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Assessment of ecosystem services and benefits in village landscapes – A case study from Burkina Faso

Hanna Sinare*, Line J. Gordon, Elin Enfors Kautsky

Stockholm Resilience Centre, Stockholm University, SE-106 91 Stockholm, Sweden

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ABSTRACT

Most methods to assess ecosystem services have been developed on large scales and depend on secondary data. Such data is scarce in rural areas with widespread poverty. Nevertheless, the population in these areas strongly depends on local ecosystem services for their livelihoods. These regions are in focus for substantial landscape investments that aim to alleviate poverty, but current methods fail to capture the vast range of ecosystem services supporting livelihoods, and can therefore not properly assess potential trade-offs and synergies among services that might arise from the interventions. We present a new method for classifying village landscapes into social-ecological patches (landscape units corresponding to local landscape perceptions), and for assessing provisioning ecosystem services and benefits to livelihoods from these patches. We apply the method, which include a range of participatory activities and satellite image analysis, in six villages across two regions in Burkina Faso. The results show significant and diverse contributions to livelihoods from six out of seven social-ecological patches. The results also show how provisioning ecosystem services, primarily used for subsistence, become more important sources of income during years when crops fail. The method is useful in many data poor regions, and the patch-approach allows for extrapolation across larger spatial scales with similar social-ecological systems.

1. Introduction

The majority of the world's poor depend on their surrounding landscapes for multiple ecosystem services that underpin their livelihoods (WRI et al., 2005). Seventy percent of the 1.4 billion people living on less than US$ 1.25 a day live in rural areas where agriculture is a major livelihood activity (IFAD and UNEP, 2013), and where the majority only has access to small (< 2 ha) areas of agricultural land (World Bank, 2007). Substantial investments are currently being made in agriculture to reduce the large yield gaps (see e.g. Dzanku et al., 2015) that exist across smallholder systems with the intention to increase food security and reduce poverty. In order to obtain sustainable poverty alleviation and food security, it is important to ensure that these investments are done without unintentional trade-offs with other ecosystem services on which the population also depends. Spatially explicit tools that identify, map, and model ecosystem services in response to different investments are therefore becoming increasingly important for decision makers and land use planners (Burkhard et al., 2013; Crossman et al., 2013). These tools can help facilitate the design and targeting of interventions aimed at improving agriculture and alleviating rural poverty, and explicitly deal with ecosystem service trade-offs resulting from different policy and management changes.

Several reviews on spatial analyses of ecosystem services (e.g. Crossman et al., 2013; Egoh et al., 2012; Malinga et al., 2015; Martínez-Harms and Balvanera, 2012) have highlighted that these analyses have so far focused mainly on regulating services and have used secondary data (e.g. land cover maps and global or national databases) rather than field data. Using secondary data requires substantial amounts of available input data, which seldom exist in poor and marginalized areas where people depend heavily on ecosystems for their livelihoods (Ramirez-Gomez et al., 2015; Vrebos et al., 2014). Most mapping studies of ecosystem services have been done on large spatial scales (regional, provincial, and national), with only a very few studies comparable to the size of a village (Malinga et al., 2015; Martínez-Harms and Balvanera, 2012). The data used for mapping at large spatial scales often has a relatively low spatial resolution. Ecosystem services estimations vary substantially depending on the resolution of the spatial input data (Grêt-Regamey et al., 2014; Kandziora et al., 2013). Current ecosystem services assessments can thus cause misleading estimates of the provisioning ecosystem services generated and used on a very local scale, and more village level studies are needed to

* Corresponding author.
E-mail address: hanna.sinare@su.se (H. Sinare).

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increase the spatial resolution of data.

Methodologies for studies on ecosystem services across units relevant to local stakeholders are scarce (Potschin and Haines-Young, 2013), although there are several recent studies that address this gap. These studies have used questionnaire surveys (Abram et al., 2014) and different combinations of semi-structured interviews, focus group discussions, transect walks and participatory mapping (Fagerholm et al., 2012; Paudyal et al., 2015; Ramirez-Gomez et al., 2015), sometimes combined with expert opinions (van Oort et al., 2014), to assess ecosystem services of value for local populations. These combinations of participatory methods are important contributions to ecosystem services assessments. However, there is still a gap between location specific assessments, including local knowledge, and scales at which land use planning and development interventions operate. This is partly because ecosystem services are not related to particular landscape units, which would allow for the extrapolation of results to larger areas with similar landscape configuration and socio-economic conditions. Another aspect seldom addressed in ecosystem services assessments is the role of temporal and spatial heterogeneity for the generation of services (Verburg et al., 2009). If this heterogeneity is masked behind a single land cover or land use when mapping, the full function of the landscape cannot be assessed. This is particularly important in regions with integrated crop-livestock systems and where high rainfall variability results in highly variable landscape productivity and ecosystem services generation across space and time.

One such region is the West African Sahel. Although there is a diversification of livelihood strategies in the region (see e.g. Nielsen and Reenberg, 2010), the population here depends heavily on provisioning ecosystem services from the local landscape for their livelihoods, with 68% of revenues coming from livestock and crop production and 45% of food sources coming from subsistence activities (INSD, 2003). Current production systems have very low yields (300–1000 kg/ha; FAO, 2014) and experience a high probability of yield reductions due to the high rainfall variability (Lemoalle and de Condappa, 2010). The majority, 74–92%, of the population suffers from multidimensional poverty with deprivations that include a combination of health, education and standard of living indicators (UNDP, 2013).

Studies from a range of fields have demonstrated the many ways in which Sahelian smallholders rely on their local landscapes; however, no study has linked landscape pattern to the generation of provisioning ecosystem services in a comprehensive way. Studies within the *terroir*-school, for example, offer detailed descriptions of natural and anthropogenic features as well as management in the rural landscape (see e.g. Kohler, 1971; Marchal, 1983), but they do not provide an overview of resource use from different landscape units. In the ethnobotanical literature, ecosystem services such as nutritional and medicinal use of fruits and leaves and, to some extent, the use of firewood and construction materials, are emphasized (see e.g. Belem et al., 1996; Lykke et al., 2004; Zizka et al., 2015). However, this literature does not give a spatially explicit understanding of where in the landscape they are harvested, making it difficult to attribute these services to specific land units. Similarly, agroforestry literature on, for example, Sahelian parklands (crop fields with scattered trees) provides an understanding of the multiple contributions to livelihoods that come from parkland trees (see e.g. Gustad et al., 2004; Faye et al., 2010). However, this is limited to the consideration of only one land unit, i.e. fields with trees (with one exception in Gakou et al., 1994), which makes it difficult to understand the relative contribution to livelihoods of these parklands compared to e.g. shrublands that co-exist in the landscape.

Our study addresses the need for a more nuanced understanding of the multi-facetted dependence that people have on their local landscapes in order to guide management and interventions. One key challenge is to map landscape units relevant for local people that include local knowledge of priority ecosystem services, and then up-scaling to a scale that can be used in development interventions without loss of relevance for the local people. This issue is particularly pressing in areas such as the West African Sahel, where it is needed to guide much-needed investments in agriculture and poverty alleviation in a context where secondary data is scarce, dependence on local provisioning ecosystem services is high, and climate change is expected to make the generation of ecosystem services more unpredictable. This paper is a first step in addressing this need. Its focus and novelty is in tracking the contribution of locally relevant landscape units to multiple ecosystem services, analyzing how these ecosystem services translate into different livelihood benefits, and studying how these flows vary with inter-annual differences in rainfall. We specifically address the following questions: (i) What are the different units in village landscapes (the land belonging to a village as defined by the villagers) that are relevant to local people? (ii) Which set of ecosystem services is generated in each of these units? (iii) What benefits do these services contribute to livelihoods, and how do benefits for livelihoods change under different rainfall conditions?

2. Methods

The fieldwork was carried out in six villages, located in the Nord and Centre-Nord administrative regions of Burkina Faso (Fig. 1). These regions are interesting areas for ecosystem services research for at least two reasons. First, they have for several decades been focal areas for interventions aiming to combat land degradation and improve landscape productivity (Reij et al., 2005; Stith et al., 2016). Second, while remote sensing studies show that vegetation has increased across parts of the Sahel over the past 30 years, rainfall alone cannot explain the increase in vegetation in these two regions (Herrmann et al., 2005; Stith et al., 2016). This suggests that management practices may have played an important role in changing the landscape, possibly also impacting the generation of ecosystem services.

We chose the village landscape as our focal spatial scale, which is a relevant scale since almost all land in the regions belongs to villages, hence the landscape units found in villages are the main units that can be found across the regions. We introduced the concept of social-ecological patches to characterize the landscape and use it as a unit for ecosystem services assessment. Social-ecological patches are landscape units (subunits of the village landscape) that correspond with the words that local people use when describing their landscapes, characterized by a combination of land use, land cover and topography. The social-ecological patch concept is a way to spatially describe land systems that generate multiple ecosystem services (Verburg et al., 2009). The social-ecological patch concept is different from other landscape classifications commonly used in ecosystem services assessments as it takes into account social-ecological interactions, acknowledges seasonal change in how the unit is used, and is not defined by the conditions for generation of individual ecosystem services, which allows us to attribute sets of ecosystem services to each patch (Table 1). This provides opportunities to scale up results from villages to municipalities or provinces with similar social-ecological conditions.

We defined ecosystem services as co-produced in social-ecological landscapes (sec. Reyers et al., 2013) meaning that they are shaped by geobiophysical and social processes. We separated between ecosystem services and benefits from these services (as in for example Fig 2. in de Groot et al., 2010). For example, production of shea

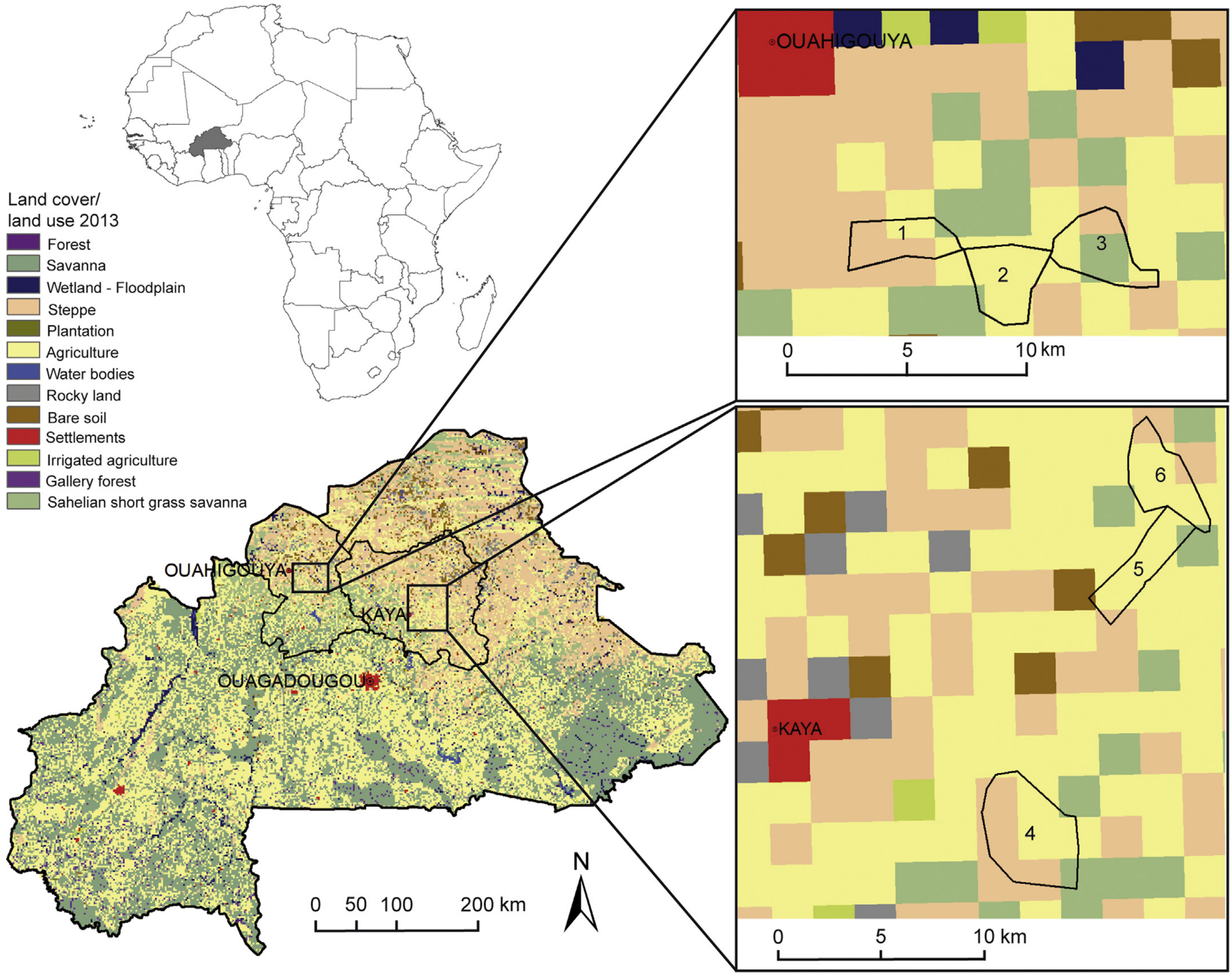


Fig. 1. Location of field sites in the regions Nord (including the town Ouahigouya) and Centre-Nord (including the town Kaya) in northern Burkina Faso, West Africa: (1) Boursouma, (2) Oula, (3) Reko, (4) Lebda, (5) Koalma, and (6) Zarin. Background: Land cover/land use 2013, courtesy of U.S Geological Survey, West Africa Land use Dynamics Project.

(*Vitellaria paradoxa*) fruits is a service, whereas the benefit could be either nutritional value from direct consumption or cash income from selling the fruits. While acknowledging the key importance of regulating and cultural ecosystem services for sustaining landscape productivity, regulation of extreme events, and well-being, this study focused on provisioning ecosystem services as the population has a high direct dependency on provisioning services that can be translated to direct livelihood benefits.

2.1. *Study sites*

We selected six villages (Fig. 1) representative for the conditions of the majority of the population in the study regions. The villages are not located in immediate proximity of major towns or main national roads, and had a population of between 500 and 1500 people in the 2005 census (Burkina Faso, 2005; Table 2), where the median population of all villages in the regions Nord and Centre-Nord was 895 inhabitants (Burkina Faso, 2005). The villages are located within the Sudano-Sahelian agro-ecological zone in an area with a similar rainfall (close to the 600 mm per year isohyet 1960–1986; DEP, 1993) and land cover (savanna-steppe-agriculture mosaic).

2.2. *Research process*

We collected data during four field periods: 1) September–November 2011 (major data collection), 2) July–August 2012 (complementary data collection), 3) October–November 2012 (major data collection), and 4) January 2016 (reporting back and feedback). A range of methods were combined to obtain a spatially explicit understanding of how the entire village landscape, with different social-ecological patches, contributes to livelihoods and to understand the role of the local landscape in compensation strategies for crop loss during dry years (Fig. 2). An important step in the process was to identify social-ecological patches that make sense in relation to how the local population sees the landscape, and to identify provisioning ecosystem services that are key for local livelihoods. Most of the research was participatory, requiring the active interest and engagement of the people who lived there. In each of the six villages, before starting the actual research, we therefore contacted a representative from the elected "conseil villageois de développement" (CVD), a structure present in all villages in Burkina Faso that is responsible for local development (Burkina Faso, 2007). This person helped us to organize a public information meeting where we presented the planned research

Table 1
Comparison between social-ecological patches and other land classifications commonly used in ecosystem services (ES) assessments.

Concept	Definition	Social-ecological interactions	Seasonal change/events	Unit defined by conditions for generation of individual ES
Land cover	The observed (bio)physical cover on the earth's surface (Gregorio and Jansen, 2000)	No	No	No
Land use	The arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (Gregorio and Jansen, 2000)	Yes	No	No
Service providing unit	Population category (Luck et al., 2003) or collection of organisms (Burkhard et al., 2009) or smallest distinct physical unit (Andersson et al., 2015) providing an ecosystem service.	Yes (Andersson et al., 2015)	Yes (Andersson et al., 2015)	Yes
Social-ecological patch	Landscape units that correspond with the words that local people use when describing their landscapes, characterized by a combination of land use, land cover and topography	Yes	Yes	No

and asked about the interest among the villagers to participate. When coming back for data collection, the representative of the CVD also assisted in identifying suitable respondents for the different research activities (transect walks, seasonal calendars etc. See below). The respondents were men and women of different ages, but all of them were active members of the local communities who were knowledgeable of local natural resources and their use. All communication with villagers was done through a research assistant who translated between Mooré (the local language) and French.

2.3. Identification of social-ecological patches and their spatial distribution in the villages

We identified social-ecological patches based on several field methods: (i) drawing resource maps (a map of the village, its units and resources; see e.g. Kumar, 2002) in focus groups with men and women, which provided an overview of important units for the generation of ecosystem services in the villages (in six villages, fieldwork 1); (ii) transect walks across the village landscape together with two to four villagers, with stops every 300 m to describe vegetation, soil and crops, which gave insights into differences between social-ecological patches in terms of land use, distribution of woody vegetation and soil type (in six villages, fieldwork 1); (iii) preliminarily identified social-ecological patches from the two previous steps were tested in focus groups, which led to adjustments, e.g. the separation of shrubland and fallow (in two villages, fieldwork 2). After fieldwork 2 we mapped the social-ecological patches in the villages on recent (March 2006 for Boursouma, Oula and Reko, October 2010 for Koalma and Zarin, and November 2010 for Lebda) Google Earth Pro satellite images in ArcGIS 10.1 (ESRI, 2011), with photographs and notes from transect walks as groundtruthing. Boundaries for homesteads were defined to be 50 m from buildings, based on field observations of the range of visible impact regarding increased nutrient concentrations close to homesteads.

2.4. Identification of ecosystem services

To identify provisioning ecosystem services in the focus groups (in six villages, fieldwork 1), the participants drew resource maps and seasonal calendars (the sketch of a year including seasons for harvest of different crops and non-cultivated resources, as well as agricultural practices; see e.g. Kumar, 2002). By this method, the villagers articulated resources from the local landscape of importance for local livelihoods. Citations of species and their respective use from all villages were also listed, and all citations classified into ecosystem services. We verified this classification of ecosystem services with the villagers when reporting back the results (fieldwork 4).

2.5. Scoring of ecosystem services from social-ecological patches

The importance of different social-ecological patches for provisioning ecosystem services was assessed using matrix scoring in focus groups (see e.g. Mikkelsen, 2005). In each of the six villages, three focus groups with men and three focus groups with women were held (36 focus groups in total; fieldwork 3) with each group consisting of 5–10 individuals. Photographs with the social-ecological patches and provisioning ecosystem services were used. For each ecosystem service photograph, the focus group was asked to distribute in total 50 beads among the social-ecological patches, representing the relative contribution of each social-ecological patch to the generation of this particular ecosystem service. To understand the type of benefit the identified ecosystem services had for livelihoods, a survey of the proportion of each ecosystem

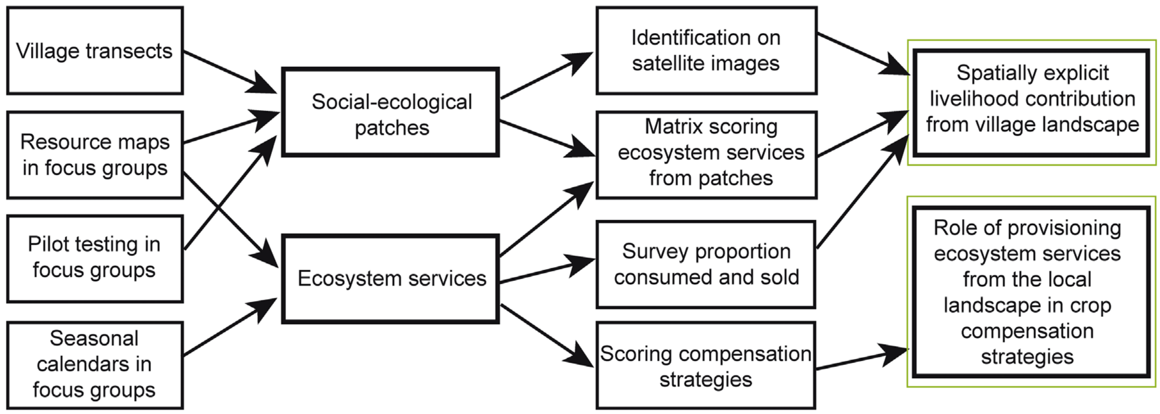


Fig. 2. Scheme illustrating the methods used and how they are related to each other and the outcome of the research process.

Table 2
Location, size and population of the studied villages.

Village	Location	Province	Region	Surface [km^2]	Population in the 2005 census (Burkina Faso, 2005)
Boursouma	13°30′N; 2°22′W	Yatenga	Nord	7.1	597
Oula	13°29′N; 2°20′W	Yatenga	Nord	8.3	1380
Reko	13°30′N; 2°18′W	Yatenga	Nord	9.4	587
Lebda	13°02′N; 0°58′W	Sanmatenga	Centre-Nord	20.1	1022
Koalma	13°10′N; 0°55′W	Sanmatenga	Centre-Nord	9.5	1404
Zarin	13°12′N; 0°55′W	Sanmatenga	Centre-Nord	11.1	872

service consumed in the household or sold was conducted with 38 farmers (20 in Reko, region Nord and 18 in Zarin, region Centre-Nord).

2.6. Scoring of compensation strategies

In order to assess the temporal dynamics in ecosystem services use, the same focus groups as described in Section 2.5 scored the relative importance of (a) all provisioning ecosystem services (except cereals), (b) activities not related to the local landscape (including migration, small-scale business not related to local ecosystem services, and employment in other sectors) and (c) decreased consumption to compensate for cereal yield loss during dry years. The cropping seasons of 2011 and 2012 were very different from each other in terms of rainfall and crop yield, which gave us the possibility to relate the scoring to a recent event. As one example of the high temporal variability in the generation of provisioning ecosystem services in the area, the precipitation in Ouahigouya, Yatenga in 2011 was 505 mm with unfavorable distribution for crop production, and in the three study villages in Yatenga in 2012 it was on average 762 mm with good distribution (the average yearly precipitation 1984–2009 in Ouahigouya was 645 mm). The median sorghum yield estimated in preliminary yield evaluations in the villages was 430 kg ha^{-1} in 2011 and 890 kg ha^{-1} in 2012. Statistics from the region for 1984–2011 show that the yearly sorghum yield has varied between 165 and 1354 kg ha^{-1} (Ministère de l'agriculture de l'hydralique et des ressources halieutiques, 2012, 2011, 2010, 2009).

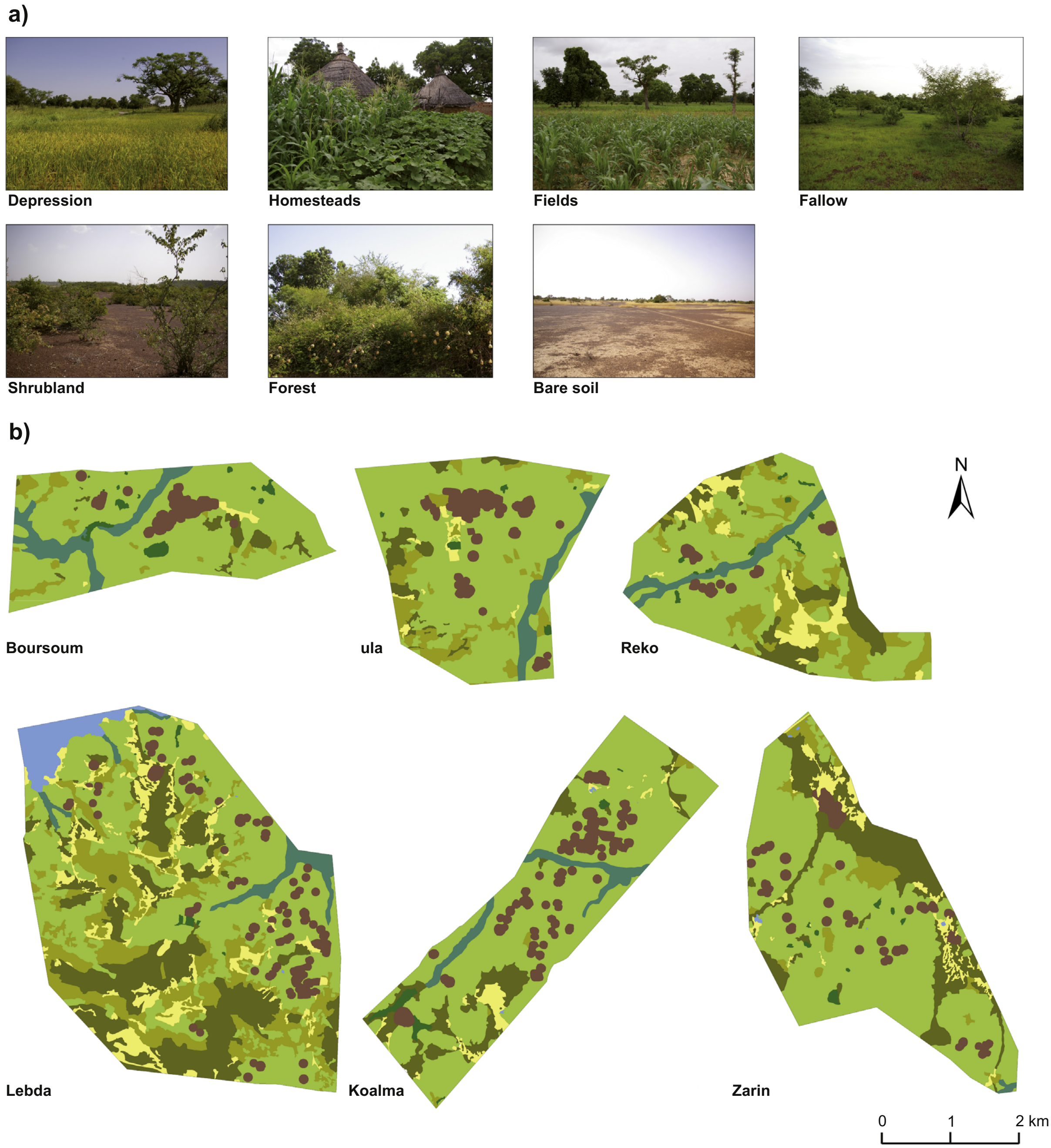
2.7. Data analysis

To investigate whether the differences between groups were large enough to justify separate analysis of data, or if group similarity allowed them to be analyzed together, the results from the matrix scoring of ecosystem services from social-ecological patches and compensation strategies were analyzed using *t*-tests (for regions and gender) and one-way ANOVA (for villages) in SPSS 21.0 statistical software (IBM Corp., 2012). Each provisioning ecosystem service was analyzed for differences between scores for each social-ecological patch among villages, between regions (villages in region Nord versus villages in region Centre-Nord) and between men and women, with every focus group as one case. The analysis showed a few cases with differences in the score of one particular social-ecological patch's contribution to one particular service or compensation strategy, but no consistent differences over the whole distribution of scores for social-ecological patches or different compensation strategies. Since no consistent differences were found, the data sets were used as one group in further analyses. Scores of ecosystem services generated in each social-ecological patch were multiplied with the proportion of each ecosystem service consumed and sold (an average for the two villages surveyed, see Section 2.5) in order to identify the types of benefits for livelihoods that originated from different social-ecological patches.

Forest was pooled with shrubland in the analysis. The main reason for this was that the way people defined forests differed between different groups. In some groups and for some services it was considered a sacred grove where no or very few services should be harvested, whereas in other groups and for other services it was considered as an ordinary forest, which has characteristics most similar to shrubland. The total area covered with this social-ecological patch is also very small in all villages (0.3–2.5%; Fig. 3), and the scores for all ecosystem services very low (from 0% contribution to about 3–4% contribution for fruits, medicine and livestock).

2.8. Reporting back to the communities and incorporating feedback on results

The identified social-ecological patches and ecosystem services, as well as the scoring results, were discussed with representatives from each village in a feedback session (fieldwork 4). Participants gave feedback on social-ecological patches, ecosystem services and scoring results. As a basis for the discussion, we distributed a popular science booklet presenting our results (contact the corresponding author if you are interested in the booklets). The



	BoursoumaO	ula	Reko	Lebda	Koalma	Zarin	[% of village area]
Depression	9.4	5.6	5.5	2.6	5.1	0.3	
Homesteads	6.2	8.2	2.8	5.7	11.3	6.5	
Fields	72.6	68.3	54.0	40.0	67.9	63.7	
Fallow	4.9	10.5	17.8	18.1	0.7	5.1	
Shrubland	3.6	5.0	11.3	21.0	10.6	19.7	
Forest	2.5	0.6	1.0	0.3	1.5	0.6	
Bare soil	0.8	1.8	7.6	8.7	2.6	4.0	
Water	0	0	0	3,6	0,3	0,1	

Fig. 3. a) Photographs illustrating the seven identified social-ecological patches. b) Spatial distribution of social-ecological patches and their percentage of cover in the studied villages.

booklet was printed in two versions, one in Mooré (the local language in the villages) and one in French (the official language). The feedback was used to verify the classification of social-ecological patches, ecosystem services and benefits.

3. Results

3.1. Identified social ecological patches and ecosystem services

We identified the following social-ecological patches: depression, homesteads, fields, fallow, shrubland, forest, and bare soil. These short names do not fully illustrate the social-ecological definition of the patches, and we refer to Table 3 for a description of the characteristics of each social-ecological patch. The following ecosystem services emerged from the focus group discussions: cereals, legumes, vegetables, leaf vegetables herbs, leaf vegetables trees, fruits, medicine, firewood, construction material, and resources to sustain livestock. More information on this can be found in Table 4, which includes components and the common international classification of ecosystem services (CICES) division, group and class (European environment agency, 2016). When available, a quantification of the service at provincial or regional scale is included. During the feedback sessions (fieldwork 4), villagers confirmed that the social-ecological patches represent landscape units present in their villages, and that the identified ecosystem services cover what they harvest in their landscapes.

3.2. Distribution of social-ecological patches and generation of ecosystem services

Fields are dominant in all villages, covering 40–73% of the village area (Fig. 3). The proportions of depression and homesteads are relatively small. Fallow and shrubland have a similar range of coverage but vary substantially among villages. Forest appears only in small patches. Bare soil occupies relatively small patches but covers up to 9% of the village area.

The studied landscapes are multifunctional. No ecosystem service is generated only in one social-ecological patch, and all social-ecological patches except bare soil contribute to the generation of multiple provisioning ecosystem services (Fig. 4a). Homesteads, fields, and depressions are central for the generation of food, particularly food from annual plants that require high management input (cereals, legumes, and vegetables), but also very important for all other ecosystem services. Homesteads and depressions are important service providers in relation to the proportion of the village landscape that they cover (on average 5% of a village for depression and 7% of a village for homesteads). These social-ecological patches are central for the cultivation of vegetables and for leaf vegetable herbs, which are preferably sown close to homesteads since they are the most important accompaniment to food staples. Depressions are less important for legumes, as they are too wet for these crops.

Shrubland and fallow are central social-ecological patches for ecosystem services from woody vegetation, including fruits, firewood, construction material and medicine, and they are also used as pasture. In focus group discussions, about half of the species mentioned for fruit harvest were also used for firewood. However, some important fruit bearing species (e.g. *Vitellaria paradoxa*, *Tamarindus indica* and *Adansonia digitata*) used less as firewood, are harvested in homesteads, fields and depressions. Similarly, important sources of leaf vegetables such as *A. digitata* and *T. indica* are more common in homesteads and fields. This increased scores for these social-ecological patches. Wood from *Azadirachta indica,* preferably planted and regenerated in homesteads and fields is an important component of construction material. Fields provide the grass *Andropogon gayanus* used in for example the construction of granaries. Leaves, fruits and bark for medicinal use are harvested from a wide range of species found across all social-ecological patches except bare soil, with shrubland as the dominant source.

All social-ecological patches except bare soil play an important role in sustaining livestock and are used in different ways with seasonal variation. Fields, homesteads, and depressions provide crop residues for fodder. Depressions are important for drinking water and pasture for free ranging livestock. Shrubland and fallow are important for pasture and for shrubs browsed by livestock. Almost no provisioning ecosystem services are generated on bare soil, but people see the potential to reclaim bare soil for cultivation with substantial investment in soil and water conservation methods, and free ranging livestock sometimes occupy these areas.

3.3. Livelihood contributions from social-ecological patches

We identified five groups of benefits for livelihoods by separating ecosystem services depending on consumed and sold proportions, and combining those with similar benefits. The majority of the studied provisioning ecosystem services are consumed within the households (Fig. 4b). Cereals, firewood and medicine are only used for consumption, while construction material, leaf vegetables herbs, leaf vegetables trees, vegetables and fruits are either consumed or sold. Legumes are on average equally consumed and sold, with a large variation among households. Livestock is accumulated over time and almost exclusively sold.

The five benefit groups are: annual crops for consumption (including cereals and the consumed part of legumes and vegetables); nutritional diversity and medicinal uses (including medicine and the consumed part of leaf vegetables herbs, leaf vegetables trees and fruits); material assets and energy (including firewood and the consumed part of construction material); saving/insurance (livestock, as accumulating a herd is a considerable investment and respondents say they only decrease the herd in case of a real need to gain cash income); and income (including the sold parts of legumes, fruits, vegetables, leaf vegetables trees, leaf

Table 3
Identified social-ecological patches with description of characteristics.

Social-ecological patch	Description
Depression	Temporary watercourse with bordering fields. Topographically defined, clayey soil dominant. Often higher density of larger trees as compared to the other social-ecological patches, except forest.
Homesteads	Land around homesteads, influenced by nutrient accumulation due to animal and human excreta. Also influenced by what humans plant, e.g. trees for shade and vegetables.
Fields	Agricultural fields on different soil types. Trees and shrubs are present in a range of densities.
Fallow	Land that has been cultivated but left for fallow >2 years. Shrubs have been established, trees are present.
Shrubland	Non-cultivated land dominated by shrubs. Trees present in some cases, grass sprout around shrubs during the rainy season.
Forest	Area with trees and shrubs in high density. Includes sacred groves, forest patches and densely reforested areas.
Bare soil	Land with no or very scarce vegetation.

Table 4
Provisioning ecosystem services identified in the villages with components cited during focus group discussions, as well as their common international classification of ecosystem services (CICES) division, group and class, and quantification at provincial or regional scale.

CICES division/group/class (European environment agency, 2016)	**Ecosystem Services**	**Components**	**Quantification**
Nutrition/biomass/cultivated crops	Cereals	Sorghum (*Sorghum bicolor*), millet (*Pennisetum glaucum*), maize (*Zea mays*) and rice (*Oryza sativa*).	Mean production 1995–2011 [tonnes] in Sanmatenga and (Yatenga): sorghum 64,000 (72,000); millet 32,000 (61,000); maize 4000 (3000); and rice 2000 (1000).[a]
Nutrition/biomass/cultivated crops	Legumes	Cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea* L.), and bambara groundnut (*Voandzeia subterranea*). Also includes sesame (*Sesamum indicum*).	Mean production 1995–2011 [tonnes] in Sanmatenga and (Yatenga): Cowpeas 25,000 (28,000); groundnuts 7000 (10,000); bambara groundnuts 3000 (2000); and sesame 500 (300).[a]
Nutrition/biomass/cultivated crops	Vegetables	Tomato (*Lycopersicon esculentum*), egg plant (*Solanum melongena*), bitter tomato (*Solanum aethiopicum*), okra (*Abelmoschus esculentus*), onion (*Allium cepa*), potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), cabbage (*Brassica* sp.), carrot (*Daucus carota*) and lettuce (*Lactuca sativa*).	Total production in 2011/2012 was 21,000 t in region Nord (60% onion, 27% cabbage and 10% tomatoes), and 73,000 t in region Centre-Nord (68% onion, 6% cabbage and 18% tomatoes).[b]
Nutrition/biomass/wild plants, algae and their outputs	Leaf vegetables herbs	Leaves of roselle (*Hibiscus sabdariffa*), cowpea (*Vigna unguiculata*), *Corchorus* sp., and *Cleome gynandra*.	
Nutrition/biomass, wild plants/algae and their outputs	Leaf vegetables trees	Leaves from *Adansonia digitata, Tamarindus indica, Balanites aegyptiaca* and *Piliostigma reticulatum*. Flowers of *Bombax costatum* are included.	
Nutrition/biomass, wild plants/algae and their outputs	Fruits	Fruits from *Diosyros mespiliformis*, *Ziziphus mauritania*, *Acacia machrostachya*, *Vitellaria paradoxa*, *Lannea* sp., *Tamarindus indica*, *Saba senegalensis*, *Parkia biglobosa*, *Balanites aegyptiaca, Adansonia digitata, Sclerocarya birrea* and *Mangifera indica*.	
Nutrition/biomass/reared animals and their output	Livestock	Resources used by both free ranging (pasture, drinking water, shade) and stalled (crop residues and fodder from trees and shrubs) livestock.	In 2008, an estimated 170,000 cattle, 346,000 sheep and 426,000 goats were held in Yatenga, and 176,000 cattle, 403,000 sheep and 457,000 goats held in Sanmatenga.[c]
Materials/biomass/fibers and other materials from plants, algae and animals for direct use or processing	Medicine	Wide range of trees and shrubs used for medicinal purposes.	
Materials/biomass/fibers and other materials from plants, algae and animals for direct use or processing	Construction material	Wood, branches, *Andropogon gayanus* grass and other material harvested for construction	
Energy/biomass-based energy sources, plant-based resources	Firewood	Branches of trees and shrubs used for cooking.	

[a] Data from (Ministère de l'agriculture de l'hydralique et des ressources halieutiques, 2012, 2011, 2010, 2009).
[b] Data from (Ministere de l'agriculture et de securite alimentaire, 2014).
[c] Data from (Ministere des ressources animales, 2008).

vegetables herbs and construction material).

Fields, depressions and homesteads generate the majority of annual crops for consumption and income, but also all other types of benefits, including large parts of the nutritional diversity and medicinal uses, as well as savings/insurance (Fig. 4c). Depressions contribute less to income than homesteads and fields, mainly because fewer legumes are cultivated in depressions, and the vegetables referred to by the respondents are mainly cultivated during the rainy season without irrigation (e.g. okra and bitter tomatoes). The contribution of depressions to income is probably higher in villages with access to dry season irrigation. The sets of benefits generated in fallows and shrubland are similar, but shrubland is more important, especially for material assets and energy.

3.4. Compensation for cereal loss during dry years

When the cultivation of cereals fails, villagers compensate for that loss in various ways. The local landscape contributes with 68% of what is used to replace the value of cereals when crops fail (Fig. 5). Livestock is ranked highest (33%), and its use as compensation is based on accumulated use of pasture, fodder and water from the local landscape over several years. The majority of the local ecosystem services (82%) are sold to gain cash income, while increased direct consumption of fruits and leaves from trees, shrubs and herbs only plays a limited role. Activities not related to local ecosystem services are the second most important way of compensating for crop loss. Hence, compensation activities generate money to buy food, while the value they replace is mainly nutrition through direct consumption (Fig. 4b). Decreased consumption represents 12% of the total compensation for crop loss. Examples of decreased consumption are to postpone ceremonies for baptisms, weddings and funerals, and to postpone travels.

4. Discussion

We have developed a method to track multiple provisioning ecosystem services from social-ecological patches in landscapes and the benefits for livelihoods that are generated by these ecosystem services. Below we discuss the contribution of this method to ecosystem services assessment and management, as well as its limitations. We also discuss the high variability that characterizes the landscape and its productivity in the West African Sahel, highlighting some future research needs.

4.1. Contribution and limitations for the use of the social-ecological patch approach in ecosystem services assessments and management

One factor that often weakens assessments of ecosystem services is the failure to include landscape diversity that corresponds to the perceptions of local people (Dawson and Martin, 2015). The

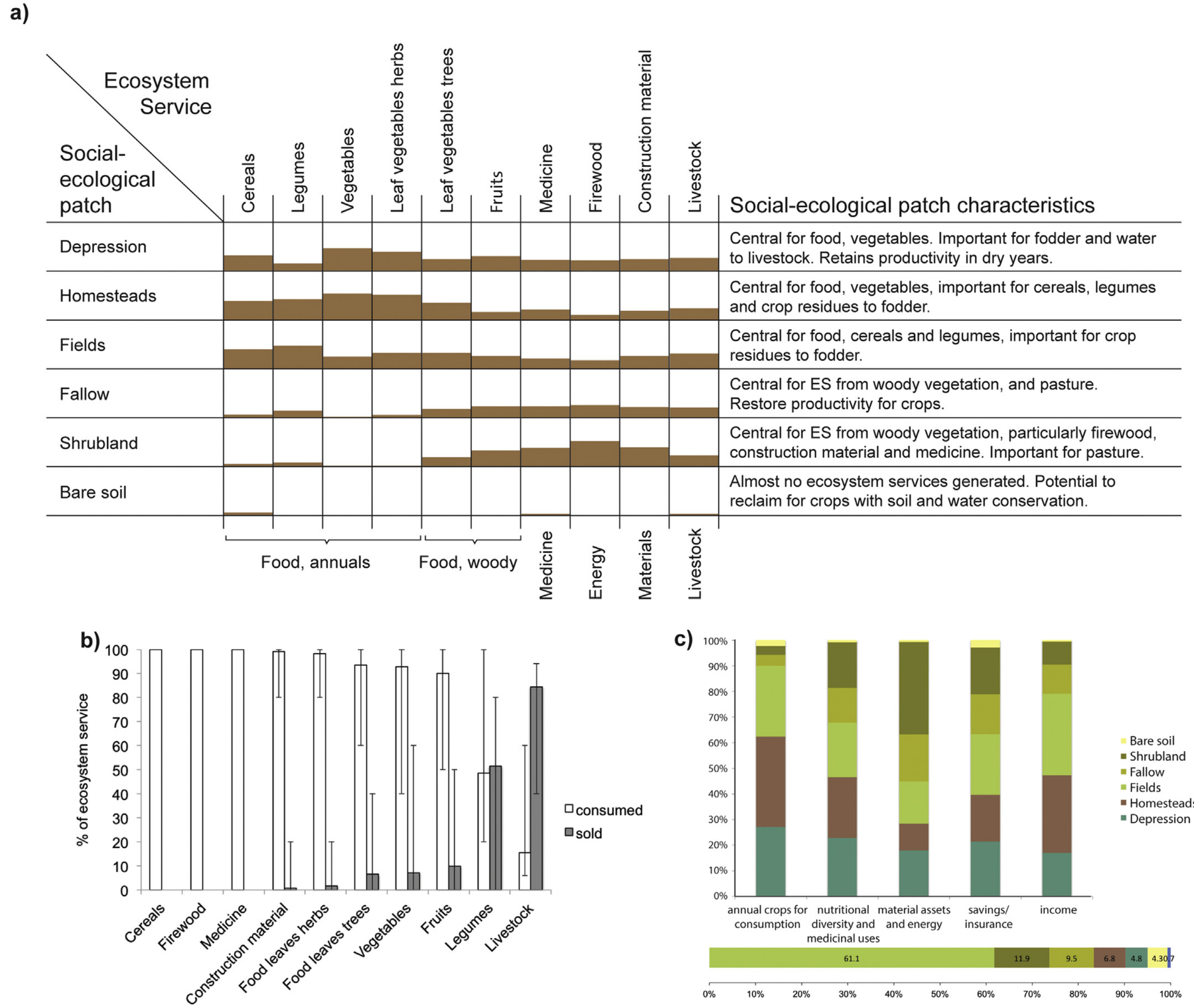


Fig. 4. a) Distribution of scores for provisioning ecosystem services among social-ecological patches. Cell fills represent the score (%) for the contribution of a particular social-ecological patch to a particular ecosystem service. The sum of each column is 100%, while each row illustrates the set of ecosystem services characterizing a social-ecological patch. This is summarized in the last column; b) Proportion of ecosystem services consumed in the household and sold, respectively. Error bars show the interval in responses (n=38); c) Distribution of different types of benefits from ecosystem services among social-ecological patches. Bar sections show the percentage of the total of a type of benefit coming from a particular social-ecological patch, based on the scoring of ecosystem services in focus groups and the proportion consumed and sold. Horizontal bar illustrates the average percentage of the village landscape that each social-ecological patch covers.

social-ecological patch approach is a way to address this gap as it highlights the presence of multiple land units not defined by a single land-use, but in a way that corresponds to the local perspective of multiple functions from the same patch. The difference between land-use as basis for assessment and the social-ecological patch approach is clear when comparing the land cover/land use map used as background in Fig. 1 with maps of the identified social-ecological patches in Fig. 3. It has also been emphasized that the use of coarse land-use data and agricultural statistics to map the ecosystem service of food can be problematic, since it only includes domesticated food sources and misses wild foods and the diversity of crops for nutritional value (Crossman et al., 2013), which can be of great value for local livelihoods, particularly in poor parts of the world. In our case study, fields, depressions and homesteads are three social-ecological patches that could be classified as croplands on a land cover map. The main benefit from these social-ecological patches is the production of annual crops (cereals, legumes, and vegetables; Fig. 4a). However, our classification emphasizes that the relative importance for these ecosystem services differs between social-ecological patches, where fields and homesteads are more important for legumes, and homesteads and depressions are more important for vegetables. More importantly, these social-ecological patches are central for wild leaf vegetables from herbs and trees, and provide fruits, medicine, firewood, construction material, and resources for livestock-ecosystem services that are not recognized if these parts of the landscape are seen as cropland. Fields, depressions and homesteads also respond in different ways to drought, and floods, which are common in this region. When faced with a drought the relatively wetter depressions can maintain production longer than fields and homesteads. In contrast if faced with floods, fields and homesteads can sustain crop production beyond the capacity of depressions. Hence, having access to land in all three patches increases the likelihood to gain a decent yield every year.

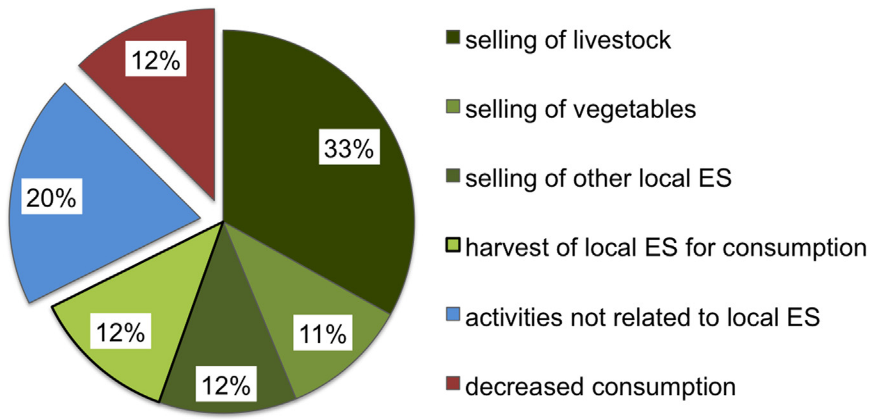


Fig. 5. Distribution of scores among groups of ecosystem services (ES), non-farm activities and decreased consumption for crop loss compensation during dry years [% of total scores]. Selling of other local ES includes legumes, fruits, firewood and construction material. Harvest of local ES for consumption includes food leaves herbs, food leaves trees and fruits.

Our method, focusing on multiple and seasonally variable ecosystem services from social-ecological patches, also highlights the dependence of livestock on multiple resources from multiple social-ecological patches, where the relative importance varies between seasons. Homesteads, fields and depressions are grazed after harvests and contribute to fodder and water, whereas shrubland and fallows are used for grazing and browsing during cropping seasons, and as a source of fodder from woody vegetation during the dry season. This would likely not have been evident in a study based on land cover or land use classes, since separating cropland and pasture easily masks the importance of grazing crop residues after harvest for livestock in the region.

The social-ecological patch approach is also useful for highlighting landscape diversity in the context of development interventions. Many interventions to increase farm productivity neglects how farmers interact with landscapes not only for yields but also for the generation of multiple other ecosystem services (Snyder and Cullen, 2014). The method developed here can be used to assess the influence of landscape interventions such as intensification of agriculture, tree planting or the construction of small-scale dams for the generation of multiple ecosystem services. Although poverty reduction strategies are becoming increasingly integrated, in terms of the different poverty dimensions they address, many investments address crop production in particular, with the aim to close yield gaps (the difference between actual and potential yields for a region; AGRA, 2013; Nin-Pratt et al., 2011). High yield gaps are often correlated to high poverty levels; hence, decreasing yield gaps seem to be a promising strategy for poverty reduction (Dzanku et al., 2015). However, an evaluation of such investments must not include only yield measurements but also indicators for the other ecosystem services generated in the social-ecological patches where the investments take place, in order to understand the full bundle of ecosystem services, synergies and trade-offs among them (Bennett et al., 2009). One example of synergies between investments to enhance crop productivity and the generation of other ecosystem services are the techniques of soil and water conservation such as stone bunds, planting pits and half-moons with manure and fertilizer. These are used by farmers in northern Burkina Faso both to intensify crop production on fields and to expand/reclaim fields on bare soil (Douxchamps et al., 2014; Reij et al., 2005), a social-ecological patch with hardly any benefits for livelihoods. These efforts can thus simultaneously increase crop production and improve the regulating services of nutrient retention, erosion control, and carbon sequestration (Bossio et al., 2010; Reij et al., 2005).

The usefulness of the method for interventions is currently limited by two factors. First, it only explicitly addresses provisioning ecosystem services; secondly, it can only address interventions that cause change between two different patch categories, as it does not take into account the heterogeneity within social-ecological patches. This study does not explicitly deal with cultural ecosystem services, but we acknowledge that all ecosystem services have cultural aspects (Chan et al., 2012) and that the way people perceive their landscapes depends on culture. In addition, the current study does not assess regulating ecosystem services from the patches. The heterogeneity within patches is probably most pronounced on fields; the production of cereals, legumes and vegetables is particularly dependent on the efforts invested in the land through manure, fertilizer and labor (e.g. weeding). During the feedback sessions (fieldwork 4), representatives from all villages stressed that beyond access to a few hectares of land, the inputs a farmer can afford is much more important for the yield than the area of field the farmer has access to. This is a region with high population density (60–80 people per km^2; Burkina Faso, 2005) where the majority are farmers; therefore no one has access to very large areas of land.

The local user perspective was of key importance for the identification of social-ecological patches. For example, we did not originally separate shrubland from fallow, but their differences were strongly emphasized by villagers when they were involved in groundtruthing (fieldwork 2). Our results illustrate the substantial difference in benefits generated between these social-ecological patches (Fig. 4c), which highlights the importance of a participatory approach for understanding and mapping ecosystem services from a landscape. A participatory approach also has its potential biases, for example related to the selection of respondents, as different people have different values and interests and different levels of power (Dawson and Martin, 2015). The way of selecting respondents in this study, through an elected village representative, probably biased the selected respondents towards more influential villagers, as well as towards middle-aged rather than young respondents. However, as the purpose was to establish how the landscape is used at the village scale, we considered this acceptable for answering the research questions.

There is a risk that village level studies only have relevance in the village where the study has been conducted (Potschin and Haines-Young, 2013), and that high-resolution mapping and field-based measurements are too resource-intensive to be used in studies across larger regions (Ellis et al., 2009). The analysis of social-ecological patches and their ecosystem services in this paper builds on a substantial dataset gathered through fieldwork. Interventions for poverty alleviation must target larger spatial scales to make a difference; hence ways in which the village level data can be extrapolated to scales of provinces or administrative regions must be developed. There are strong indications from our data that the results are valid outside the six studied villages, in particular for villages with similar social-ecological conditions in Sudano-Sahelian Burkina Faso. This is due to the fact that there were no significant differences in the scores of ecosystem services generation from social-ecological patches in our study and that villages were intentionally selected as representatives for villages in the study regions.

4.2. Dealing with variability

Any type of landscape investment for poverty alleviation in Sudano-Sahelian West Africa must consider the extremely high rainfall variability in the region and the fact that droughts will continue to cause crop failures even with improved agricultural productivity. Therefore, the maintenance of a variety of benefits from the local landscape, including insurance capacity, is of particular importance in this region. Our results show some of the ways in which people deal with this temporal variability. Direct use of ecosystem services for subsistence is an important part of livelihoods (Fig. 4b), but we also show that cash income based on provisioning ecosystem services is the main benefit from the local landscape to compensate for crop loss during dry years (Fig. 5). More than 80% of the ecosystem services from the local landscape that become more important when crops fail are used as a basis for cash income. Not surprisingly, livestock is most important for income generation, and the build-up of a livestock herd as insurance takes advantage of resources from all social-ecological patches. The build-up of a herd takes several years, which means that households will use up a large part of their insurance capacity for the coming years if they sell livestock and cannot use the strategies employed during dry years to gain income every year. Years with crop failure resulted in a decreased average consumption of 12%, which could be perceived as relatively small. However, this is a decrease from an already very low consumption level, and worse-off households are probably forced to decrease their consumption more as they have less opportunity to use strategies such as selling livestock.

4.3. Future research

Combining this study with assessment of cultural and regulating ecosystem services will further improve the understanding of village landscapes in Burkina Faso. We expect some regulating services such as water regulation and erosion control to be more dependent on patterns of patches than on differences between patches. Using the mapped pattern of social-ecological patches combined with measurements and/or modeling of e.g. water and sediment flows could therefore be one approach to study regulating ecosystem services. Our results indicated a potential for up-scaling to areas with similar social-ecological conditions. This needs to be addressed in a future study that evaluates up-scaling of the local use perspective to scales that are more relevant for development interventions. The social-ecological patches and associated ecosystem services were identified in a participatory process, which in this study was aggregated on a village level. To understand the contributions of interventions aiming at poverty alleviation, the wellbeing impact needs to be better disaggregated (see Daw et al., 2011) for different groups, e.g. based on gender, age and income.

5. Conclusions

We have developed a method to obtain a more nuanced understanding of how people use landscapes for their livelihoods through the assessment of ecosystem services and their benefits. This is a method for collecting primary data on village scale, a scale rarely addressed in ecosystem services assessments. It links livelihood benefits to landscape units that resonate with local landscape perception. We have obtained this through the identification of social-ecological patches, the sets of provisioning ecosystem services generated in the patches, and the benefits these ecosystem services have for livelihoods. Our case study results clearly illustrate the multifunctionality of Sudano-Sahelian village landscapes, where all social-ecological patches, except bare soil, are shown to generate substantial contributions of multiple provisioning ecosystem services, and all livelihood benefits (such as direct food production, income sources, and insurance capacity) are generated across at least three different social-ecological patches. These patches have seasonal variation in generation of ecosystem services, and the type of benefit from these services varies between years, where income from ecosystem services becomes more important when staple crops fail.

This method must be further developed in order to assess its potential to be up-scaled (e.g. to provincial level) and to make it more useful for landscape planning, fully bridging the gap between the local use perspective and the scales at which development interventions operate. This method will be further strengthened for management purposes if combined with the assessment of regulating ecosystem services. In the context of poverty alleviation and agricultural development, this method should be further developed to disaggregate who benefits from the ecosystem services in the villages and how different efforts in terms of nutrient and labor inputs create within-patch heterogeneity in ecosystem services generation.

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