Perceptions of ecosystem services provision performance in the face of climate change among communities in Bobirwa sub-district, Botswana

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Abstract

Purpose – Between 2006 and 2016, local communities in semi-arid Bobirwa sub-district in the Limpopo Basin part of Botswana had endured notable fluctuations in the delivery of critical ecosystem services. These changes have been coupled with adverse effects on local people's livelihood options and well-being. However, a few such studies have focussed on the semi-arid to arid landscapes. This study therefore aims to provide recent knowledge and evidence of consequences of environmental change on semi-arid arid landscapes and communities.

Methodology – To examine these recent changes in key ecosystem services, the authors conducted six participatory mapping processes, eight key informant interviews and several rapid scoping appraisals in three study villages. The analyses were centred on changes in seasonal quantities, seasonality, condition of ecosystem service sites, distance to ecosystem service sites and total area providing these services. Drivers of change in the delivery of key ecosystem services and the associated adverse impacts on human well-being of these recent changes in bundles of ecosystem services delivered were also analyzed.

Findings – Results show that adverse weather conditions, drought frequency, changes in land-use and/or land-cover together with unsustainable harvesting because of human influx on local resources have intensified in the past decade. There was circumstantial evidence that these drivers have resulted in adverse changes in quantities and seasonality of key ecosystem services such as edible Mopane caterpillars, natural pastures, wild fruits and cultivated crops. Similarly, distance to, condition and total area of sites providing some of the key ecosystem services such as firewood and natural pastures changed adversely. These adverse changes in the key ecosystem services were shown to increasingly threaten local livelihoods and human well-being.

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Research limitations/implications – This paper discusses the importance of engaging rural communities in semi-arid areas in a participatory manner and how such information can provide baseline information for further research. The paper also shows the utility of such processes and information toward integrating community values and knowledge into decisions regarding the management and utilization of local ecosystem services under a changing climate in data-poor regions such as the Bobirwa sub-district of Botswana. However, the extent to which this is possible depends on the decision makers' willingness to support local initiatives through existing government structures and programmes.

Originality/value – This study shows the importance of engaging communities in a participatory manner to understand changes in local ecosystem services considering their unique connection with the natural environment. This is a critical step for decision makers toward integrating community values in the management and utilization of ecosystem services under a changing climate as well as informing more sustainable adaptive responses in semi-arid areas. However, the extent to which decision makers can integrate such findings to inform more sustainable responses to declining capacity of local ecosystems in semi-arid areas depends on how they value the bottom-up approach of gaining local knowledge as well as their willingness to support local initiatives through existing government structures and programmes.

Keywords Perceptions, Ecosystem services, Botswana, Climate change, Participatory mapping, Semi-arid regions

Paper type Research paper

1. Introduction

Anthropogenic and climate-induced changes in the environment have significant impacts on the livelihood options of people highly dependent on ecosystem services for their well-being (Huitric *et al.*, 2009; Barker *et al.*, 2010; Rocha *et al.*, 2014). The impacts of such changes are huge especially among those people living in the semi-arid, rural areas where rain-fed agriculture has proved to be very unsustainable in recent years (Ainslie *et al.*, 2008; FAO, 2012). The lack of other meaningful sources of income in most of semi-arid rural areas magnifies the impacts of fluctuations in critical ecosystem services (Iniesta-Arandia *et al.*, 2014). As climate change effects continue to manifest more clearly in most semi-arid areas of many developing countries, a further decline in the future supply of critical ecosystem services is expected (SafMA, 2004). More so, as countries are putting measures in place to keep the rise in global temperatures to less than 2°C of pre-industrial levels, semi-arid areas of Southern Africa are expected to have temperatures rising above this threshold (Engelbrecht *et al.*, 2015).

Despite the varied impacts of fluctuating supply of important ecosystem services across different regions and geographic areas (Serdeczny *et al.*, 2016), semi-arid rural areas are likely to be impacted by climate change in almost similar fashion because of the similarity of their conditions in many developing countries. With limited livelihood options, people living in such areas continue to rely on the already declining supply of ecosystem services. With rising population, economic growth and the associated changes in land-use and land-cover (LULC), the combined impact on those highly dependent on the natural environment could be huge (Palomo *et al.*, 2014).

Changes in LULC and climate modify the supply of important ecosystem services in those areas which have always provided critical ecosystem services in many different ways (Grimaldi *et al.*, 2014). As these changes continue to manifest, humans will also have to keep changing and continue anticipating change, so as to put in place measures which can safeguard their well-being. The limited adaptive response capacity characteristic of many poor people, especially those highly dependent on the natural environment, makes communities in semi-arid even more vulnerable to further adverse changes in climate (Agarwala *et al.*, 2014). As the climate continues to change, rising poverty, illnesses, malnutrition, land degradation and degradation of ecosystems are some of the associated challenges developing country governments need to anticipate especially if the global goals on sustainable development have to be realized by 2030 (Agarwala *et al.*, 2014).

Modelling of ecosystem services is often rigorous, complex, imperfect and time consuming hence arguments about their usefulness (Ding and Nunes, 2012). Furthermore, the unavailability of data on ecosystem service inventories in many developing countries makes modelling of important resources very difficult. While arguments surrounding modelling of ecosystem services at the landscape level continue, there is enough evidence that natural environments have been modified significantly, with adverse impacts on the availability of ecosystem services. In many semi-arid regions of Africa, this has been mainly ascribed to the rising average temperatures, declining rainfall, land-use and land cover change, as well as population pressure among other human actions (SafMA, 2004). Despite the differences in the actual causes of the declining capacities of natural environments to provide services critical for human livelihoods, there is consensus that the potential of semi-arid areas to provide ecosystem services is declining, in some places even dramatically (Pereira *et al.*, 2005). People living in semi-arid rural areas of developing countries are likely to become even more vulnerable to the effects of adverse changes in the supply of ecosystem services because of their uniquely high dependence on the natural environment for their well-being (Adger *et al.*, 2013; UNEP, 2010). With a 2°C rise in average temperatures, coupled with erratic rainfall which is highly likely in the semi-arid regions of Southern Africa (Daron, 2014), governments should rethink about how they can safeguard the lives of people living in such areas in a more sustainable way. Without planned adaptive responses, the decline in natural resources is likely to pose challenges on progress made on the fronts of sustainable development and poverty eradication in many developing countries.

Botswana is largely semi-arid to arid and is experiencing similar effects of climate change (Batisani and Yarnal, 2010). These effects are posing a unique threat on the lives of those rural poor who heavily depend on the natural environment for their well-being (Dube and Sekhwela, 2012). Despite the declining capacity of many ecosystem services, increasing numbers of people are depending on the natural environment thus adding weight to the climate stress (Sieber, 2006). The continued unsustainable exploitation of most of the key ecosystem services thus makes future livelihoods not only vulnerable to further anthropogenic and/or climate-induced changes but also compromises the adaptive capacity because of limited options in many rural communities of developing countries (Rocha *et al.*, 2014). Individuals and communities must appreciate that ecosystems' capacity to provide services that have always been critical for their well-being is continuously being compromised and declining in many places before they can take measures to redress the situation (Neelo *et al.*, 2015). However, unless individuals and communities perceive adverse trends in availability of critical services that have safeguarded their livelihoods for many years, it may be difficult for them to appreciate that ecosystems' capacity to provide key ecosystem services is declining.

Importantly, effective and sustainable responses to any adverse change in the availability of important ecosystem services requires a good understanding of the actual and potential drivers, as well as how they are likely to change going forward (Rocha *et al.*, 2014). Any adaptive response to the changes in supply of important ecosystem services should show a strong correlation to how individuals perceive changes in their availability as well as to what they perceive to be driving those changes. However, human perceptions are not only influenced by the actual changes in availability of important ecosystem services but also by those factors driving the change such as climate change, population trends and land-use/land cover change (Xiong *et al.*, 2014). Hence, maladaptation usually occurs because the response measures are not strongly related to the perceived changes in ecosystem services or to factors driving ecosystem change (Ziervogel and Cartwright, 2008). Despite the number of studies on changes in the provision of ecosystem services (Pagella and Sinclair, 2014; Nelson *et al.*, 2013; Dube and Sekhwela, 2007), no study has focussed on understanding and evaluating societal perceptions of ecosystem services in semi-arid Botswana and the role they play in responding to perceived changes. More so, societal perceptions differ from one place to another and may not be inferred, deduced or simulated from another community; hence, the need to carry out sight specific inquiries for different communities to understand how people in different areas perceive changes in key ecosystem services. Understanding human perceptions about changes in ecosystem services which are critical to their livelihoods and well-being is essential for appropriate policy interventions and effective decision-making. Such participatory and inclusive policy and decision processes can enhance the effectiveness and sustainability of adaptive responses to changes in key ecosystem services. These also necessitate contextualization of findings which enables appropriate measures to be taken to reduce further impacts on ecosystem services.

This study aimed to understand and evaluate perceptions of people living and depending on the natural environment in Bobirwa sub-district, in the Limpopo Basin of Botswana, regarding recent changes in availability of important local ecosystem services (2006-2016). The study was therefore guided by the following research questions:

RQ1. What are the key ecosystem services in Bobirwa sub-district?

RQ2. What changes in key ecosystem services have been observed between 2006 and 2016?

RQ3. How have the perceived changes in availability of key local ecosystem services impacted local livelihoods and human well-being?

2. Methodology

2.1 Study area

This study was conducted in Bobirwa sub-district in the Central District of Botswana. Bobirwa sub-district lies between 21°58′14″S and 28°25′24″E occupying the northeastern tip of Botswana. The sub-district has an elevation of 590-886m above sea level, making it the lowest part of the country. As such, the area is characterized by a network of drainage channels which drain into the Limpopo River. The sub-district is entirely semi-arid with an average annual rainfall of 300-400 mm making it prone to frequent droughts. Soils are mainly loams to sandy clay loams. Three villages of Gobojango, Mathathane and Tsetsebjwe were chosen for this study from nine rural villages using stratified random sampling. The nine villages were placed in three groups (A: Semolale, Mabolwe, Gobojango; B: Motlhabaneng, Mathathane, Molalatau; C: Tsetsebjwe, Moletemane, Lepokole) to cater for even spatial distribution, as well as their proximity to the confluence of Botswana, Zimbabwe and South Africa national boundaries. The sub-district has been heavily degraded by agricultural activities and is also home to abundant livestock especially cattle (Figure 1).

2.2 Data collection

Qualitative data were collected for this study. Primary data were generated from key informant interviews and participatory mapping exercises which allowed some focussed group discussions. Focussed discussions during participatory mapping exercise provide more insight and deeper understanding of local knowledge about their surrounding

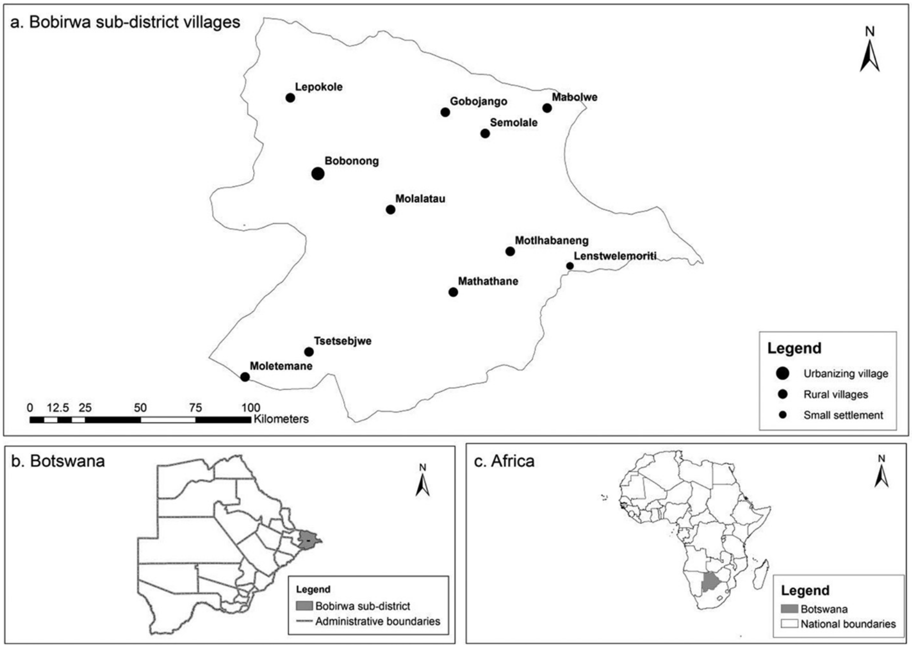


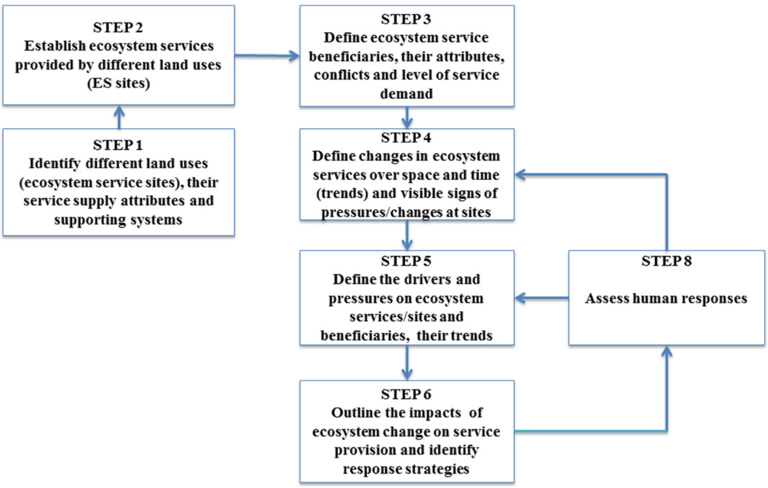
Figure 1.
Location map of the villages in Bobirwa sub-district

environment (Ramirez-Gomez *et al.*, 2015). Previous studies have shown the effectiveness of participatory mapping techniques in capturing community perspectives regarding their natural environment especially in data poor regions (Rambaldi *et al.*, 2006; Gilmore and Young, 2012; Palomo *et al.*, 2014; Ramirez-Gomez *et al.*, 2015). Rapid scoping appraisals at selected LULC types were aimed at verifying ecosystem service locations as well as assessing the effect of drivers of change on ecological conditions hence service provision. A total of eight key informant interviews (seven men and one woman) and six participatory mapping processes (two in each village) were conducted at sub-district level, respectively. Each participatory mapping exercise had between seven and ten participants.

2.2.1 Key informant interviews. Key informants were purposively conducted with personnel and experts from the departments of Crop Production; Animal Production; Forestry, Rangelands and Natural Resources; National Parks and Wildlife; Water Utilities; Sub-land Board; Poverty Eradication Programme; and Social and Community Development at the sub-district. These departments were specifically chosen as they either managed the actual ecosystem services, the areas providing ecosystem services or both. These interviews provided more insight about the study area as well as expert opinion on the availability, use, management, distribution and trends in critical ecosystem services under their jurisdiction considering that local level personnel and experts are in close contact with communities and local realities than those at the national level. Furthermore, these interviews provided background information and later on, provided more insight, explanations as well as validating of the outcomes of the participatory mapping exercises. A key informant interview guide was used to facilitate and focus the interviews. Key informant interviews were therefore critical for informing the organization of the participants of the participatory mapping exercises. These interviews turned out to be critical, as they highlighted some of the actual and potential adaptive responses to the decline in the delivery of local ecosystem services. As such, these interviews provided a useful basis to explore implications for policy and practice regarding the use and management of local provisioning ecosystem services under a changing and variable climate.

2.2.2 Participatory mapping exercises. Participatory mapping (also referred to as community-based mapping) describes all the various methods and techniques that engage local people, in a collaborative manner, to represent their spatial understanding of their surrounding environment (Rambaldi *et al.*, 2006; Sieber, 2006). For this study, the process comprised various age groups of community members in the three study villages who undertook to collaborate with each other in identifying local provisioning ecosystem services, mapping their location (by land-use and/land-cover type), establishing recent trends in their availability, as well as discuss the influence of climate and other drivers of change on the reported trends. Goodchild and Li (2012) and Goodchild (2007) termed this exercise as volunteered geographic information.

Similar to Ramirez-Gomez *et al.* (2015), participants of the participatory mapping exercises were purposively selected on the basis of those who had at least a 10-year experience of harvesting provisioning ecosystem services in and around their community. The participatory mapping exercises and discussions were stratified into young, adults and elderly. These three age groups conveniently comprised social and economic groups of importance to this study, i.e. crop farmers, livestock farmers, hand crafters (basketry), Mopane caterpillar harvesters, firewood/timber harvesters and other non-timber forest product harvesters. The participatory mapping focus processes and discussions were guided by a semi-structured participatory mapping guide prepared for each step of the mapping process so that all the relevant information could be collected. In total, 51 participants (31 females and 20 males) were involved in the mapping exercises (Young = 18 per cent; Adults = 31 per cent; Elderly = 51 per cent). The step-by-step procedure of the participatory mapping process is presented in Figure 2. A rapid scoping appraisal was then conducted to verify and assess some of the LULC types providing local ecosystem services,



Source: Adapted and modified from Rounsevell (2010)

Figure 2.
Participatory mapping of ecosystem services procedure

provisioning ecosystem services and effect of climate and other drivers on ecological conditions (including ecosystem service provision).

The first steps of the participatory mapping process (Steps 1 and 2) produced an inventory of provisioning ecosystem services by land-use and/or land-cover type (sites providing each of the identified ecosystem service). Mapping provisioning ecosystem services by land-use and/or land-cover type allowed verification of ecosystem service sites during the rapid scoping appraisal. It also allowed assessing the effects of climate and human activities on land-use and land-cover and consequently on ecological conditions and ecosystem service delivery in steps 4 and 5. This approach was critical to this study, especially for understanding the impacts and trade-offs as a result of climate-induced and/or anthropogenic changes in the spatial, temporal and seasonal changes in the delivery of local ecosystem services. However, this would require the decoupling of the effects of climate and human activities on the delivery of local ecosystem services (especially through influencing the ecological conditions and/or changing the land-use and/or land cover regimes), i.e. establishing the actual underlying cause of the decline in the delivery of local ecosystem service to understand the influence of climate. This was beyond the scope of this study, as the study relied on the reported perceived effects of climate on the delivery of critical ecosystem services. Steps 4 and 5 were therefore critical for understanding the effect of climate; Step 4 established the trends in the availability of local provisioning ecosystem services, while Step 5 went on to identify the factors driving the reported changes in the respective ecosystem services. The actual ecosystem service beneficiaries identified in Step 3 were very critical during the discussions in providing more insight into the trends as well as factors driving changes in the delivery of local ecosystem services because of their close connection and rich knowledge of the LULC types (locations) providing specific provisioning ecosystem services, as well as changes in availability over time (Rounsevell *et al.*, 2010). The final steps of the participatory mapping process involved discussing the impacts of the reported trends in the delivery of local ecosystem services (Step 6) and the associated responses to both the drivers and the impacts of the recent trends (Step 8).

The participatory mapping exercise methodology conducted in smaller, focussed groups can also be extended to identify areas which have undergone recent changes in land-use and/or land-cover, including even those areas that have been targeted for conservation or ameliorative measures. Such kind of analyses and methodological mixes are critical for facilitating participatory planning and decision-making at the local level with the aid of spatially explicit information (Rambaldi *et al.*, 2006). For this reason, several researchers recognize the benefit of focus group discussions during the participatory mapping exercises. When used as an extension to participatory mapping processes, focus group discussions provide a “methodological mix” that strengthens the drawing of the research conclusions, as well as triangulation, i.e. complementing two or more different methods to answer the same questions.

After the mapping exercise, the focus groups concluded by discussing the management of local resources to understand the implications of climate change and policy on the management regime and access to critical ecosystem services. This discussion, together with the key informant interviews with resource managers, provided information to establish the adaptive capacity of the local communities to climate-induced changes in the delivery of local ecosystem services.

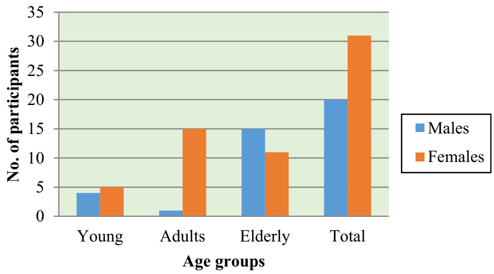
2.3 Data analyses

Textual data generated from the key informant interviews and participatory mapping exercise discussions were coded and analyzed using thematic analysis using NVivo 11, a qualitative data analysis software (Dawson *et al.*, 2015). The coding process involved assigning a short description for classifying responses into different themes which formed the framework for analysis and these were ecosystem service trends, drivers of ecosystem service change, human impacts from ecosystem service changes. Furthermore, trends and drivers of the key ecosystem services and the associated human impacts from their decline were manually coded in Excel to validate the results (Ramirez-Gomez *et al.*, 2015). The identified key provisioning ecosystem services were classified by LULC types from where they were obtained. A table showing seasonal availability of the key ecosystem services for the current and historical time periods (i.e. post-2006 and pre-2006, respectively) was then generated from the discussions.

3. Results and discussion

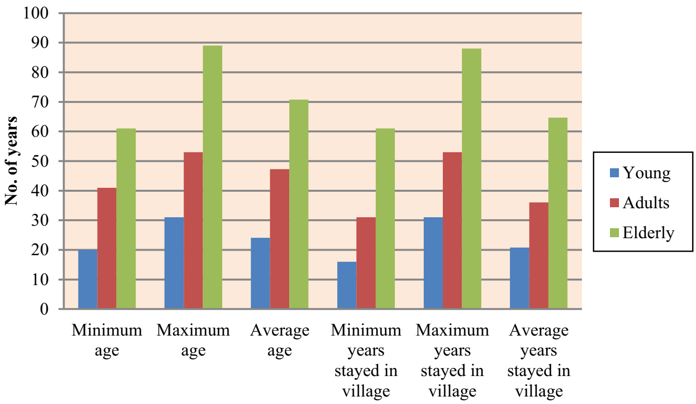
Figure 3 shows the age and gender distribution of the study participants. Elderly participants (>60 years) are shown to be the dominant group, followed by the adults and then the young. A total of 51 individuals participated in the focus group discussions and participatory mapping exercises.

Figure 4 shows the recorded minimum and maximum ages for the young (20-40 years), adults (40-60 years) and elderly (>60 years), as well as the minimum, maximum and average length of stay in the village for the same categories of participants.



Source: Fieldwork (2016)

Figure 3.
Distribution of focus group participants by age group and gender



Source: Fieldwork (2016)

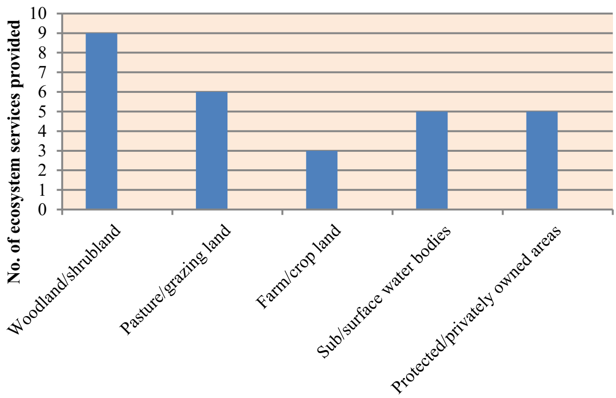
Figure 4.
Age and years stayed in village by participants

The gender, age and length of stay in the village of the study participants play a significant role in understanding the interaction of the local community with the natural environment. Gender is a critical determinant of differentiated participation in different household and livelihood activities which makes it an important factor in climate change adaptation (Katengeza *et al.*, 2012). As such, the differentiated access to local ecosystem services, hence impacts and responses to changes in local ecosystem services, can be influenced and shaped-up by the gender of the beneficiaries. A study by Bidogeza *et al.* (2009) noted that age of the study participants, especially the number of years stayed in the village, is a proxy for experience, risk perception and knowledge of the surrounding landscape; hence, it is an important factor in identifying local ecosystem services, establishing recent trends in availability, as well as the drivers of change, and also comprehending well with the impacts of recent changes.

3.1 Key ecosystem services in Bobirwa Sub-district

Figure 5 shows that, from the ecosystem services list in Table I, woodlands provided the most number of ecosystem services with nine different ecosystem services followed by pasture/grazing land which provided six ecosystem services. Water bodies and protected areas each provided five different ecosystem services, while farmlands provided only three ecosystem services.

To have a complete understanding of ecosystem service provision among local communities, it is critical to establish where they are produced and where they are consumed (Pagella and Sinclair, 2014). As noted by Habib *et al.* (2016), the identification of local ecosystem services by LULC type is critical for demonstrating the impacts of climate as well as human-induced land-use change on the delivery of bundles of ecosystem services they provide. More so, such a design simplifies trade-off analyses on the effects of both climate and human activities on the landscape such that they can be construed at the local level without technical experts. Pagella and Sinclair (2014) note that mapping ecosystem services by the spatial extent of landscape features is an important precursor for establishing both the type and value of the ecosystem services produced. However, the importance of land-use or land-cover type is not determined by the number of ecosystem



Source: Fieldwork (2016)

Figure 5.
Number of ecosystem services provided by different land-use/ land-cover types

Ecosystem service	Description
Firewood (P)	Provision of firewood for cooking and lighting
Edible Mopani caterpillars (P)	Provision of edible Mopani caterpillars *(Imbrasia belina)*
Water for household/ livestock use (P)	Purification, retention, storage and provision of fresh water for household consumption and livestock production
Pastures for livestock (P)	Provision of pastures and forage for livestock production
Fertile soil for cultivating crops (S; R)	Provision of fertile soil for cultivating crops and pastures
Timber/poles (P)	Provision of timber and poles from native woodlands and shrub land
Palm leaves (P)	Provision of palm leaves *(Hyphaene petersiana)* used mainly in basketry making and roofing traditional houses
Wild fruits (P)	Provision of edible wild fruits for human consumption
Game meat (P)	Provision of meat for human consumption
Thatching grass (P)	Provision of grass used in thatching traditional houses
Wind breaking (R)	Reducing the impact of wind on humans, buildings, crops etc.
Fish (P)	Provision of fish for consumption
Preventing livestock from fields (R)	Providing a buffering effect which prevents livestock from going to the fields
Crop residues for feeding livestock (P)	Provision of crop residues after harvesting for livestock feeding
Biodiversity conservation (S)	Capacity of natural landscapes supporting various forms of plant and animal life
Erosion control (R)	Prevention of soil erosion by vegetation on landscape
Place for cattle posts (S)	Capacity to hold/carry livestock and provide a habitat
Reeds (P)	Provision of reeds for basketry making
Sand (P)	Provision of sand for brick moulding and construction

Notes: Letters in parentheses represent Millennium Ecosystem Assessment (2005) categories of ecosystem service: P-Provisioning; R-Regulating; C-Cultural; and S-Supporting

Table I.
Description of ecosystem services in Bobirwa sub-district

services it provides but by the value the local community puts on the bundle of ecosystem services they provide (Ramirez-Gomez *et al.*, 2015). For instance, despite providing several ecosystem services, privately owned farms were reported to be the least important to the local communities as the freehold land tenure arrangement prohibits trespassing, hence accessing ecosystem services from them. More so, these privately owned farms are fenced far away and often have dangerous wild animals. Previous studies have shown that Bobirwa sub-district is a unique region in which conservation in the Tuli Block and human development in the villages have been coexisting and coevolving over many decades (Dube and Sekhwela, 2007; Dube and Sekhwela, 2012; Quintas-Soriano *et al.*, 2016). However, conflicts between human well-being and conservation have generated increasing concern because of the declining delivery of ecosystem services at the traditional sites surrounding the villages (Quintas-Soriano *et al.*, 2016). These conflicts can be explained by similarity in the bundle of ecosystem services provided by communal woodlands and privately owned coupled with a decline in ecosystem service provision in the former.

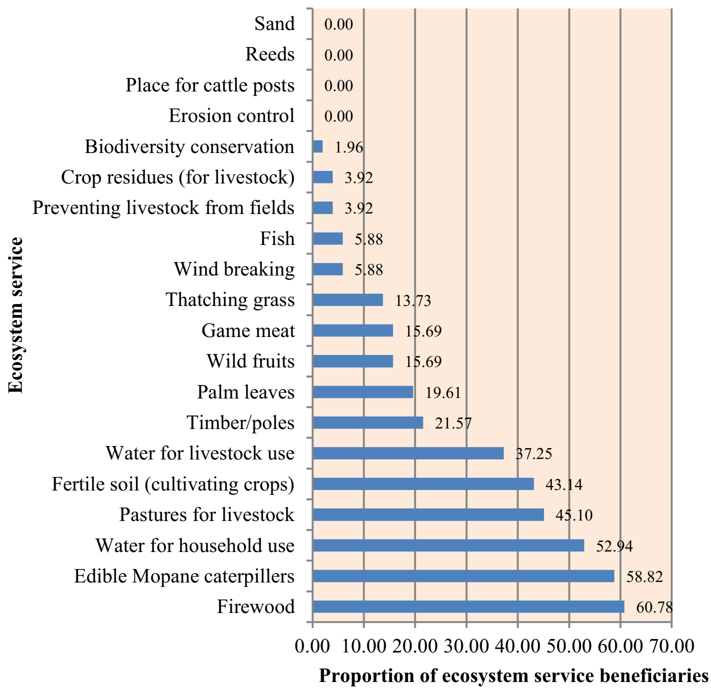
Although the farm lands provide the least number of ecosystem services, this was reported to be the most important land-use type over the years, as it provides food for subsistence purposes for most of the households. However, with the adverse impacts of climate in recent years, the importance of different LULC types to the local communities varies seasonally because of the differential impacts of climate on the landscape.

Figure 6 shows the ecosystem services identified in the study area and how they were ranked in terms of their importance towards household food security and income (Table II).

The ranking of the relative importance of various ecosystem services among the local communities mainly considered the impacts of marginal changes in the delivery of each service on household food security and income as similar to a study by Shelton *et al.* (2001). The focus of the study was however on provisioning ecosystem services. Nonetheless, the ranking process was done individually and not intended to produce a definitive ranking but to establish the highly ranked ecosystem services in the study area.

3.2 Trends in key ecosystem services

Figures 7-10 show the various changes associated with key ecosystem services in Bobirwa sub-district. Figure 7 shows that the majority of the participants perceived a decline in quantity of all the key ecosystem services compared to 10 years ago. Figure 8 also shows that almost all the participants perceived a decline in the condition of sites providing firewood, Mopane caterpillars and natural pastures. More so, Mopane woodlands which are important for the provision of firewood and Mopane caterpillars were reported to be in state of degradation. Figure 9 shows that a remarkable proportion of the participants also perceived an increase in the walking distance from household to sites where they are now obtaining firewood, Mopane caterpillars and pastures for livestock (especially cattle) compared to 10 years ago. However, water for household consumption was reported to be closer while no change was reported for walking distance to access water for livestock and



Source: Fieldwork (2016)

Figure 6. Relative importance ranking of ecosystem services

Table II.
Benefits derived from key ecosystem services in Bobirwa sub-district

Ecosystem services	Actual benefits
Firewood	Main source of energy for cooking; charcoal making; source of income for villagers and outsiders from selling; Mopani tree (*Colophospermum mopane*): produces more energy, lasts longer, produces less smoke than other wood fuels: Leadwood, Knob thorn, Red Bush Willow; cheaper source of energy than electricity, paraffin and gas
Edible Mopani caterpillars (*Imbrasia belina*)	Very nutritious food; rich in protein; selling to cater for other household requirements; sold to livestock farmers in South Africa who make livestock feeds; fetches more on selling than firewood
Water for household/livestock use	Cooking, drinking, bathing, washing and watering community gardens; watering livestock (an important part of livelihoods in Bobirwa); livestock provide draft power especially (cattle) for ploughing; cattle and goats provide milk and meat; livestock sold for income; without water livestock production not possible; important for constructing houses
Pastures for livestock	Natural pastures for feeding cattle, goats, sheep and donkeys (rainy season); main source of livestock feed; making drought reserves (for dry season); Pasture lands separate grazing land and fields (prevent livestock from destroying field crops); livestock important for many households in the villages e.g. paying schools fees; paying bride price; livestock production possible with rotational grazing in some places
Fertile soil for cultivating crops	Growing crops like maize, water melons, beans, groundnuts, millet, sorghum, squash, pumpkin for household consumption selling some for income; growing lablab (*Lablab purpureus*) for livestock to supplement natural pastures in dry season; crop residues fed to livestock after harvesting and in the dry season

Source: Fieldwork (2016)

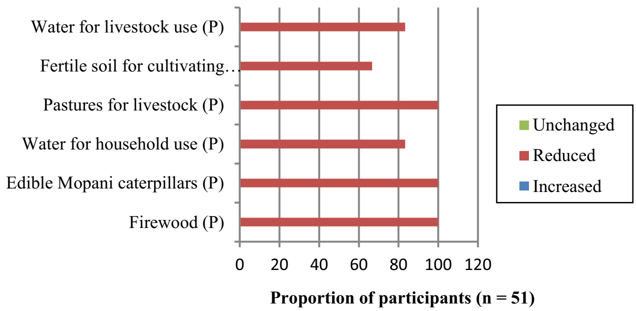
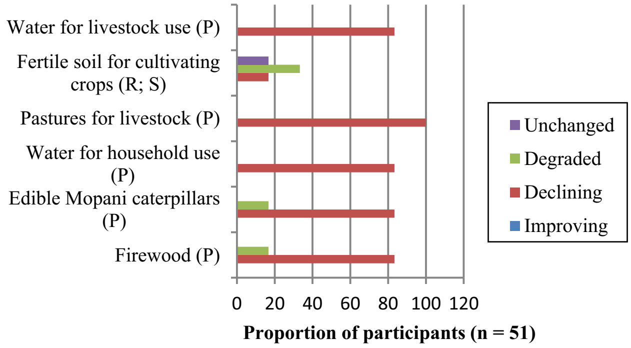


Figure 7.
Changes in seasonal quantities of key ecosystem services

Source: Fieldwork (2016)

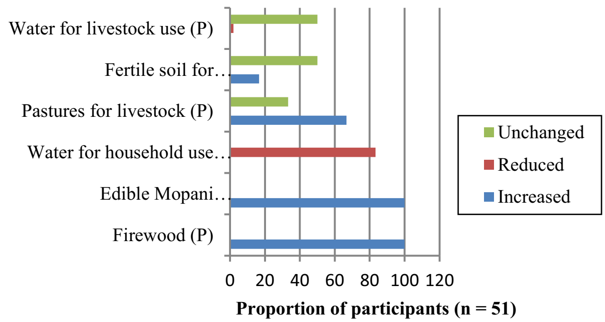
fields compared to a decade ago. All the participants concurred that the distance to water for household consumption had reduced compared to the past 10 years. This is because of most households being connected with a standpipe for water albeit a decline in water quantity.

Figure 10 shows that a decline was perceived in total area providing firewood, edible Mopani caterpillars and pastures for livestock. Water sources for both livestock and humans were perceived either to have increased or unchanged.



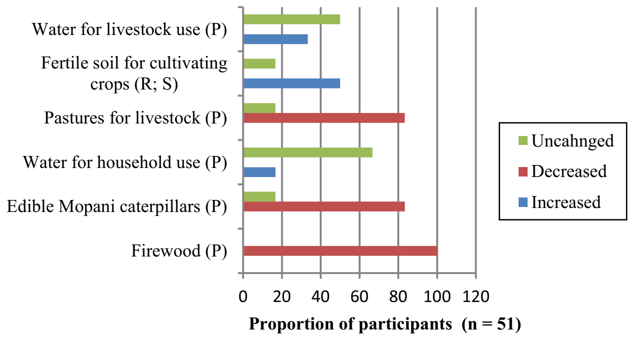
Source: Fieldwork (2016)

Figure 8.
Changes in condition of sites providing key ecosystem services



Source: Fieldwork (2016)

Figure 9.
Changes in distance from household to sites providing key ecosystem services



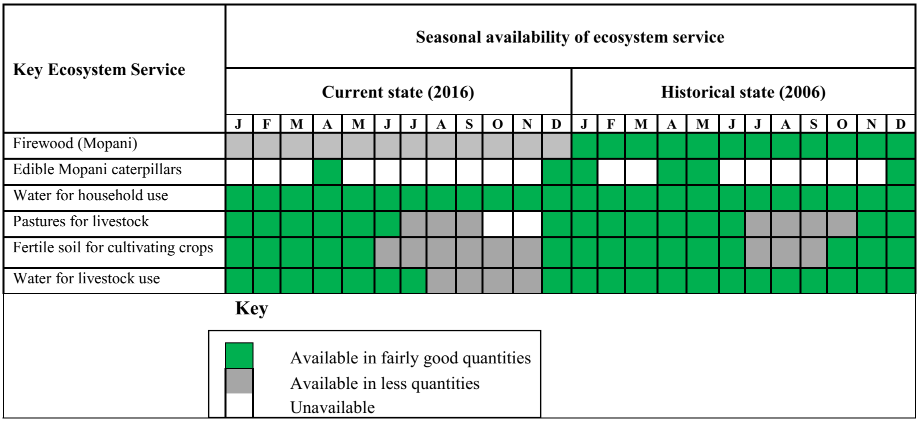
Source: Fieldwork (2016)

Figure 10.
Changes in total area of sites providing key ecosystem services

Figure 11 shows seasonal availability of key ecosystem services in 2016 as compared to 2006. Although firewood is shown to be currently available throughout the year, the quantity was reported to be lower compared to 2006.

Results for the trend analyses revealed the perceived changes in quantity, walking distance to the sites, condition of sites and total area providing the service, as well as seasonality of several key provisioning ecosystem services between 2006 and 2016. The reported decline in quantity of these key provisioning ecosystem services, an increase in walking distance and time to collect similar or less quantities of the resources characterized by a decline in total area and condition of some LULC types between 2006 and 2016 is similar to findings from previous studies (SafMA, 2004; Ramirez-Gomez *et al.*, 2015; Palomo *et al.*, 2014). Several studies have highlighted the how such changes in the delivery of local ecosystem services have adverse impacts on human well-being. Declining availability of critical ecosystem services for human well-being has also been reported in the Southern Africa Millennium Ecosystem Assessment report (SafMA, 2004), the Adaptation at Scale in Semi-Arid Regions (ASSAR) Southern African Region Diagnostic study (Spear *et al.*, 2015) and the Vulnerability and Risk Assessment study (Masundire *et al.*, 2016). In all these studies, the main highlight was that climate change burden interacts with other non-climatic drivers to further constrain the ecosystem-based livelihood options leaving those highly dependent on the natural environment even more vulnerable. The reduction in walking distance to access water for household consumption can be ascribed to the Government of Botswana prioritizing the provision of safe drinking water since the early years of independence. In this regard, the 2011 Census selected indicators report that access to piped or tapped water in the sub-district was at 73.7 per cent of the total households (Statistics, 2015).

The study findings suggest that the decline in the delivery of key provisioning ecosystem services such as firewood, Mopane caterpillars, pastures for livestock, cultivated crop yields and water for human and livestock consumption may be leading to significant changes in household income and food security. Such negative impacts on local livelihoods were also noted in a study by Ramirez-Gomez *et al.* (2015) who found that declining provisioning ecosystem services was causing acute changes in incomes of the indigenous



Source: Fieldwork (2016)

Figure 11.
Perceptions on seasonal availability of key ecosystem services

people. Ramirez-Gomez *et al.* also noted that such changes in economic needs of local people led to unsustainable ways of harvesting while the need for better incomes because of changing lifestyles resulted in overexploitation of these natural resources.

3.3 Drivers of changes in key ecosystem services

3.3.1 Firewood. The main cause of decline in firewood quantities was cited as the excessive harvesting especially of Mopane trees (*Colophospermum mopane*) which is the favoured option by many households. As noted by Dube *et al.* (2014), Mopane firewood is especially desired for producing more energy and lasting longer compared to other wood fuels. Lack of cheaper alternative sources of energy has also resulted in most households using firewood for cooking. The Bobirwa sub-district population and housing census report for 2011 shows that wood is by far the most used source of energy with 69.3 and 87.6 per cent of the households using firewood for cooking and heating, respectively (Statistics, 2015). The available alternatives to wood fuel such as electricity and liquid petroleum gas which were used by 19 per cent of the total households were reported to be more expensive compared to firewood (Statistics, 2015). Despite being connected to the electricity grid, more than 80 per cent of the households in Sub-Saharan Africa's rural areas use biomass fuels for cooking (Statistics, 2015). Many households in the study villages have as such increased their demand for, and dependence on, firewood especially from Mopane tree because of lack of cheaper alternatives and this threatens the future availability of desired wood fuels (Dube *et al.*, 2014). Considering the projected growth in population of about 5.73 per cent between 2011 and 2026 in the sub-district (Statistics, 2015) the demand for firewood may far exceed the capacity of local woodlands leading to deforestation, land degradation and desertification. Besides household use, a boarding school in the study area was also identified as an excessive single user of wood fuel, particularly from Mopane woodlands. More so, an increasing number of people, especially from outside the study villages, were reported to be harvesting truckloads of firewood for commercial purposes such as selling wood fuel, making charcoal and even exporting to South Africa for processing into charcoal. The commercialization of Mopane wood fuel has negative implications on the sustainability of Mopane woodlands especially considering that those who harvest it for commercial purposes often cut down live trees because of scarcity of dead wood. Such commercialization of natural resources was also noted to by Ramirez-Gomez *et al.* (2015) to have intensified the exploitation of natural resources. Palomo *et al.* (2014) further noted that the restricted access to local ecosystem services, in this case on the privately owned farms, also results in overexploitation on the historical sites. As such, people end up even resorting to cutting down live trees because of high demand for firewood, as well as desire for more income and better lifestyles. Furthermore, the observed decline in Mopane woodlands as a result of deforestation was also reported to have serious trade-offs with the provision of other important ecosystem services such as Mopane caterpillars, air regulation, erosion control and water regulation (Dube and Sekhwela, 2007).

Another reason identified for the declining quantity of firewood was the illegal occupation and clearing of land for ploughing crops in some parts of the sub-district. The clearing of previously forested areas (sites providing firewood) into ploughing fields reduces the area providing firewood, i.e. clearing of land by new, legal and illegal, farm owners reduces size of forested areas especially the Mopane woodlands. More frequent droughts in recent years have also been cited as leading to natural death of trees which causes remarkable degradation, deforestation and intensifying desertification. Droughts have also constrained rain-fed agriculture and productivity of other weather-dependent livelihood options resulting in some people harvesting firewood for selling (Smith, 2010). Very cheap permits to harvest firewood for commercial purposes were noted to be failing to limit unsustainable harvesting; instead, they have increased the number of harvesters. This can be explained by inadequate monitoring mechanisms as well as lack of capacity and resources by the Department of Forestry and Rangeland Resources as noted by the many people either using expired permits or not using them at all to access firewood for selling.

3.3.2 Edible mopane caterpillars. The rampant cutting down of Mopane trees (*Colophospermum mopane*) for firewood and clearing forested land for growing crops was observed to be reducing the total area of Mopane woodlands which are hosts for Mopane caterpillars (*Imbrasia belina*). Participants reported that the recent frequent rainfall extremes (excessive droughts and floods), highly variable and unreliable rainfall onset was also adversely affecting the breeding, quantity and quality of Mopane caterpillars compared to a decade ago. Consequently, the breeding season for Mopane caterpillars becomes shortened by the late and unreliable rainfall. The sensitivity of ecosystem services closely-linked to vegetation to adverse climate have been widely reported (SafMA, 2004; Paudyal *et al.*, 2015; King, 2002). With Botswana being among the first countries projected to surpass the 1.5°C average rise in global temperature above pre-industrial levels (Schleussner *et al.*, 2016), coupled with more erratic and extreme rainfall events, the future availability of Mopane caterpillars, including many other vegetation based ecosystem services, is greatly threatened. More so, some eggs get eaten by birds before favourable conditions for hatching (after the rains) thus further reducing the quantity of the edible caterpillar. Flash floods in recent seasons have also been cited as interfering with the breeding of Mopane caterpillars leading to a decline in quantities as was also noted by Dube and Sekhwela (2007).

Unsustainable harvesting was also reported to be leaving less breeding stock for the following seasons as similar to findings by Edward *et al.* (2015), Shackleton *et al.* (2008), and Thomas (2013) However, non-residents to the study area have mostly been blamed for the unsustainable harvesting since they only care about maximizing their harvest. Ramirez-Gomez *et al.* (2015) noted that the shift from traditional ways of harvesting local resources to more unsustainable ways which maximizes economic benefits was leading to overexploitation of important resources and even threatened their future supply. Considering that subsequent breeding cycles of Mopani caterpillars depend, to a large extent, on the quantity of caterpillars left to complete the life cycle in the harvesting season, overharvesting thus can significantly reduce availability of Mopane caterpillars. However, the extent to which overharvesting of the caterpillars is a problem needs to be further explored. The conversion of Mopane woodlands into ploughing fields through legal and/or illegal land occupation was also cited to be reducing the total area providing the edible caterpillars through destroying the host trees. Illegal occupation and clearing of land for cultivating crops has been reported around Tsetsebjwe village and cattle posts. The clearing of Mopane woodlands thus reduces the host for the caterpillars, therefore resulting in reduced quantities. Once the clearing of Mopane woodlands continues unabated, there are higher chances that the availability of this most important source of livelihood will continue to decline (Dube *et al.*, 2014).

Increasing number of Mopane caterpillar harvesters has also been reported each year especially as a result of the influx of people from other villages, sub-districts or even across the national border, e.g. Kanye, Maun and across the Zimbabwe border. Besides putting pressure on the Mopane caterpillars and reducing their availability to the local villagers, chances of unsustainable harvesting are also very high which is in line with findings by

Dube and Sekhwela (2007). The expansion of markets beyond the local communities was resulting in overexploitation of Mopane caterpillars on the one hand. The nutritive content of the Mopane caterpillars for both human consumption and livestock feeds on the other hand was also reported to be responsible for the influx of Mopane caterpillar harvesters similar to findings by Ramirez-Gomez *et al.* (2015). Furthermore, as a consequence of the very affordable harvesting permits from the Department of Forestry and Rangeland Resources which can be obtained by any citizen of Botswana, people from different parts of Botswana visit the study area to harvest the edible caterpillars. From one of the key informant interviews and participatory mapping discussions, it was discovered that such permits are usually issued to an unlimited number of people (especially non-residents to the study area) and also without considering the potential supply in that particular season (or even previous seasons), thus leading to congestion and unsustainable harvesting. Considering those harvesters who travel from far-off places and usually incur transport costs, maximizing their harvest to recover transport costs normally leads to unsustainable harvesting. In a way, the very cheap harvesting permits have led to an increase in demand for Mopane caterpillars in the sub-district albeit with negative implications on future availability.

3.3.3 Water for household and livestock consumption (P). As one of the most critical ecosystem services to both humans and livestock, water availability in the sub-district has been reported to be declining. With high dependence on the underground water system, the water situation in the sub-district often has periods of critically low supply. Low rainfall and even more frequent droughts have been identified as the main cause of declining quantities of underground water during the dry season especially between August and November. Considering that all the rivers in the study area are ephemeral, coupled with damming of rivers up stream of major rivers, the surface water flow has been greatly reduced in the sub-district. Surface water resources are the main source of water for urban areas some of which are located around the study area. For instance, the damming of Motloutse River upstream of Bobirwa sub-district at Letsibogo Dam which supplies urban water through the famous North-South Water Career is one example of the reasons for the declining of underground water recharge in the study area catchment. As the ground water resource becomes very limited, the resource is likely to become more finite and non-renewable (Central Statistics Office, 2009) partly because of projected more infrequent and extreme rainfall events which may not allow meaningful ground recharge (Schleussner *et al.*, 2016). Boreholes supplying households with water as well as wells at the cattle posts have been reported to yield lower water compared to a decade ago. While this can be ascribed to low rainfall which fails to recharge and sustain the underground water system, the very high temperatures experienced in recent years may also be leading to more water loss through evaporation especially during the summer months (Smith, 2010; UNEP, 2009). Although the construction of Thune Dam along Thune River has increased the size of water sources, the sub-district is yet to fully benefit from the land-use change considering it has also disadvantaged the downstream communities. Whether the Thune Dam water reticulation project is a response to community water demands or it had been on the plans of the Water Utilities Corporation, it is anticipated that the dam will help alleviate the current water scarcity by capturing surface run-off which would otherwise ultimately run-off to the Limpopo River. Previously, Thune River and several other rivers in the study area have all been draining into Limpopo River which is not accessible to local communities, as it constitutes the national boundary with South Africa and Zimbabwe (Central Statistics Office, 2009). As already highlighted, population growth within the villages has also been identified as another cause for the increased demand for water, further putting pressure on water availability. Recently, as a result of growing human and livestock population, a further strain is exerted on the scarce water resource, i.e. livestock are increasing with human population leading to increased demand for water. Accelerating population growth has been identified as a threat to the sustainable delivery of local ecosystem services (Perrings, 2010; Chidumayo and Gumbo, 2010; Nelson *et al.*, 2013; Serdeczny *et al.*, 2016). More so, the rising temperatures may also be increasing water consumption by both humans and livestock (Engelbrecht *et al.*, 2015). This is especially so during the summer months between August and November.

3.3.4 Pastures for livestock (P). Very little, unreliable and very late rainfall was identified to be critically delaying re-growth of pastures and vegetation in recent years leading to poor pastures. Several study participants noted that more frequent droughts (at times lasting for three consecutive years) and high temperatures were continuously reducing the productivity (condition and quantity) of pastureland. For instance, a decade ago, the onset of rains was reported to be around November, but in recent years, there are no meaningful rains till late December as also noted by UNEP (2003). Another driving force of declining availability and quantity of pastures identified by the study participants was village expansion because of population growth, as well as increased demand for ploughing fields. These were reported to be taking up grazing areas and woodlands, thus leading to reduced total area for grazing pastures as compared to a decade ago. A major concern was the new farm allocations by the Land Board of 4-16 ha (integrated farms) per individual. Although the new farm owners would be able to graze their livestock, other villagers would likely have their traditional grazing areas and woodlands not only reduced but also experience excessive grazing. This is further worsened by the poor conditions of pastureland in the study area because of semi-arid conditions coupled with high livestock populations. The increased number of cattle posts also means increased pressure on the already declining pastureland. Palomo *et al.* (2013) also found land-use change characterized by an increase in settled area, crop fields, open spaces as well as a decline in shrub lands and grasslands. Considering that livestock production, especially cattle, is one of the main livelihood strategies in the study area, unchecked decline in natural pastures threatens an important livelihood strategy and option for coping with declining crop productivity. The large numbers of cattle in the study area imply more pressure on the already constrained capacity of natural pastures. The prevalence of the Foot and Mouth Disease (FMD) and the demarcation of the sub-district as an FMD red zone also means that cattle owners cannot easily sell to outside markets (Dube and Sekhwela, 2007). This could result in overgrazing, degradation and desertification if the livestock populations exceed the carrying capacity of the natural environment.

3.3.5 Fertile soil for cultivating crops (R; S). Very low and delayed rainfall was also reported to be reducing crop yields and productivity of cultivated land. More frequent and intense droughts and floods in recent years were also reported to perennially reduce the yield potential of farmlands. Extremely high temperatures and the heat waves in the past few years have also been reported to scorch crops such as maize leading to poor or no harvests at all (Daron, 2014; Masundire *et al.*, 2016). With the projected increase in average global temperatures above the 1.5°C of pre-industrial levels expected to hit Botswana much earlier than any other countries, the effect of hot temperatures on crops are expected to increase. Another reported cause for the declining productivity of croplands in the sub-district was theft of draft animals (cattle and donkeys) especially across the Zimbabwe border. This was noted to significantly reduce draft power availability hence delayed land preparations and ploughing. The new farm allocations on areas which used to be woodland or pasture land were observed to have increased the total area providing fertile soils around many villages. However, in some villages such as Tsetsebjwe, the farming area cannot expand because of the physical limitations imposed by drift fences separating pastureland (cattle posts) and arable farms. As such, the increasing demand for ploughing fields in such areas has seen people being allocated farms outside their villages with some, for instance, staying in Tsetsebjwe but with farm lands as far as Molalatau, Mathathane, Sefophe and Bobonong. The increased distance to farmlands was also likely to reduce productivity of farmlands.

The direct and indirect drivers of change of the delivery of each of the critical provisioning ecosystem services in semi-arid Bobirwa presented above highlight the interaction between the adverse impacts of climate change and anthropogenic pressure in the past decade. As climate is a critical determinant of net primary productivity, continuous adverse climate change and extreme weather events further reduce the capacity of ecological systems by limiting ecological functions. The Regional Diagnostic Study for Southern Africa on vulnerability and adaptation to climate change in the semi-arid regions of Southern Africa (Spear *et al.*, 2015) and the Vulnerability and Risk Assessment in Botswana's Bobirwa sub-district (Masundire *et al.*, 2016) reports have also highlighted how climate change has had additional limits on livelihood options of those living in semi-arid regions and relying on the natural environment.

Nonetheless, the adverse changes in climate, coupled with human pressure, are gradually leading to loss of traditional ecosystem service sites through changes in LULC as well as loss of ecosystem integrity (Leroux *et al.*, 2017; Reyer *et al.*, 2017). As such, ecosystem functions become impaired because of gradual decline in ecological conditions hence reduced delivery of these important ecosystem services. The most immediate outcome will be reduced access to local ecosystem services which may lead to conflicts among ecosystem service beneficiaries (Rambaldi *et al.*, 2006). Consequently, the declining availability of local ecosystem services further constrain local livelihoods hence well-being. Considering that the provisioning ecosystem services identified in the study area are sensitive to climate, especially rainfall, any further adverse climate will result in further decline in the delivery of these ecosystem services although the link between climate and delivery of ecosystem services need to be further investigated with empirical data.

3.4 Conclusion

Local provisioning ecosystem services such as edible Mopane caterpillars, firewood, wild fruits, natural pastures, cultivated crops from fertile soils and water for household and livestock consumption have a great significance for marginalized communities, as they are a critical component of their livelihoods and economy. Results of this study highlight remarkable adverse changes in the quantity, condition and size of ecosystem service sites, walking distance and seasonal availability of several ecosystem services. The perceived adverse changes were reported to be mainly driven by adverse weather conditions, more frequent droughts, unsustainable harvesting and land-use change. The declining delivery of local provisioning services was shown to have negative effects on livelihoods and well-being of the local community as well as highlighting the limit of the ecological system. Whereas ecosystem services provide a pathway to effective climate change adaptation in some semi-arid communities, local livelihoods were shown to be increasingly exposed and more vulnerable to the recent decline in the delivery of these critical ecosystem services.

As the adverse impacts of climate change and anthropogenic pressure on local ecosystems intensify and continue to threaten the delivery of critical ecosystem services in data-poor, semi-arid communities, there is urgent need for alternative information to inform decisions. Decision makers need to optimize decisions as informed by outputs from both qualitative and quantitative studies as well as using both indigenous and scientific knowledge. Local knowledge about the condition, trends and drivers of ecosystem change equally provides critical information for decision-making. The study has shown that participatory mapping processes allow marginalized rural communities to collaborate in identifying key local provisioning ecosystem services, important land-use and/or land cover types providing them, recent trends as well as their causes. Such processes provide critical baseline information in data-poor regions which can facilitate informed, relevant and timeous decision-making regarding the management of local ecosystem services which can improve the adaptive capacity of both social and ecological systems. More so, such information provides a basis for further analyses using freely available remotely sensed data. Making such information on participatory assessments of local ecosystem services readily available, and with the aid of non-participatory assessments using freely available remotely sensed data, can significantly improve the adaptive capacity of marginalized communities to sustainably utilize local ecosystem services. Although participatory mapping processes are relatively simple and inexpensive to organize, they provide rich spatial and temporal knowledge about the local communities which can be critical for management of local resources. However, participatory methods can be more effective when used in combination with quantitative techniques such as from remote sensing which have more inference power. While participatory mapping is the first step for assessing the delivery of local ecosystem services in our study area, further analyses using freely available, remotely sensed data are required to authenticate and improve the quality of these findings.

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