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Mapping ecosystem service flows with land cover scoring maps for data-scarce regions.

Authors:

Dirk Vrebos[a], Jan Staes[a], Tom Vandenbroucke[b], Tom D'Haeyer[b], Robyn Johnston[c], Moses Muhumuza[d], Clovis Kasabeke[d], Patrick Meire[a]

[a]University of Antwerp, Universiteitsplein 1c, B-2610, Belgium
[b]Antea Group, Poortakkerstraat 41, B-9051 Gent, Belgium
[c]International Water Management Institute, 127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka
[d]Mountains of the Moon University, 837, Fort-Portal, Kabarole, Uganda

Corresponding Author: Dirk Vrebos, University of Antwerp, Universiteitsplein 1c, B-2610, Belgium
, dirk.vrebos@uantwerpen.be, 3232652385

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Abstract

Natural resource management requires spatially explicit tools to assess the current state of landscapes, to analyse trends and to develop suitable management strategies and interventions. The concept of ecosystem services can help in understanding the importance of natural resources for different stakeholders and at different spatial and temporal scales. Simple methods to map ecosystem services using scoring of land cover types are particularly useful in data scarce regions, but do not reflect the dynamics of supply and demand. Within this study, GIS scripts were developed to represent and assess several different modes of ecosystem service flows between supply and demand, using ecosystem services scoring tables. By integrating the flows, the ecosystem services can be better evaluated. The outcomes do not give quantitative information on whether supply meets demand, but indicate the spatial distributions of both supply and delivery and where ecosystem services are under threat because of changes in ecosystem or flow mechanisms. The scripts allow us to identify sites that are vulnerable to ecosystem service loss and to evaluate possible management scenarios.

Keywords

Ecosystem service maps; Spatial flows; Natural resource management; Indicators; Land cover map

Abbreviations

Integrated natural resource management = INRM

1. Introduction

Africa and other developing regions are often highly dependent of natural resources for livelihoods and development (Reardon and Vosti, 1995). The degradation and decline of ecosystems and related ecosystem services (the benefits people obtain from ecosystems) can have a large impact on local livelihoods especially of the poor. In the long term this degradation can threaten sustainable development (Scherr, 2000). Integrated natural resource management (INRM) aims to provide a management framework for sustainable use of natural resources and ecosystem services and to prevent further degradation. One requirement for INRM to work in practice is the availability of tools for spatial analysis to map and understand the spatial relationships between ecosystems and the socio-economic system (Frost et al., 2006). Spatial distribution of natural resources and major processes need to be analysed at an appropriate scale (Lovell et al., 2002), to allow researchers, managers and authorities to identify opportunities for and threats to sustainable use, and to define spatially differentiated management plans.

Ecosystem services have gained much attention in recent years (de Groot et al., 2012; MEA, 2005; TEEB, 2010) and are often considered to be helpful in natural resource management (e.g. Tallis and Polasky, 2009; Wainger et al., 2010). The concept can bridge the gap between research and management (Sitas et al., 2014) and provide a common language for managers, researchers and different stakeholders (Granek et al., 2010). But its place within management as a whole (Norgaard, 2010) and specific management and impact assessment frameworks is still disputed (Baker et al., 2013; Cook and Spray, 2012). Where and how ecosystem services can be integrated in natural resource management remains therefore a topic of discussion.

Operationalization of the ecosystem services framework requires different aspects and dimensions to be taken into account (Seppelt et al., 2011; Seppelt et al., 2012). One of these aspects is how ecosystem service supply and demand can be separated in time and space: ecosystem services are often used at different locations and scales from where they are produced (Luck et al., 2009). Different types of flow mechanisms can deliver the service to the demanding areas. These flows can be mediated by both natural (e.g. water flow) and human induced processes (e.g. movement of people.). The flow mechanism can differ between ecosystem services, the ecosystems considered and the spatial dimension of the analysis (Blaschke, 2006). Assessment of ecosystem service flows is sporadic and usually remains conceptual (Serna-Chavez et al., 2014). Therefore ecosystem service flows are currently difficult to incorporate in ecosystem service assessments.

In recent years a large variety of mapping methods and models has been developed within the ecosystem services framework that can be used in parts of the INRM framework (e.g. Johnson et al., 2010; Nelson et al., 2009) e.g. to improve stakeholder interaction (Brown et al., 2012) or for scenario analysis (Wang et al., 2009). Each of these mapping methods and models was developed with a specific goal in mind, incorporating different parts of the ecosystem services concept and addressing different levels of complexity (Pagella and Sinclair, 2014). Methodologies vary from simple land use/land cover based assessments (Burkhard et al., 2009) to highly complex systems that model ecosystem service flows in a detailed manner (Bagstad et al., 2013; Tallis and Polasky, 2009) and incorporate economic, ecological and also social values (Bryan et al., 2010). One of these relatively simple methods has attracted much attention both inside and outside the scientific community. The ‘table scoring’ method developed by Burkhard et al. (2009) uses land cover or land use maps as proxies for ecosystem service supply and demand (Burkhard et al., 2012). The methodology assumes ecosystems to be the main unit for ecosystem service supply. Based on expert and local knowledge, the land use types can be scored against different values and criteria (quantities, monetary, etc.). Therefore the methodology requires only a limited amount of data and technology (e.g. computer power), making it an easy to use, popular mapping and evaluation method (e.g. Kaiser et al., 2013; Nedkov and Burkhard, 2012; van Oudenhoven et al., 2012). The method has also been used to assess changes in ecosystem service delivery over time (Kroll et al., 2012; Lautenbach et al., 2011). However the use of land use proxies for ecosystem service assessments has also been criticized as being a poor fit for the actual ecosystem service provision due to uncertainties in the scoring system and discrepancies between the land use classes and the ecosystem functions that provide the ecosystem service (Eigenbrod et al., 2010; Hou et al., 2013).

Previous studies in Africa on ecosystem services have made use of both complex models e.g. (Swallow et al., 2009) and landscape proxies (e.g. O’Farrell et al., 2012; Willemen et al., 2013), but mapping of ecosystem services is potentially limited, especially in data scarce regions as Africa, by the available data (Egoh et al., 2012). In the absence of local data, primary data from regional or global studies e.g. (de Groot et al., 2012) are often used (e.g. Leh et al., 2013). However previous ecosystem service studies have demonstrated that data and value transfer between case-studies should be handled with care (Plummer, 2009). Correspondence between the case-study and data source sites can be limited and/or difficult to assess. As INRM encompasses all natural resources, all relevant ecosystem services need to be addressed and the risk of missing data increases. As an alternative, INRM considers local knowledge to be highly relevant for good management as it can improve analysis and increase local support for management actions (Frost et al., 2006). Therefore the integration of local knowledge in a qualitative assessment in combination with land cover proxies might be more appropriate than relying on data transfer for quantitative assessments in data scarce case studies and regions.

In this study we developed a methodology to take different flow types into account while using expert scoring tables for ecosystem service mapping and evaluation. The methodology was developed and tested within the Lake George catchment in western Uganda as part of a larger INRM research project, Afromaison, which incorporates ecosystem services into different steps of the INRM framework. Our approach was designed to integrate ecosystem services into INRM for implementation in data-scarce regions. The presented analysis was developed as a communication tool for stakeholders. The tool facilitates communication on how management actions can have an impact on the ecosystem service distribution within the region. The study focusses on local, semi-subsistence livelihoods but does not consider ecosystem service supply, demand and flows on larger scales. Different GIS scripts were designed to reflect the different ecosystem service flows that are relevant to the local communities. To evaluate the impact of the flows, the outputs of these scripts were compared with the original maps from expert scoring. To evaluate the delivery of ecosystem services in the region ant test different INRM strategies, several land use change scenarios were used to test the effect of these different interventions on the delivery of provisioning and cultural ecosystem services.

2. Material and methods

2.1.Study area

Lake George catchment, located in Western Uganda (Fig. 1), consists of a series of rivers that are situated around and drain into Lake George. The catchment is part of the Great Rift Valley and is characterized by diverse geophysical and ecological systems: high mountains, tropical high forest, savannah and papyrus wetlands. It includes also several important protected areas: Queen Elisabeth Park, Kibale National Park and Rwenzori Mountains National Park (Fig 2).

Figure 1: Location of the Lake George Catchment within Uganda.

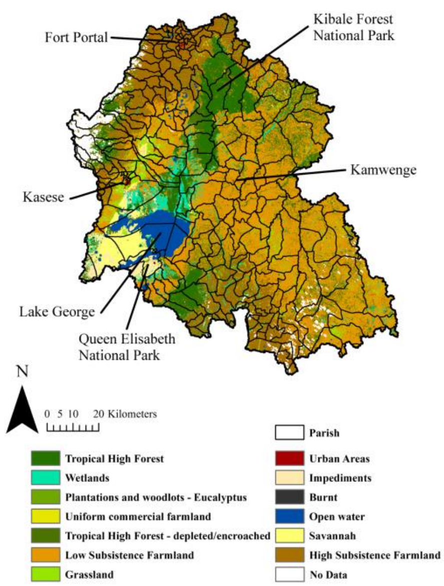

Figure 2: Overview of the Lake George Catchment.

Land and natural resources are essential for rural livelihoods in Sub-Saharan Africa (Abalu and Hassan, 1998). In Uganda 88% of the population lives in agrarian areas, making them vulnerable to natural resource degradation. Population densities in Western Uganda are high and were reported in 2002 to be 110 inhabitant/km². At the same time the region is confronted with a high birth rate (245 births/1000 inh. in 2011) and immigration from Congo. This results in high population growth in Uganda (3.4% per year) and rapidly increasing population densities (Uganda Bureau of Statistics, 2005). For example at the eastern border of Kibale National Park population density is now estimated to have reached more than 335 inh./km² (Hartter and Southworth, 2009).

High population densities and ongoing growth, combined with low agricultural efficiency, have resulted in an ever increasing demand for natural resources (e.g. wood, water, etc.) and additional agricultural land in Uganda (Nkonya et al., 2008). These pressures have resulted in increasing deforestation and land degradation. Conversion of natural ecosystems to agricultural land is associated in Uganda with deforestation, wetland degradation and soil erosion (Hartter and Southworth, 2009; Laurance et al., 2014; Mutekanga et al., 2010; Nakakaawa et al., 2011). This also results in an increasing pressure on the remaining natural ecosystems for resources, leading to additional overexploitation and loss of biodiversity (Hartter et al., 2011). The high rate of ecosystem degradation in the region threatens the long term delivery of many ecosystem services and the sustainable development of the region (Zhen et al., 2014).

In the past decades Uganda has undergone a process of decentralization in which rights and responsibilities were transferred to the local government. However at a local level there is confusion on the right of access and use of natural areas. Nevertheless natural resource management on a local level is the only viable option for effective management in Uganda (Hartter, 2010), as it is the only scale at which actions for management can be effectively communicated to those who need to implement them, the local communities and people. Therefore, methods are needed to help in the development of this local natural resource management.

2.2. Mapping ecosystem service supply

For this study, we used the ecosystem service classification system of *The Economics of Ecosystems and Biodiversity* report (TEEB, 2010). This classification system was found to be the best suited system at the beginning of the project. However some changes were made by a team of local researchers, familiar with the region, to better represent the local situation. For example 'raw materials' from the TEEB study was split into 'Timber and Fuelwood' and 'Fodder', because the high significance of both to the region. Other services were removed as they were considered to be less important. To assess ecosystem services, scoring tables for ecosystem service supply were developed. The same team of researchers was responsible for scoring the different tables, incorporating knowledge they gathered during several stakeholder meetings in the period 2012 – 2013. In these stakeholder meetings discussions on INRM took place between local representatives from government, management agencies, relief and development organisations and industry. Scorings were assigned between 0 (no supply) and 5 (high supply). Tables were scored for each land cover type present in the region (Table 1). The land cover typology was based on a national biomass study (Drichi, 2002). Initially the tables were used to create ecosystem provisioning maps following the methodology developed by Burkhard et al. (2009). No detailed land cover map of Uganda existed that represented the current situation in Uganda, so a land cover map was developed based on Landsat 5 TM images from January 2010 and other local data sources, resulting in a map with a 30m resolution. The region is cloudy throughout the year and no data was available for some areas (Fig. 2)

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	Provisiong Services	Water supply	Timber and Fuelwood	Capture and Collection	Crops	Fodder	Regulating Services	Water Quality Regulation	Water Flow Regulation	Soil Maintenance	Erosion Control	Flood Control	Carbon Storage	Habitat services	Habitat	Maintenance of Biodiversity	Cultural Services	Ecotourism	Cultural Significance
Tropical High Forest		5	5	5	0	2		4	5	4	4	4	5		5	5		4	5
Wetlands		5	1	5	2	5		5	5	0	0	5	4		5	5		2	1
Plantations and woodlots - Eucalyptus		0	4	0	0	0		0	0	4	4	0	0		1	1		0	0
Grassland		2	0	2	0	5		2	2	2	4	2	1		2	2		0	5
Tropical High Forest - depleted/encroached		2	5	2	1	2		2	2	2	2	2	3		3	3		1	3
Uniform commercial farmland (lowland		1	0	0	5	0		1	0	2	2	0	1		1	1		0	0
Woodland		2	5	4	0	2		4	3	4	4	3	3		5	5		1	3
Urban		0	0	0	0	0		0	0	0	0	0	0		0	0		0	0
Savannah		3	2	3	1	1		3	3	3	3	2	4		2	3		2	3
Burnt		0	0	0	0	0		0	0	0	0	0	0		0	0		0	0
Open water		5	0	5	0	0		5	5	0	0	5	0		5	5		4	5
Impediments		0	0	0	0	0		0	0	0	0	0	0		1	1		1	1
Subsistence Farmland (highland)		2	2	2	5	2		2	2	3	3	2	1		2	2		1	5
Agroforestry (lowland)		3	5	2	4	4		3	2	4	4	3	4		2	3		2	1
Agroforestry (highland)		3	5	2	4	4		3	2	4	4	3	4		2	3		2	1

Table 1: Overview of the ecosystem service supply scores for the different ecosystem services and land uses.

2.3. Mapping ecosystem service demand

Beneficiaries of ecosystem services can be situated at different scales (local, regional, global). In this study, ecosystem services were only assessed in relation to local livelihoods at meso-scale. Therefore ecosystem services demand was evaluated on a local level using population density data, disregarding potential demand on higher geographic levels (e.g. national or international demand). Ugandan census data from 2002 (Uganda Bureau of Statistics, 2005) were recalculated to population densities per parish, to adjust for the differences in parish sizes. Parishes are the smallest administrative level in Uganda and the level on which census data are collected, but parish size can differ strongly and ranges within the study area between 102ha and 26.334ha. To integrate the demand data into the qualitative ecosystem service supply maps, the range of population densities were reclassified to an indicator between 0 (no population/no demand) and 5 (high population density/high demand). Population densities above 0 were reclassified using an 'equal area' algorithm, so that indicator values between 1 and 5 approximately cover the same proportion of area within the catchment. This reclassification method was selected, instead of a linear classification, to better represent the spatial distribution of the demand across the catchment.

2.4. Mapping ecosystem service flows

Fisher et al. (2009) identified four different flow mechanisms between ecosystem services supply and ecosystem services demand areas. This classification was selected for this study as it encompasses the most important ecosystem service flows and it is easily to communicate. In some cases, e.g. water supply, these flow mechanisms have to be combined to encompass the entire flow of the ecosystem service. Therefore an extra flow mechanism, 'combination of flows', was developed that combines both gravitational and omni-directional flow. Scripts were developed to incorporate each of these flow mechanisms into the ecosystem service scoring evaluation (Fig. 3). For each ecosystem service, the associated flow mechanisms are set out in Table 2. The scripts were developed in Python incorporating tools available in ArcGIS 10.2 (ESRI Inc., 2010). An overview of the data processing steps are given for each flow mechanism in Table 3.

Provisioning Services	
Water supply	Combination of flows
Timber and Fuelwood	Omni-directional flow
Capture and Collection	Omni-directional flow
Crops	In situ
Fodder	Omni-directional flow
Regulating Services	
Water Quality Regulation	Gravitational flow
Water Flow Regulation	Gravitational flow
Soil Maintenance	In situ
Erosion Control	In situ
Flood Control	Gravitational flow
Carbon Storage	In situ
Habitat services	
Habitat	In situ
Maintenance of Biodiversity	In situ
Cultural Services	
Ecotourism	Omni-directional flow
Cultural Significance	Omni-directional flow

Table 2: Overview of ecosystem services and associated flow mechanisms.

a) In situ	Input	Ecosystem service score map
	Steps	No special calculations are needed.
	Output	The original ecosystem service score map
b) Gravitational flow	Input	Ecosystem service score map
	Steps	1. Calculate total upstream area for each river reach.
		2. Calculate total ecosystem service score based on the upstream area for each river reach.
		3. A mean ecosystem score for each reach is calculated by dividing the total ecosystem score from step 2 with the total upstream area of step 1.
		4. Reclassify mean values into 5 classes/scores. Each class contains an equal number of reaches.
	Output	Ecosystem service supply score map with values for the different river reaches
c) Omni-directional flow	Input	Ecosystem service score map
	Steps	1. Create separate maps for each score occurring in the Ecosystem service score map.
		2. Calculate Euclidean distance to data pixels for each map (score), with a threshold distance of 10 kilometers. The score will decrease with increasing distance from the score value to zero.
		3. Recombine these Euclidean distance maps by selecting the highest value for each raster cell.
		4. The combined "maximum score" map is reclassified in to 5 classes/scores using an equal area algorithm. Each score will cover the same amount of area within the Lake George catchment.
	Output	Ecosystem service supply score map for the entire region
d) Combined flow	Input	Ecosystem service score map
	Steps	1. The different steps of the gravitational flow method are calculated
		2. The different steps of the omni-directional flow method are calculated. As input, the map with ecosystem service scores of the reaches is used.
	Output	Ecosystem service supply score map for the entire region
e) Demand	Input	Population density map on parish level
	Steps	1. reclassification with equal area algorithm
	Output	Ecosystem service demand score (0-5) for each parish

Table 3: Overview of the analysis steps used to map supply and demand.

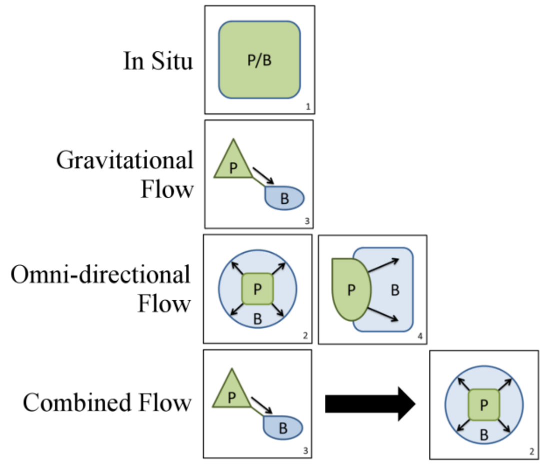

Figure 3: Overview of the different flow mechanisms between provisioning (P) and benefiting areas (B) evaluated within this study (Symbols after Fisher et al (2009)).

2.4.1. In situ

For only a few ecosystem services, demand spatially coincides with the ecosystems that generate/supply these services (= In situ). Most of the ecosystem services require some kind of movement or flow between provisioning area and beneficiary. Agricultural provisioning is considered to be used locally within the region, since most of the population in the Lake George basin depends for their food provisioning on the harvest of their gardens, which surround their houses. Part of the harvest is traded on local markets in the surrounding parishes and along the main roads that cross the basin. Some specific agricultural products (e.g. tea) are traded nationally or even internationally, but these flows are not taken into account due to the focus on local livelihoods and a lack of data.

For some ecosystem services, especially regulating services, the demand takes mainly place on a higher spatial and/or temporal scale (e.g. carbon storage for climate mitigation). Although the impact of these services can be large over time on local livelihoods, we consider demand being equal across the entire catchment. Therefore no specific flow needs to be integrated. Erosion control has a local effect as well as an impact downstream. In this study we only consider the local effect.

In these cases no special calculation is needed and the supply scoring tables can be used directly.

2.4.2. Gravitational flow

Several ecosystem services – particularly those related to water flows - are mediated by a (partially) gravitational flow between areas supplying ecosystem services and beneficiaries. Water is transported downstream to users, while the amount and quality of the water is influenced by the upstream land uses, activities and management. Although a local ecosystem score can be relatively good, the upstream areas can severely degrade the actual supply of the service. Therefore the impact of the entire upstream areas must be evaluated to assess the ecosystem services along a river.

Incorporating gravitational flow in the analysis required the following steps. First, the ecosystem scores of upstream land uses were combined to give an overall score for the upstream areas. Secondly, a river network needed to be defined. The river network and subcatchments of the Lake George catchment were delineated from the Aster II digital elevation model using the hydrological tools in ArcGIS 10. Then, both the subcatchments and the river network were then used to calculate mean ecosystem services scores for the different river reaches (= part of the river between two confluences). For each river reach a total ecosystem service score was calculated by multiplying the ecosystem services table scores of the land cover types with the associated land cover areas within the upstream catchment. This total score was then divided by the total upstream area to get a mean ecosystem service score for the river reach. Finally, the mean scores were finally reclassified using an equal area algorithm to reduce the values to integer scores (1 – 5). The equal area algorithm ensured that each score was attributed to almost the same number of reaches within the catchment. The ecosystem services that are evaluated with the gravitational flow have an impact on the river itself but no or only a limited impact on the surrounding region. Therefore scores are only attributed to the reaches and not to the surrounding land. The scores allowed for further analysis (see 2.5 and 2.6).

Ecosystem services that are evaluated with the gravitational flow script are water bound (water quality regulation, water flow regulation and flood protection) and have no or limited impact on the surrounding region. Flood protection does have a significant impact on the flood areas adjacent to rivers, but it is difficult to assess the size of the area affected and it is difficult to translate this in to maps. Therefore values are assigned to segments of the river system itself and not to the surrounding land. As a result, ecosystem services scores are limited to the river reaches and cannot be evaluated on a parish level. Instead a comparison is made between the original mean ecosystem services scores on sub catchment level and the output of the flow script for the related river segments within the sub-catchment.

2.4.3. Omni-directional flow

The most common flow mechanism for ecosystem services is the movement of people to the supplying areas for local use or extraction of the service. Service provisioning depends on both the intensity of the supply (supply score) and the distance that needs to be covered to the provisioning area (distance decay effect). Because the focus of this study was on the role of ecosystem services in semi-subsistence livelihoods, the actual service delivery is limited by the ability of people to walk to the supplying areas. We hereby disregard other means of transportation. Maximum walking distance was established at 10 kilometres, based on local knowledge.

A Euclidean distance algorithm was used to calculate a separate distance map for each of the six ecosystem services scores (0-5). Therefor the original supply map was split into 6 different maps, where each map comprises the areas with the same score and for which the Euclidean distance was calculated. The Euclidean area algorithm results in maps with decreasing ecosystem services scores as distance from the supplying areas increases. At a distance of 10 kilometres the ecosystem services score will be zero. The 6 maps were then integrated into one by selecting the highest value for each cell. The assumption here is that people will make a trade-off between the amount and quality of the provided ecosystem service and the distance they have to walk to reach these supply areas. The integrated map was finally reclassified, using the previously described equal area algorithm.

2.4.4. Combination of flows

For many ecosystem services, multiple flow mechanisms contribute to the flow of ecosystem services to the beneficiaries. Therefore a combination of flow mechanisms is needed to mimic delivery. As an example, we take the case of water provisioning, where water first flows downstream through the rivers (gravitational ecosystem services flow mechanism), and beneficiaries walk to the stream or lake to collect the water (omni-directional ecosystem services flow). Water provisioning is evaluated based on both supply from the upstream catchment and the maximum distance people can walk to get to a water supply. Because the catchment has many crater lakes, these sources also have to be taken into account as potential supply. This is achieved by integrating the procedures for gravitational and omni-directional ecosystem services flows. First a score is calculated for the different river reaches. Subsequently, the omni-directional flow is calculated for both the river reaches scores and the crater lakes that are extracted out of the original ecosystem service maps.

2.5. Evaluation of flow effects

The effects of accounting for ecosystem service flow mechanisms on the spatial configuration of the scoring maps were evaluated by comparing the resulting maps with the original ecosystem service scoring maps. Analysis was done on a level that allowed us to compare the different maps and assess changes in spatial distribution of the ecosystem service provisioning. Therefore mean ecosystem scores were calculated on a parish (omni-directional flow and combination of flows) or subcatchment (Gravitational flow) level. Ecosystem scores were evaluated as a value per square meter, summed for the entire parish or subcatchment and divided by total area of the parish or subcatchment. The derived mean values were then reclassified to an integer score between 1 and 5 (no zero values were present on parish or subcatchment level) using an equal area algorithm. As a result indicator scoring between 1 and 5 covered almost equal areas within the catchment for both the original as well as flow maps. By ruling out the effect of changes in value distribution (applying the equal area algorithm), the effect of the flow calculations on the spatial configuration of ecosystem services could be analysed.

2.6. Evaluation of ecosystem services delivery

Parishes are the smallest scale for which demand maps can be made and management can take place. As such they can be regarded as service supply/demand units. Analysis of supply/demand mismatch at the parish level is only useful for provisioning and cultural services because the demand for regulating and habitat services is independent of population densities and/or takes place on higher spatial levels. The maps of the selected ecosystem services supply and demand on parish level were combined and evaluated with a conversion table (Table 3), which translates each of the supply and demand combinations in to a new value class between 0 and 5 (Fig. 4), representing ecosystem services delivery. High values imply a combination of a high demand and a low supply, indicating an important shortcoming in delivery. Low values indicate a sufficient availability of the ecosystem services or a low demand.

Score		Demand 0	1	2	3	4	5
Supply	0	0	4	4	5	5	5
	1	0	3	4	5	5	5
	2	0	2	3	4	4	4
	3	0	2	3	3	3	3
	4	0	1	2	2	2	2
	5	0	1	1	1	1	1

Table 3: Table to assess delivery of ecosystem services based on the supply and demand map. High values indicate a potential deficiency in ecosystem service supply compared to the demand.

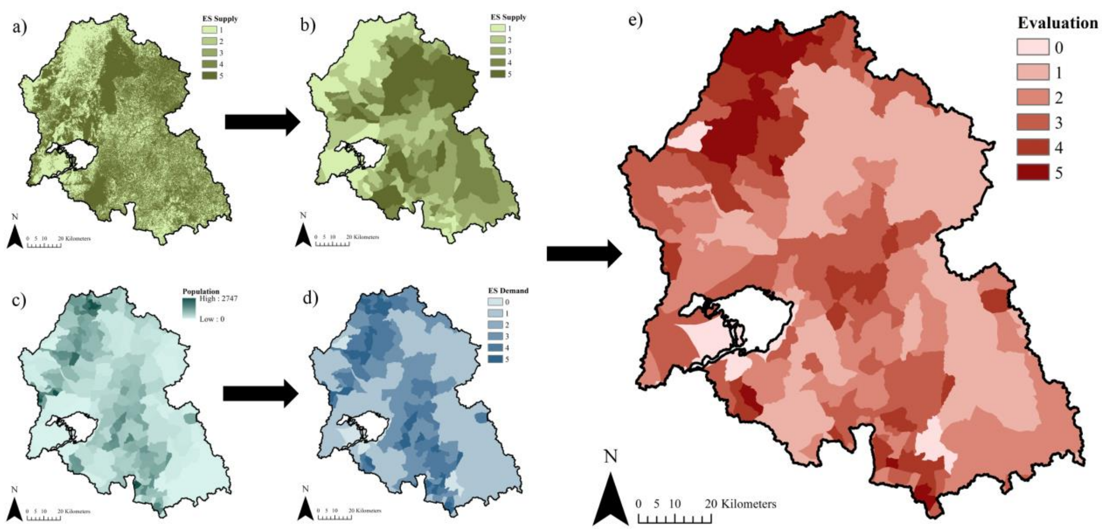

Figure 4: Overview of how both ecosystem services supply (A) and ecosystem services demand (B) are translated to qualitative indicators on parish level (B and D) and are combined to assess the actual delivery of ecosystem services (E).

2.7.Scenario analysis

Three land use change scenarios were developed to simulate potential trends in development and implementation of specific natural resource management actions. Each of the scenarios targets a specific type of land use and associated range of ecosystem services. But improving specific land-uses and ecosystem services typically also affects other ecosystem services. The evaluation of these scenarios gives an indication on how ecosystem service delivery is affected across the research area. This information allows better informed choices in land development to improve local livelihoods.

- **Deforestation:** For this scenario we consider a complete deforestation of the region (including national parks) in five time steps. This represents a worst case scenario for deforestation in the catchment. Due to a lack of reliable data we did not define a specific time-step for the deforestation. Therefore we opted for the following approach. In each of the five time steps one fifth of the remaining forests is converted to agricultural land. The scenario is developed to first deforest the smaller, fragmented areas. Only in the later stages the large forests will fully disappear. The goal of this scenario is to see how the different ecosystem services are impacted by the ongoing deforestation and which areas will be affected the most.

- **Agroforestry:** 25% of the most erosion-vulnerable areas of the region that are now used for agriculture are converted to agroforestry. The scenario targets improvement in both water related services and wood production.
- **Plantations:** Parts of the agricultural land are converted to plantations for wood production. The areas for conversion are selected based on population densities and erosion vulnerability. The higher the population density the more of the agricultural land (maximum 25%) will be converted to plantations for wood production. This scenario targets wood production at the expense of agricultural production.

In order to make a comparison between the current land use and scenario outcomes, we used the following protocol. For the actual land-use, the results from the flow scripts were reclassified using an equal area reclassification for each ES. The break values of this equal area reclassification were then used to reclassify the ecosystem service scores for all scenarios. Applying a new equal area algorithm for each scenario and service would make a comparison between the scenarios impossible. This would in fact change the meaning of each ecosystem score and shifts in values would be masked, because it would result different break values for each scenario and service. The deforestation scenario would for example result in a significant decrease in timber and fuel wood provisioning. However, the equal area algorithm would still give one fifth of the case-study a score of 5, making a comparison between scenarios meaningless. Instead the break values used in the equal area algorithm to reclassify current land use scores after calculating the different flows were applied to the scenario outcomes. As a result the areas with a certain ecosystem services score would increase or decrease compared to the current land use analysis.

Ecosystem services demand was considered static, although we are aware that also demand is affected by land-use change. The high population growth in Uganda will result in increases in population densities and eventually also affect population distributions within the catchment. Local increase in population densities will for example coincide with conversion from forest to agricultural land and vice versa. The scenarios will therefore also result in local changes in ecosystem service demand. We were however not able to develop reliable population scenarios that can objectively be linked to the scenarios. Therefore the land use scenarios were evaluated with the existing population data.

3. Results

3.1. Original scoring table

Together, local experts scored the ecosystem services for each land use class, incorporating knowledge they gained from several stakeholder workshops. Natural vegetation types generally provide more ecosystem services and generate higher scores than anthropogenic land uses. Local knowledge was especially valuable for the evaluation of some provisioning and cultural services. Most of the scorings are in line with expert scoring from other studies. However, some results are case-study specific. The water supply score of plantation and woodlots is lower than farmlands, since plantations and woodlots generally consist of plants (e.g. eucalyptus) that have a higher water use than crops, which results in lower water availability. Grasslands also have a high cultural significance for some of the ethnic groups in the research area.

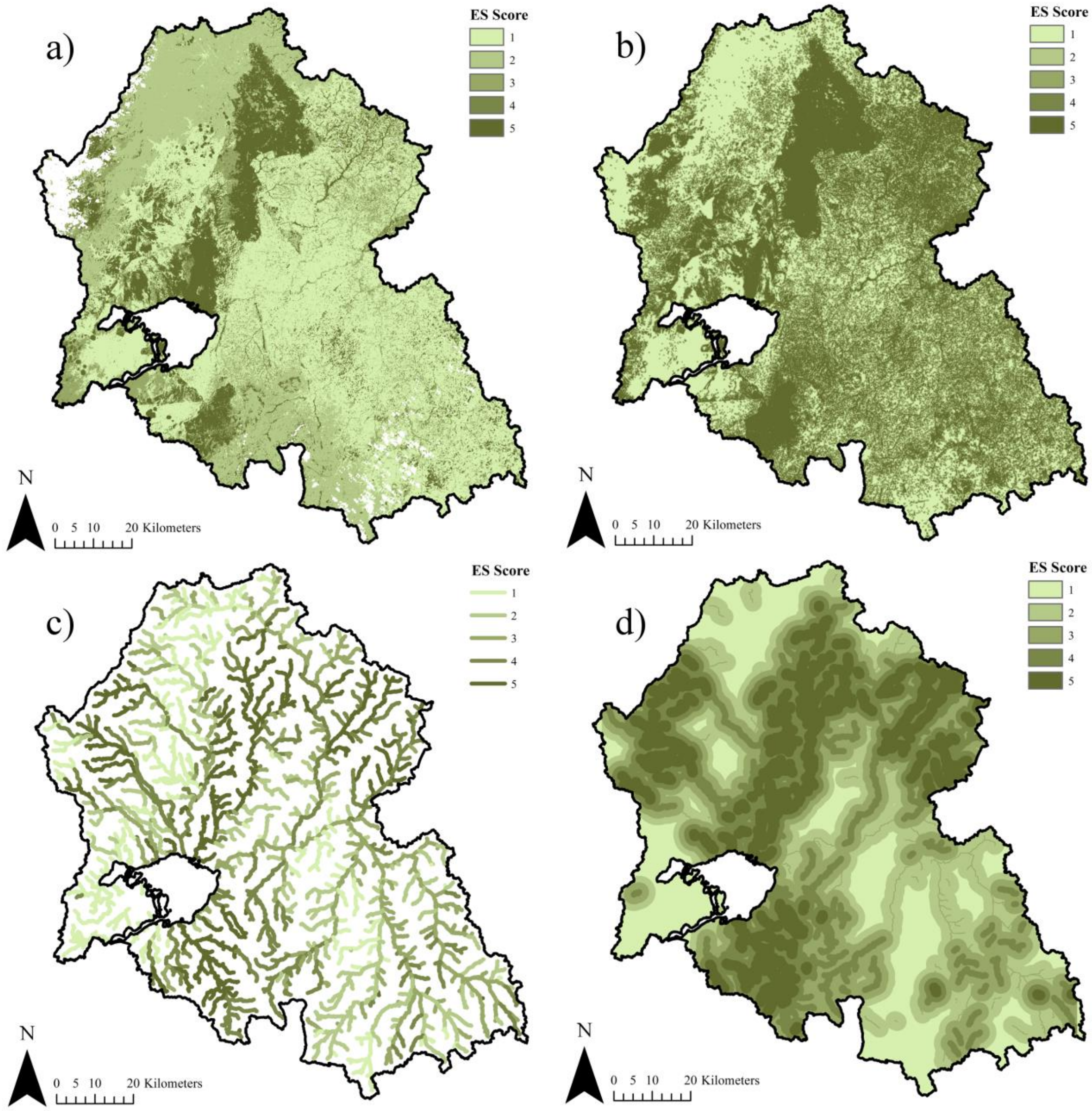

Figure 5: Output examples of the different flow scripts a) In Situ (biodiversity), b) Omni-directional flow (Timber and Fuelwood), c) Gravitational Flow (Water Quality Regulation) and d) Combined Flows (Water Provisioning).

3.2. Flow effects on scores

Each of the ecosystem services flow calculations has a different impact on the evaluation of the service, changing how scores are distributed within the region (Fig. 5).

Integration of the omni-directional flow in the ecosystem services score calculation has a clear impact on the spatial configuration of the ecosystem services scores (Fig. 6). When comparing the mean ecosystem services score on parish level there are clear changes in values. The impact for many parishes is relatively small, some parishes are heavily affected; and the impact differs between the different services. Fodder production scores for example changed drastically, completely altering the spatial configuration of the service. This indicates that provisioning areas for fodder production are unevenly distributed within the region and located outside of the main living areas.

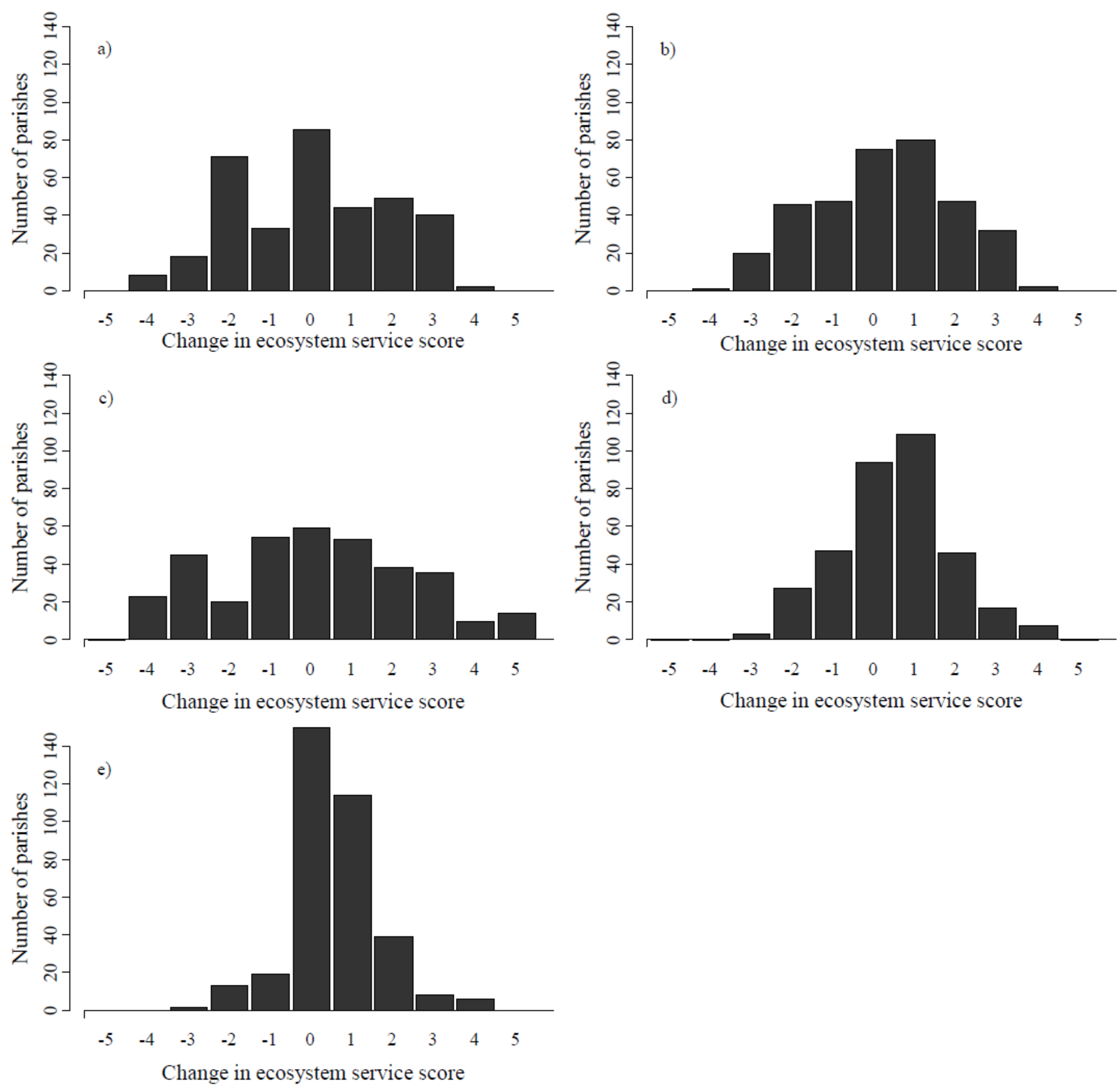

Figure 6: Changes in ecosystem score on parish level between original calculation and after taking the ecosystem services flows (Omni-directional) into account a) Timber and Fuelwood, b) Capture and Collection, c) Fodder, d) Cultural Significance, e) Ecotourism.

Incorporating gravitational flow results in a different type of output compared to the other three flow mechanisms. Values are assigned to the different river segments of the river system itself and not to the surrounding land (Fig. 7). Again the different ecosystem services are impacted to a different extent by the flow script. For example, some mountain sites of the Rwenzori Mountains are heavily impacted by deforestation and the development of agriculture. Streams downstream of these areas have a poorer water quality compared to the more pristine rivers coming from the mountains. These differences are reflected by the flow calculation. Water provisioning scores were calculated and evaluated on a parish level by combining both gravitational and omni-directional flow scripts. The results after incorporating the combination of flows correspond more closely with the actual situation than the scores mapped without accounting for ecosystem services flows. For example, water provisioning downstream of Kibale Forest is much better due to water quality improvement and buffering of flow, compared to the reaches upstream of the forest, which are polluted by the city Fort Portal. Areas located nearby or downstream of forests and wetlands sites have the highest ecosystem services scores as, the upstream forests ensure a better provisioning of water to areas where it is not expected in first instance. This effect is also visible along downstream river reaches that run through agricultural areas. The effect of the upstream forest weakens further downstream as agriculture and habitation progressively degrade the water provision. The changes in ecosystem service scores on parish level are depicted in figure 8.

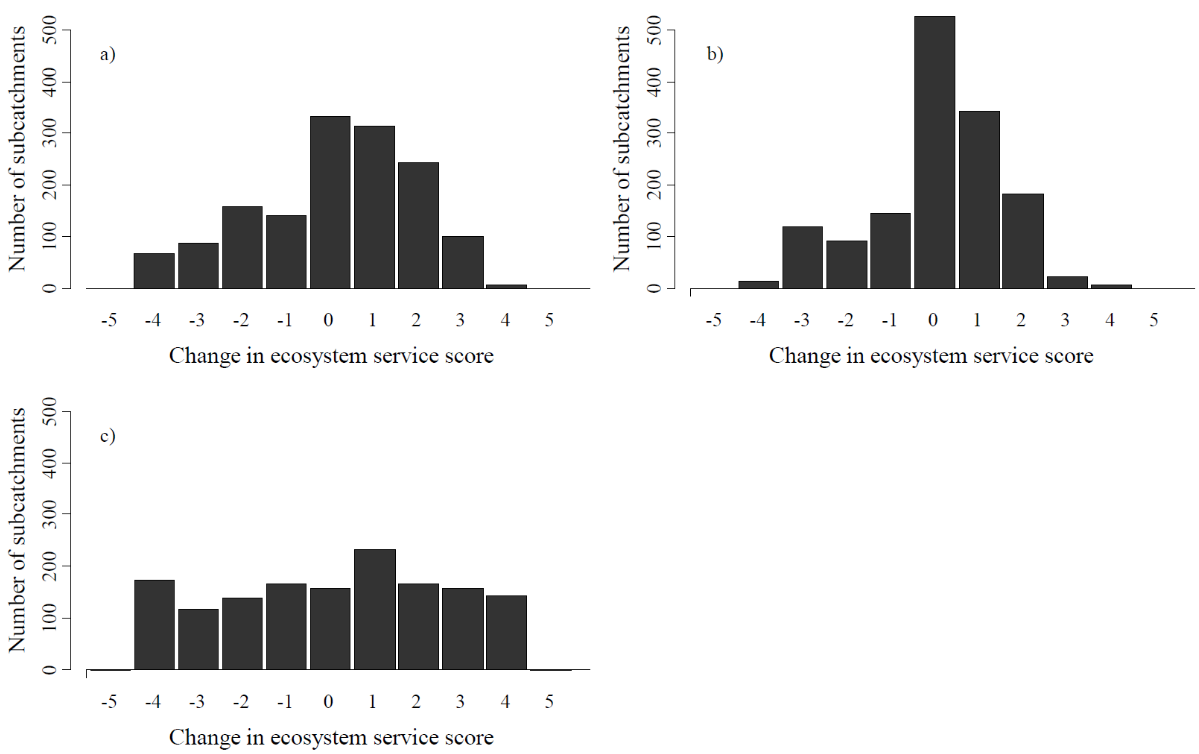

Figure 7: Changes in ecosystem score on subcatchment/river segment level between the original calculation and after taking ecosystem services flows (Gravitational) into account: a) Water Quality Regulation , b) Water Quantity Regulation, c) Flood Regulation .

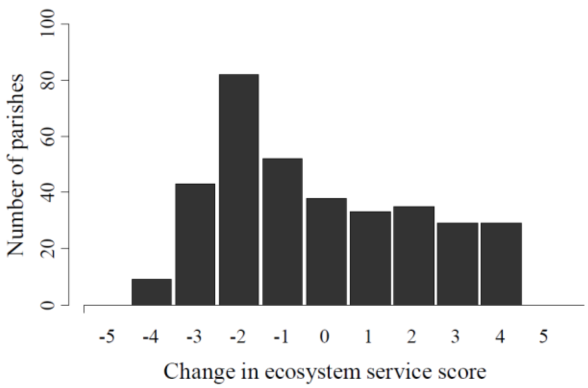

Figure 8: Changes in ecosystem score on parish level between the original calculation and after taking a the ecosystem services flow (Combined) into account for Water Provisioning.

3.3.Scenario analysis

The scenarios were analyzed, taking the different flows into account, and assessed on their impact on both ecosystem services scores and ecosystem services delivery.

Deforestation has a strong negative impact on many of the ecosystem services, for example water quality regulation (Fig. 9). The first step in the stepwise deforestation scenario has by far the strongest impact on the water quality regulation. This is because the scenario first deforests the smaller, fragmented areas. Therefore many of the smaller, upstream subcatchments are strongly impacted as they lose their last forest remnants. The larger forest areas, that are situated more downstream, are less vulnerable to this first step of deforestation. As a result the downstream reaches of the river network are only strongly impacted in a later stage of the deforestation.

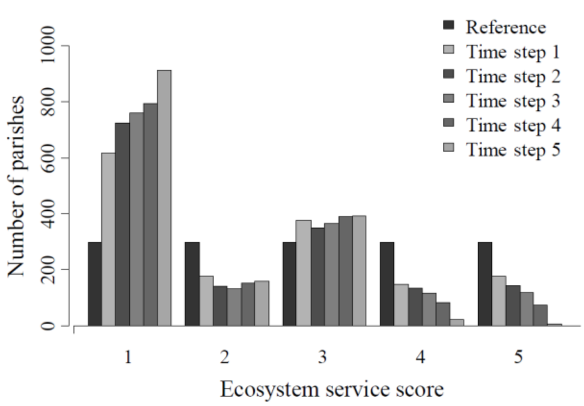

Figure 9: Changes in Water Quality Regulation on river segment level for the reference scenario and the 5 deforestation scenarios.

In addition to this worst case scenario of stepwise deforestation, two alternative management scenarios were developed to improve natural resources and ecosystem services delivery, namely agroforestry and plantations. When evaluating both management scenarios for the ecosystem service 'timber and fuel wood production', strong differences in impact were found (Fig. 10). Deforestation has clearly a negative impact on the provisioning of wood. The number of parishes that have scores between 2 and 5 all decrease, while the number of parishes with score 1 increases. At the same time the discrepancy between demand and supply for timber/wood increases. When evaluating the management scenarios, agroforestry has by far the largest impact on ecosystem services supply. Most of the parishes reach an ecosystem score of 5 and a discrepancy in delivery of 1. The impact of the plantations scenario on ecosystem services delivery is less pronounced because the experts attributed lower scores to the plantations (4 instead of 5). As a result the positive changes in ecosystem service supply have a spatial mismatch with the demand for ES.

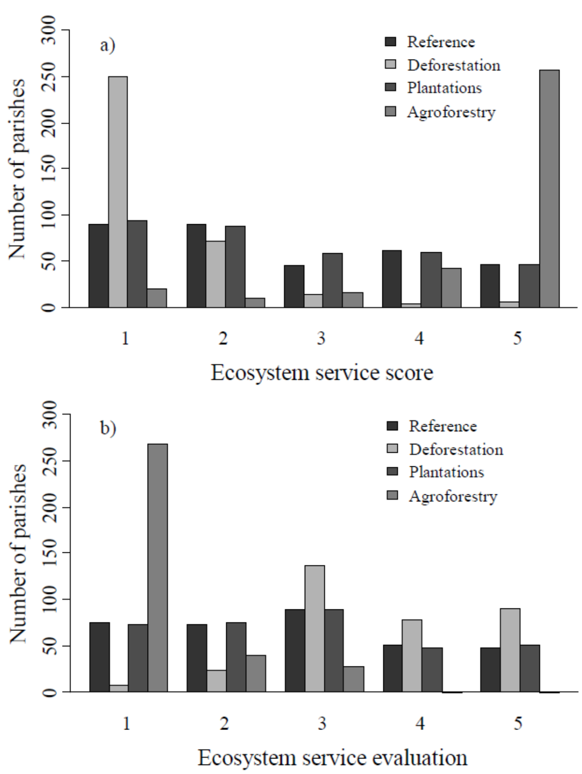

Figure 10: Changes in ecosystem service score (a) and delivery evaluation for Timber and Fuelwood production under the different scenarios.

4. Discussion

4.1. Integration of flows

A methodology was developed to integrate flows into ecosystem services scoring maps and assessments. To do so, scripts were developed to recalculate the qualitative scorings, taking spatial relationships into account. As there are distinct differences in characteristics between omni-directional and gravitational flow, the scripts reassess ecosystem scores in different ways. The resulting maps give different weights to the ecosystem scores, compared to the original scoring maps.

Taking flow mechanisms into account changed and improved the results, as it incorporates a crucial aspect of the ecosystem services concept, namely the spatial connectivity between ecosystems and their beneficiaries (Bagstad et al., 2013). Ecosystem supply and demand scores are typically evaluated on the level of administrative units, for which socio-economic data (ecosystem service demand) is available. However in the classic approach discrepancies between supply and demand are difficult to assess on this administrative level, as effects of the ecosystem service flow over administrative boundaries can have a profound effect. For example, large forests located in the adjacent parishes can have a positive impact on the delivery of the ecosystem service; but will be completely disregarded in the classic approach. By integrating flows, the full potential of the service providing areas can be taken into account, making the ecosystem service evaluation more reliable.

However, not all flows could be incorporated into the analysis. Other means of transportation like motorbikes and trucks increase/improve ecosystem service delivery in some parts of the region, but these flows are more complex and difficult to predict. Although anthropogenic infrastructure and other investments do facilitate certain flows of ecosystem services, they were less relevant within the context of this study. The aim of this study was to analyse and provide information to improve the livelihoods of the local, poor people in the region. Ecosystem services flows at higher spatial scales are less relevant as transportation is most often unavailable to these local people. Further research may be imperative, as such transport mediated ES-flows become important in developing countries and compete with local ES-flows.

Our results clearly illustrate the significance of incorporating flows in the ecosystem service analysis. However the importance is dependent on the scale and objectives of the study. For some ES, such as climate regulation, flows were not considered, because they encompass a much higher administrative or management level. The selection of the relevant ecosystem services and flows thus depends on the scale and objectives of the study.

The demand for an ecosystem service has, compared to the supply, an equal weight in the final result, when evaluating the ecosystem service provisioning. Therefore the mapping of the demand and spatial representation in the analysis is of equal importance and needs to be well considered. To evaluate and integrate the demand for ecosystem services in the region, we used population densities as proxies. Demand for the ecosystem services that were tested for delivery (provisioning and cultural services) is directly related to number of people using these services e.g. amount of drinking water needed or number of people who use an area for cultural practices. Although we initially tested land scoring tables for mapping demand, we considered population density to be a more reliable, indicator for many, (but not all) ecosystem services than the land cover map.

The results obtained from the analysis cannot give us information as to the extent that this supply meets the actual demand. Qualitative maps can therefore not be used to analyse whether ecosystems are used in a sustainable way, as the qualitative data do not contain the correct information to make these conclusions. They can however indicate where in the region the discrepancies between supply and demand are the highest, overexploitation is most likely, management actions are mostly needed and where they will have the biggest impact.

Due to the data scarcity and the qualitative nature or the output, validation of the model results remains a challenge and a research topic for the future. To what extent the qualitative model outputs represent the actual situation is difficult to assess. Further stakeholder consultation might help to improve the maps in the future and evaluate their weaknesses. But communication of the results has to be well considered and a consistent evaluation methodology needs to be developed.

4.2. Use of the methodology

Incorporating ecosystem services is not yet common practice for INRM-assessments, and how they can be integrated in INRM is still a topic of discussion. Where in the INRM framework can ecosystem services have an added value? Can quantitative and qualitative INRM and ecosystem service methods be compatible? How do we cope with different levels of accuracy? Can we integrate the different ecosystem services taking different types of flow into account?...

INRM aims to evaluate all relevant natural resources and is benefited by methods that can analyse this full range of natural resources. Qualitative assessments of ecosystem services provide an opportunity to comprehensively analyse all relevant ecosystem services. Exclusion or misrepresentation of important ecosystem services in INRM can result in misleading outcomes and undermine the reliability of proposed management actions. Qualitative assessments are less limited by data availability than quantitative approaches (Busch et al., 2012), making them highly applicable in data scarce regions.
Inclusion of local stakeholder knowledge is also an important factor in INRM, which emphasises integration of local knowledge in developing management strategies and building local support for management (Douthwaite et al., 2005). Subjective qualitative assessments by multiple stakeholder groups can help to assess the diversity of stakeholder views and perspectives relating to ecosystem services delivery, and improve stakeholder interaction.
In both cases, data scarcity and stakeholder incorporation, qualitative assessments can contribute in the development of 'good' INRM plans.

In many studies "hot spots" that provide many different ecosystem services are mapped (e.g. Naidoo et al., 2008; Raymond et al., 2009), since these are considered to be highly valuable and require protection (Egoh et al., 2008). Although this information would benefit INRM, using the results from the different scripts for the analysis and identification of ecosystem services hot spots is not recommended. Combining the final ecosystem services maps has no meaning, because of the different types of flow mechanisms and outcome of the scripts. Combining maps of ecosystem services supply is appropriate for the mapping of supply hotspots, but usually does not incorporate use or flows to beneficiaries. Incorporating use and flow aspects would require scripts that can trace back ecosystem services from beneficiaries to the supply sites. These trace-back methods would also require a quantitative approach to ecosystem service flows and will not work with the qualitative scoring.

Due to the calculation procedures, ecosystem services scores will not have the same weight for each ecosystem service. The interpretation of the values is service and case-study dependent and the interpretation exercise is of as much importance as the development of the ecosystem scoring tables. In addition, not every ecosystem service is of the same importance to the case study or has the same weight within a study. Simply combining the different output results would lead to unreliable outcomes. The results should therefore be used to evaluate the ecosystem services individually, within a spatial context.

In data scarce regions it is difficult to assess whether data and knowledge transfer from other study sites is appropriate and useful. When considering INRM and livelihoods, local ecological and socio-economic characteristics can differ significantly even over short distances, and data transfer can therefore provide unreliable results. However, when good quantitative data are available or can be compiled, the ecosystem services scoring method should be avoided and instead quantitative methodologies or qualitative derivatives of the quantitative data should be considered.

5. Conclusion

The integration of ecosystem services in IRNM has only just started and is still a topic of discussion. How and where it is integrated within the INRM framework can depend on the goal of the study and the characteristics of the study site. In data-scarce regions qualitative ecosystem services assessments provide a possibility to overcome some of the data issues and incorporate local knowledge in the analysis. However, in order to obtain reliable and relevant results for INRM, different aspects of the ecosystem service framework need to be addressed.

Ecosystem service flows are a fundamental aspect of the existing ecosystem service concept, although not often addressed, especially in qualitative ecosystem services assessments, which lack a biophysical modelling component. In many studies, ecosystem services with a strong flow component between supply area and beneficiary are excluded from the analysis. In other studies, these spatial flows are not explicitly dealt with, which results in less reliable data when supply and demand are compared at the local scale.

Within the framework of a larger INRM project we developed scripts to mimic ecosystem services flow mechanisms between ecosystem services supply sites and the beneficiaries. We used conventional expert scoring methods for ecosystem services supply in the Lake George catchment, Uganda. The ecosystem services flow scripts were applied on these datasets to calculate ecosystem services delivery maps (combination of demand and supply).

Integrating flow mechanisms into the qualitative assessment of ecosystem services provided added value, as results better represent the actual situation. In this paper we demonstrate that the comparison of supply and demand of ecosystem service scores after incorporation of the spatial flow mechanisms differed significantly from the static analysis that is more commonly applied, but does not reckon with flows across administrative or physical boundaries. The incorporation of flows makes the evaluation of ecosystem services supply and demand more relevant and reliable for applications within an INRM context. However the use of the mapping method should be carefully considered. These qualitative methods are useful for evaluation of management in data scarce regions, but do not replace more complex and accurate, models and methodologies where data are available to support them.

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