don't have to go as far because there is more near the river.*" Another informant from Kuresoi remarked that, "*Getting medicine from the forest is important for the Kalenjin, it's a cultural thing.*" Interestingly, only nine out of the 27 people we interviewed in Kedowa reported obtaining medicine even though everyone we interviewed in Kedowa was Kalenjin while almost everyone in Kuresoi we interviewed reported getting medicine from the forest, a few of which were not Kalenjin. It is possible the biophysical conditions in Kuresoi, since it does receive more rainfall and is cooler, are more amenable for these medicinal plant species than in Kedowa.

4. Discussion

4.1. Provisioning service locations as influenced by underlying conditions

The results here suggest that where and how people value provisioning services in the Western Mau Forest depends on the service and its relation to underlying social and biophysical conditions. Even though ecosystem service planning in the Western Mau Forest is often discussed at the regional or ecosystem-scale (Crafford et al., 2012; Okumu & Muchapondwa, 2017; Owino, 2009), Kedowa and Kuresoi's unique characteristics result in distinct value sets held by residents regarding provisioning services. These value sets can include how important different water sources are, how farmland is valued, etc. These distinctions can lead to different methods of engagement around conservation and land management.

As other research has shown, we demonstrate that provisioning service values are place-based and diverse (Fagerholm et al., 2012; Potschin & Haines-Young, 2013). This study adds a deeper layer of understanding as to how these distributions are linked to underlying social and environmental conditions—succinctly categorized as historical and legal arrangements, market access, social relations, site conditions and their both positive and negative potential interactions.

These results lead to a number of conclusions, one of which is that spatial planning interventions on provisioning services will indirectly affect or be affected by underlying socio-political factors, which are not easily represented spatially. For example, we found that people who do not have their own wells for water rely on access to streams and neighbors' wells, which is mediated by the strength of interpersonal relations. This research suggests that if a future drought greatly reduced the surface streamflow, the people most impacted would be those who cannot afford their own well or do not have strong relationships with others—possibly newcomers or marginalized groups. We can also see from this analysis that the most important locations for water values are wells and springs that tap into groundwater. These finding emphasize that ecosystem service interventions ought to anticipate unequal and disparate dependencies on service locations and plan for groundwater recharge influenced by land use, in addition to preserving streamflow. Research conducted by our team in the Kuresoi area has shown that the dominant water pathways are superficial, which may compromise water supply during dry periods (Jacobs, Weeser et al., 2018)

Another conclusion that can be made from these results is that to adequately and durably affect provisioning services, interventions must address and examine underlying conditions. This conclusion reflects policy science theories that seek to address root causes of policy failures (Clark, 2002). In this study, we can use firewood to illustrate this point. Areas that many people value for firewood are mediated by permits from the Kenya Forest Service. Some people report changing behavior or location of collection, such as collecting more from home, to avoid the permitting process, which has been found to be cumbersome to poorer households due to its high cost in fees and time needed to obtain a permit (Mutune et al., 2017). Spatial planning interventions that restrict firewood collection could push people to collect more from their homes to skirt further regulations. Given that growing trees is also considered an important source of income, forcing families to rely on their own land for firewood could have significant financial impacts. This knowledge can then be used to strengthen additional interventions and efforts for improving on-farm tree productivity and cultivation. Additionally, any initiatives around firewood management that seek to both conserve forests and enhance livelihoods will need to understand and address permits as a key governance mechanism.

One notable difference that emerges from a comparison of the Kedowa and Kuresoi maps is the degree to which hotspots are located around houses *versus* within the forest. Specifically, we can see that firewood, timber, grazing, and medicine are located more frequently

around homes in Kuresoi while in Kedowa they are located more frequently in the forest (Fig. 2). In analyzing interview responses between communities, we noticed responses indicating that people in Kuresoi have larger land sizes (Table 2), more frequently grow timber trees in small woodlots on the property, have fewer cows, and grow and sell tea (see Supplementary Material). It is possible that the underlying reasons for the differences between the two locations lie in historical contingencies of British rule, which has resulted in an enduring impact on how local farmers access resources and value the landscape.

British colonists were drawn to the Kuresoi area, where precipitation is high and soils are fertile, to establish large tea plantations and farms—giving the area its name 'the White Highlands' (Morgan, 1963; Boone, 2012). When Kenya gained independence, these lands were distributed to Kenyans at the time in large parcels and wealthier families moved in (Kenya Land Alliance, 2004; Overseas Development Institute, 2008). While these large parcels have been subsequently redistributed, our research suggests that they may still be larger than those in Kedowa, are more fertile, and have better access to water (personal communication).

Tracking Kedowa's history of land distribution was more difficult. Kedowa receives less rainfall and has warmer temperatures, making it less suitable for tea. From personal conversation, we heard that farms were established more recently with the construction of nearby roads and infrastructure and that land allocation was more informal. From this information, we hypothesize that larger land size, which is a product of geography and land distribution policies, in Kuresoi may enable people to grow trees in addition to their crops. Furthermore, the proximity to Kuresoi Tea Factory and multiple sawmills gives Kuresoi residents a market to sell timber and tea (which garners a higher price and more steady income stream than other crops, based on communication with farmers in the area). In sum, it is likely that the differences between Kedowa and Kuresoi in terms of reliance on home-based resources *versus* forest-based resources can be, at least in part, explained by market access and histories of land distribution—which has led to differences in land sizes between the two localities. Another potential factor could be differences in emigration and immigration over time, which we did not explore.

4.2. Implications of the spatial distributions of provisioning services

Understanding where multiple landscape service values overlap can guide prioritization of conservation and should also be used to caution against zoning any area for a single service. Similar conclusions have been made by studies in other regions (Klain & Chan, 2012; Plieninger et al., 2013; Qiu & Turner, 2013). In this area of the Western Mau Forest, at least, many locations are used for multiple provisioning services and should be planned accordingly. How these areas of overlapping services are managed is a political decision made by institutions and people in a landscape and may be based on the long-term condition of these areas (which we did not assess).

Additionally, it should be noted that service locations and their assigned values change over time. Informants repeatedly mentioned needing to change grazing, water collection, and firewood harvesting sites during the dry season due to abundance changes. During droughts, people go further into the forest for grazing, they need to focus more on collecting water from forest streams than home wells, and they need to go further for firewood because more wood is dry and thus community-wide collection

Table A1
The search radii used during Kernel Density analysis in ArcMap 10.1 for each provisioning service. These were determined by analyzing how far from any given point the value of that service should extend.

Provisioning Services	Search Radius (m)
Water	250
Firewood	200
Cultivation	140
Grazing	300
Timber	350
Medicine	250

Table A2
Percent of respondents who say that they obtain income from the stated activity/source.

Income Sources	Kedowa	Kuresoi
Potatoes	19%	86%
Maize	81%	29%
Tea	0%	61%
Beans	44%	21%
Milk	26%	39%
Employment	37%	32%
Cattle	11%	29%
Traditional Vegetables	26%	11%
Chickens	26%	0%
External Sources	11%	25%
Timber	0%	21%
Cabbage	11%	14%
Kale	0%	14%
Firewood	7%	4%
Tomatoes	7%	0%
Onions	0%	4%
Peas	0%	7%
Pyrethrum	0%	4%
Fruits	0%	4%
Honey	0%	4%
Charcoal	0%	4%
Medicine	0%	4%

increases. Resource planning for these largely subsistence activities and services need to account for changes in service locations.

4.3. Methodological implications

Many studies and initiatives, largely influenced by methods from geography and spatial ecology, have begun implementing participatory mapping as a method of empowering local knowledge and statistically-generating hotspot maps for ecosystem service planning processes (Fagerholm et al., 2012; Sherrouse et al., 2011). Concurrently, ethnographers and other social scientists rely largely on interviews, document analysis, and other text or discourse-based qualitative methods (Bhattacherjee, 2012; Perecman & Curran, 2006). Here we combine participatory mapping with semi-structured interviews to understand perceived linkages between locations of provisioning service value and underlying conditions. Using each method by itself can elicit new and novel information, but mixing methods allowed us to synthesize different types of knowledge about the Mau Forest and value people attach to its services. In our study, we achieved this by adding explanatory qualitative interview data in text boxes alongside the quantitative density maps for each provisioning service (see Fig. 3). Visualizing interview and map data together enables a more thorough articulation of the complexity inherent in provisioning service values. Without tools such as these, understanding social and spatial dynamics of provisioning services can be too cumbersome for practical application.

In the Kenya context, this combination of participatory mapping and interviews could be implemented through the PFM process, specifically step three of the process, 'Assessing the Forest Area and Communities.' Past PFM processes have employed resource mapping, but none have

Table A3
Percent of respondents in each town that stated that they obtained the following services from the forest or the land.

Provisioning Services	Kedowa	Kuresoi
Farming	96%	100%
Water	100%	100%
Firewood	100%	100%
Grazing	89%	93%
Timber	74%	86%
Charcoal	4%	39%
Medicine	33%	68%
Honey	7%	18%
Fruits	0%	14%
Chickens	7%	0%

mapped socio-cultural values to understand where hotspots of values are located, which can be different from where resources themselves are located. By mapping and weighing values, the Kenya Forest Service could gain a better understanding of how people perceive the landscape and the services it provides. Further research is needed to test this method in practice with the PFM process, as has been done in Tanzania with village land use planning (Eilola et al., 2019).

This type of mixed method can be useful for communicating and operationalizing complex local knowledge in participatory land and forest management. This assumes that innovative and bottom-up policy making processes become the norm—which remains a challenge in many countries. As more countries begin to implement land rights reforms and institute land use planning, especially in developing nations, it will be crucial to understand and translate into implementable policy processes the complexities of customary and local land use in the context of formal land use planning (Rights and Resources Initiative, 2014). Local knowledge in many places may be best interpreted qualitatively as land traditions can be multi-faceted and not easily codified (Scott, 1998). Planners, foresters, and other practitioners could use the style of mixed method outlined here, combining value mapping with interviews to understand why stakeholders perceive service locations to be important, to adequately capture and operationalize complex local knowledge around land use planning and ecosystem services.

5. Limitations

This study should be understood and contextualized within the limitations of the methodology we have used. These limitations include those regarding the choice to focus on provisioning services, the focus on studying perceptions, and caveats to applying the method in practice. For one, this study assessed informants' values of provisioning services but did not investigate other landscape services. Therefore, one should not conclude that informants do not value other services (e.g., cultural, regulating, supporting), as we did not ask about these. We acknowledge that the focus on provisioning services means this study is more relevant for interventions on direct resource use by communities than for addressing overlapping types of landscape services concurrently. We do not dismiss the importance of managing landscapes for multiple types of services and recommend the approach used here be applied to other types of services in further research.

A second caveat is that this study investigated perceptions of services, not the actual amount nor use of services. Perceptions are critical to crafting sustainable policies and plans but they are not the whole story. Studies such as this should be assessed with biophysical and quantitative studies to adequately manage ecosystem services. It should also be noted that informant responses and perceptions can also be influenced by unspoken political, social, or reputational pressure. Lastly, this study used a method that has the potential to be integrated with PFM, but it did not test its use in existing process as other studies have. These assessments would need to be undertaken to test the method's cost and time effectiveness in practice.

The goal of this study was to explore and understand the connection between underlying conditions and socio-cultural values of landscape services. As such, we chose our sample and sample size (55 people) to achieve the goal of developing a robust understanding of the diversity and nuance of perspectives on landscape services. Because of the nature of this research, the service maps should not be seen as representative of the entire population or community. Rather, these maps aid, inform, and visualize the trends that were discussed in qualitative interviews. These maps should be seen as a tool and an output that can be paired with interviews for geographically limited studies and planning processes. They also lay the foundation for future studies that could take a statistical approach to mapping population-wide value distributions.

5. Conclusion

The government of Kenya and other organizations are integrating provisioning service assessments into participatory forest management process and looking to establish payments for ecosystem services in the Mau Forest Complex. Decades of deforestation and over-extraction has promoted a perceived and potentially actual decline in water flow. This deforestation has resulted in social conflicts, and economic losses both in and downstream of the forest (Chepngeno, 2014; Kweyu, 2015; Njue et al., 2016). With the increased coordination between the Kenya Forest Service and Community Forest Associations (Ministry of Environment and Forestry, 2018), opportunities exist to plan for a future in which community values for landscape services are respected and incorporated into forest planning. However, this should be done with an understanding of where and how people value these services. This research demonstrates that each service is valued differently and in different locations by community members and that these distributions are perceived to be influenced from a few underlying drivers. Understanding this heterogeneity and embedding it into participatory policy making which integrates bottom-up with top-down approaches and considers the trade-offs between them, can lead policymakers and managers to create plans that are more adaptable to local contexts and account for socio-cultural values without harming engaged communities.

CRediT authorship contribution statement

Ethan F. Miller: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing - Original Draft, Visualization, Writing - Review & Editing, Funding Acquisition. **Amity A. Doolittle:** Conceptualization, Methodology, Writing - Review & Editing. **Paolo Omar Cerutti:** Conceptualization, Resources, Methodology, Funding Acquisition. **Jared Naimark:** Data Curation, Formal Analysis, Visualization. **Mariana C. Rufino:** Conceptualization, Resources, Project Administration, Writing - Review & Editing, Funding Acquisition. **Mark S. Ashton:** Supervision, Resources, Writing - Review & Editing. **Esther Mwangi:** Methodology, Supervision, Resources, Funding Acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Appendix A

RESOURCE QUANTITY
- More medicine grows here
- More grass in forest
- Lots of trees for firewood

RESOURCE QUALITY
- Forest trees burn stronger
- Forest stream water is cleaner
- Cedar wood is good for building

ECOSYSTEM CONDITIONS
- Medicine plants grow along rivers
- Soil is fertile for cultivation
- Less important for farming because land is steep
- Spring doesn't dry during drought
- Grass is available in forest during drought

EFFICIENCY OF ACCESS
- Forest is less important for grazing because it's too far
- Gets firewood and timber from home because it is fast
- Get medicine here because it's closer
- Home well important because requires less energy

MARKET OPPORTUNITY
- Grows trees at home so they can sell to sawmill
- Farm in the shamba system because it's easier to get to and sell at the market

COST
- Gets firewood from home because it's free, no permit
- Shamba farming land is not important because it's expensive
- Doesn't harvest timber from forest because too expensive

ENFORCEMENT
- Home firewood more important because can't be penalized
- Doesn't graze cattle in the forest because police can restrict access
- Could be caught and arrested while gathering medicine

LAND OWNERSHIP
- Home farming land more important because can make own decisions on the land
- Shamba land is less important because KFS owns it and we can get kicked out

REGULATIONS
- Illegal to harvest cedar from the forest so home is more important for timber
- Forest is important for firewood because I have KFS permit to collect there
- Forest stream is more important because there are no regulations for collecting

SOCIAL RELATIONS
- Get water from neighbor's land because we bought land from them and they give us access
- Have to buy wood from sawmill because didn't know anyone who cut
- Forest is important for grazing because we have neighbors who watch our cattle
- Borrow water from neighbor's well
- Neighbor lets them graze on their land

SIZE OF LAND AREA
- Shamba farmland is more important because it's bigger
- Pasture in the forest is more important because it's bigger
- Don't have enough space at home to plant timber
- Larger farmland at home than at rented land

ENVIRONMENTAL HISTORY
- Forest clearing important for grazing because it was burned and now growing back
- Learned to plant trees at previous town so now plant at home for timber

POLITICAL HISTORY
- Family left during political clashes so now just him and doesn't have family help
- Moved here during post-election violence when exchanged land with Kikuyu
- Lad was white owner's but in 1970's government got land and he bought title

RESOURCE SUSTAINABILITY
- Use wood from forest to conserve wood at farm
- Stream is important because it can't be depleted
- KFS plantation is more important for firewood because the supply will last longer

RESOURCE SECURITY
- Shamba farmland not as important because wild animals can destroy crops
- Don't take cattle to the forest because people can steal them
- Farm at home where crops are safe from neighbors' cattle grazing them

RESOURCE RESERVE
- Trees at home are for emergency when can't use forest wood
- Forest provides medicine when doctors are on strike
- Only collects firewood from forest during dry season, use the stash at home during rainy season

Fig. A1. Intermediate categories and illustrative initial codes. Due to the high number of initial codes (4 1 3), we have only included a sample to illustrate the types of responses we received.

Legend for colored codes

- Firewood
- Water
- Timber
- Medicine
- Cultivation
- Grazing

Biophysical Conditions

RESOURCE QUALITY
- Forest trees burn stronger
- Forest stream water is cleaner
- Cedar wood is good for building

ECOSYSTEM CONDITIONS
- Medicine plants grow along rivers
- Soil is fertile for cultivation
- Less important for farming because land is steep
- Spring doesn't dry during drought
- Grass is available in forest during drought

RESOURCE SECURITY
- Trees at home are for emergency when can't use forest wood
- Only collects firewood from forest during dry season, use the stash at home during rainy season
- Shamba farmland not as important because wild animals can destroy crops

RESOURCE QUANTITY
- More medicine grows here
- More grass in forest
- Lots of trees for firewood
- Stream is important because it can't be depleted
- KFS plantation is more important for firewood because the supply will last longer

Economic Conditions

MARKET OPPORTUNITY
- Grows trees at home so they can sell to sawmill
- Farm in the shamba system because it's easier to get to and sell at the market

COST
- Gets firewood from home because it's free, no permit
- Shamba farming land is not important because it's expensive
- Doesn't harvest timber from forest because too expensive

SIZE OF LAND AREA
- Shamba farmland is more important because it's bigger
- Pasture in the forest is more important because it's bigger
- Don't have enough space at home to plant timber
- Larger farmland at home than at rented land

EFFICIENCY OF ACCESS
- Forest is less important for grazing because it's too far
- Gets firewood and timber from home because it is fast
- Get medicine here because it's closer
- Home well important because requires less energy

Historical and Legal Arrangements

ENVIRONMENTAL HISTORY
- Forest clearing important for grazing because it was burned and now growing back
- Learned to plant trees at previous town so now plant at home for timber

REGULATIONS
- Illegal to harvest cedar from the forest so home is more important for timber
- Forest is important for firewood because I have KFS permit to collect there
- Forest stream is more important because there are no regulations for collecting

LAND OWNERSHIP
- Home farming land more important because can make own decisions on the land
- Shamba land is less important because KFS owns it and we can get kicked out

POLITICAL HISTORY
- Family left during political clashes so now just him and doesn't have family help
- Moved here during post-election violence when exchanged land with Kikuyu
- Land was white owner's but in 1970's government got land and he bought title

Social Relations

SOCIAL RELATIONS
- Get water from neighbor's land because we bought land from them and they give us access
- Have to buy wood from sawmill because didn't know anyone who cut
- Forest is important for grazing because we have neighbors who watch our cattle
- Borrow water from neighbor's well
- Neighbor lets them graze on their land

RESOURCE SECURITY
- Forest provides medicine when doctors are on strike
- Don't take cattle to the forest because people can steal them

ENFORCEMENT
- Home firewood more important because can't be penalized
- Doesn't graze cattle in the forest because police can restrict access
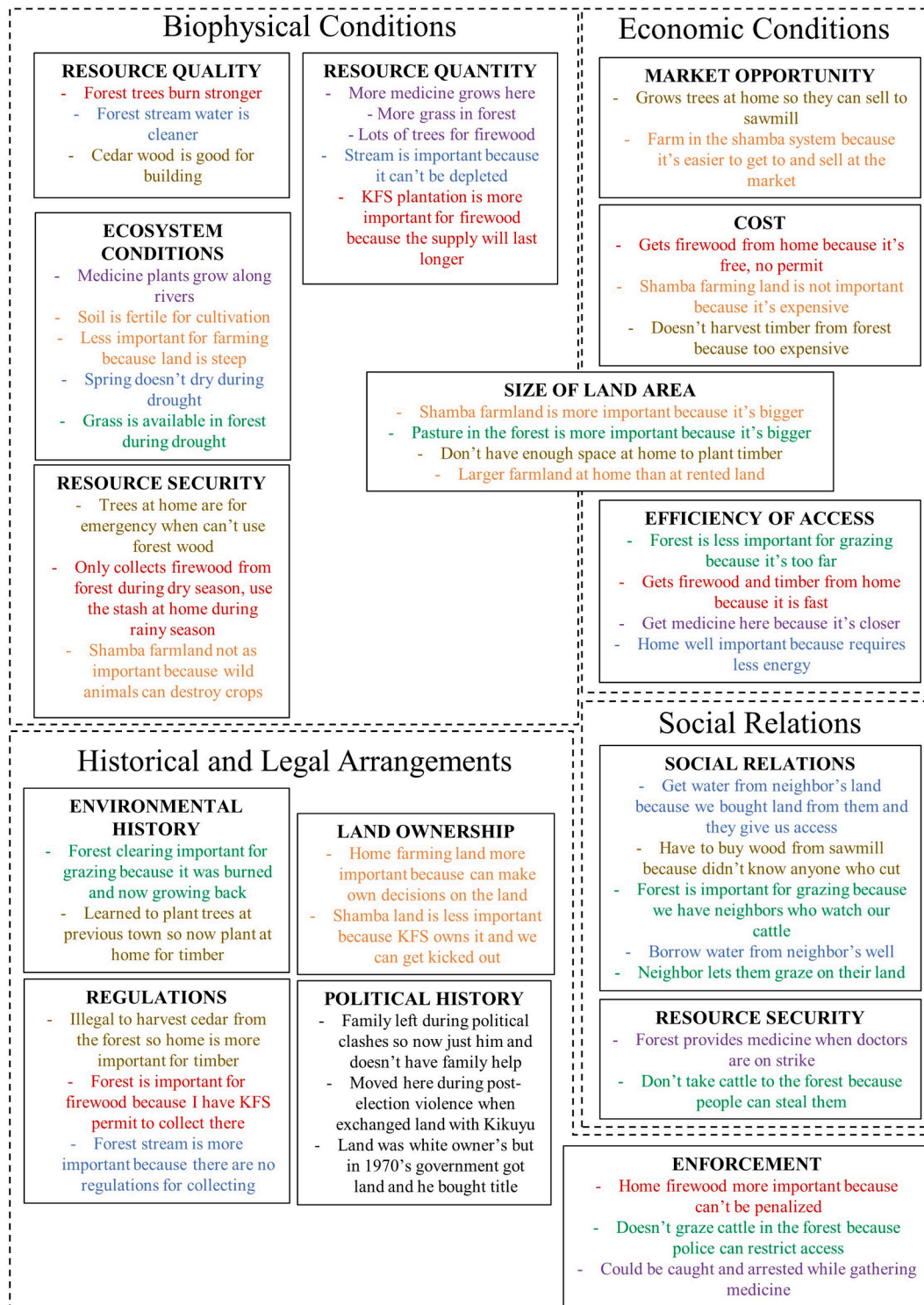- Could be caught and arrested while gathering medicine

Fig. A2. Intermediate categories and illustrative initial codes categorized into high-level themes. Colors are used to indicate which provisioning service the code applies to. Black text indicates code does not apply to a specific service.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2020.103995.

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