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Modeling trade-offs among ecosystem services for agriculture in the “Sisal Belt” of Kilosa, Central Tanzania

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Abstract

Context.

Exploring novel ways to maintain a healthy landscape while improving human welfare based on different human-environment relationships and competing interests from multiple stakeholders is critical for sustainable development under the context of the surging “global land rush” underway, and of increasing interest to landscape sustainability science.

Objectives.

This paper aims to: (1) integrate perceptions across various stakeholders to create landscape-based decision-making scenarios based on alternative future development visions, and (2) demonstrate trade-offs and synergies among ecosystem and economic benefits in a landscape under the scenarios and discuss the means to incorporate results from analyses into landscape management and planning.

Methods.

We combined the use of two spatially explicit modeling tools, Future Land Use Simulation (FLUS) and Integrated Valuation of Ecosystem Services and Trade-offs (InVEST), to project future landscape patterns and predict changes in ecosystem services and commodity production under the three stakeholder-defined scenarios for the Kilsoa sisal belt region, Tanzania.

Results.

We found that all scenarios had higher commodity production values relative to the baseline conditions but various lower levels of ecosystem services. Carbon and water services may generate synergistic effects provided specific mitigation and payment mechanisms are installed.

Conclusions.

Our approach provides an effective platform by which landscape management and planning decisions can be determined. An effort as such may enrich the dialogue amongst multi-level stakeholders dealing with the environment and development in the area and inform policymaking to balance the challenging goals among food production, resource use, poverty alleviation, and environmental conservation.

1. Introduction

The onset of the 21st century has escalated competition over global arable land (Meyfroidt 2018). While the increased agricultural demand in the previous century had been met by increasing the productivity and intensification of agriculture, various assessments indicate that an expansion of agricultural land will be needed to meet the near-future global demands (e.g., Williams et al. 2020). Moreover, the recent global crises in food, energy, finance, and the environment compound this challenge, translating into the

acquisition of large tracts of land internationally by those actors sufficiently powerful to do so to provision various products (Cotula 2012; Müller et al. 2021).

In such circumstances, large-scale farmland acquisitions in the global South have surged, creating a "global land rush," commonly referred to as land grabbing (Messerli et al. 2013; Yang and He 2021), that may also involve water grabbing (Rulli et al. 2013). According to Land Matrix (2021), most of these land-based investments involve the establishment and operations of transnational agricultural estates for commercial production. A major share of such estate-driven land grabbing has been undertaken in Sub-Saharan Africa (SSA) (Hufe and Heuermann 2017; Baterbury and Ndi 2018; Ashukem 2020; Neef 2020).

The potential implications of this wave of land rush across SSA have been controversial, especially when intertwined with local smallholder livelihoods (Herrmann 2017). On the one hand, estate investments may enhance smallholder welfare through employment, technology and expertise transfer, and new opportunities for commercial farming, potentially leading to rural economic transformation (Deininger and Byerlee 2012; Hall et al. 2015). On the other hand, the concerns about the loss of smallholder land access, disrupted subsistence food provisioning, and increasing risks of environmental degradation are widespread (Edelman et al. 2013; Hall et al. 2017; Sulle 2020). Different outcomes, both perceived and actual, often involve the trade-offs between smallholder production, estate development, and ecological functionalities.

Such trade-offs are apparent in the Kilosa "sisal belt" area, central Tanzania (hereafter, KSB), where Chinese firms have resurrected former colonial sisal estates and offered wage opportunities to neighboring communities, and where smallholders have increased commercial rice production while preserving basic subsistence production. The combination of estate labor, subsistence, and rice cultivation has enhanced the livelihoods of many households but increased land pressures from rice expansion and arriving migrants' subsistence activities, with consequences for the landscapes.

What are these consequences and sustainability implications for the estate-smallholder conditions––as coupled human-environmental systems––now and projected into the future? These questions are central to informing global environmental change and landscape sustainability sciences and serve as a backdrop to development decisions (e.g., Wu 2013, 2019; Lambin et al. 2021; Turner et al. 2021). Pragmatically, as ecosystems generate a range of goods and services essential for human wellbeing––collectively called ecosystem service (Kumar 2010)—a thorough understanding of socioeconomic and ecosystem consequences under plausible landscape patterns, smallholder, and estate nexuses is informative and may inform local resource management and environmental governance decision-making to guide estate investments, rural development, and policies/payment programs.

This study integrates public perceptions and experiences across various stakeholders with empirical field data to create three landscape-based decision-making scenarios in KSB, based on future estate-smallholder dynamic conditions under alternative development visions. The application of a suite of ecological functions and economic valuation models, integrated into InVEST (Integrated Valuation of Ecosystem Services and Trade-offs), demonstrates how these scenarios affect hydrological services

(water quality and annual yield), carbon storage, and the value of several marketed commodities (agricultural crop products). Importantly, we also explore the spatial patterns of ecosystem service provisioning across the landscape under the scenarios, highlighting synergies and trade-offs between multiple ecosystem services and market returns.

2. Ecosystem Service Assessment, Stakeholders, And Scenarios For Ksb

Large-scale estate investments in agriculture play an increasingly critical role in raising pressure on the landscapes of Tanzania. Whether these investments promote quality livelihoods and vibrant rural economies without compromising environmental losses remains a key question. Despite the existing development and policy guidelines developed at the international level (e.g., Committee on World Food Security 2014) and state/regional level (e.g., The Tanzanian Development Vision 2025; Kilimo Kwanza––Agriculture First; Southern Agricultural Growth Corridor of Tanzania––SAGCOT) to hold foreign-owned estates accountable for sustainable land use and investments, a paucity of empirical evidence exists on how the integrated goals can be reconciled. The challenge is twofold.

First, nature provides a wide range of benefits to people. There has been increasing consensus about the importance of factoring these ecosystem services into local and regional resource use decisions (Nelson et al. 2009; Tallis and Polasky 2009; Ronchi 2021). These services, however, are spatially explicit and temporally dependent––not only does the amount of a service matter, but also where and when it is provided, rendering difficulties for policy and planning assessments. Second, different stakeholders may seek different demands from the services (Li et al. 2021). In the case of KSB, the international development agencies and local governments emphasize a robust landscape, presumably maintaining a variety of ecosystem services, whereas the Chinese sisal estates and neighboring smallholder farmers, the two most important producers, land users, and stakeholders in KSB, focus on those services provisioning high agricultural returns. Reconciliation and compromises of these competing demands require novel methods and datasets to identify potential trade-offs between different services, optimize policy decisions, and generate synergies between them (Reed et al. 2016).

Various frameworks employ social-environmental assessments to integrate stakeholders' distinctions regarding ecosystem services (e.g., Whitfield and Reed 2012; Malinga et al. 2013; Villamor et al. 2014). Many of them are largely heuristic, however, with minimal capacity to provide quantitative and spatially explicit information about the likely consequences in question. Biophysical and economic models, in contrast, quantify the impacts on multiple ecosystem services derived from different policies and actions, allowing for various simplifications and uncertainties (e.g., Bagstad et al. 2013; Duarte et al. 2016; Xu et al. 2018). The model influence on actual practice is, however, commonly muted in cases where local stakeholders have not been party to the model development or the policies that follow. Their involvement is referred to as a co-design practice. Efforts addressing multiple ecosystem services by way of co-design (e.g., stakeholders, scientists, models) approaches have been few (Goldstein et al. 2012), but are increasing (e.g., Karrasch et al. 2017; Saito et al. 2019; Asah and Blahna 2020; Li et al. 2021).

The key assumption in sustainable development is the need to balance the trade-offs among the targeted ecosystem services (Reed et al. 2020; Wu 2021)—which among agriculturalists includes produce—identified by various stakeholders to achieve synergies among them. In the case of KSB, or under the prevailing circumstances of the land rush underway across SSA in general, the services supporting estate development, local livelihoods, and international/state/regional concerns for landscape conservation are at issue, with the aim of producing a land-use strategy that serves the needs and wants of all parties.

Based on existing conditions and processes, our approach employs co-design scenarios––plausible descriptions of future states of the world co-designed with local stakeholders––and applies in modeling exercises providing quantitative outcomes. To represent realistic future possibilities, three scenarios of estate-smallholder nexuses, land use, and local development in KSB are explored in light of a series of internally consistent storylines grounded on the competing interests and expectations among stakeholders, especially the Chinese sisal estate and local smallholders. Specific attention is given to the services regarding carbon, water, and commodity production to inform local land-use decisions and policy implementations. This assessment constitutes a relatively underdeveloped approach and the first quantitative-scenario-based attempt to address the human-environmental futures of KSB.

3. Study Area

As one of the six districts of the Morogoro Region in Tanzania, Kilosa has a long history of sisal production. At the time of independence in 1961 (Tanganyika), there were 14 sisal estates in operation in Kilosa (Floor and Kaihura 1990). These estates were either abandoned or discontinued by the late 1980s. In 1999, China Sisal Farm (CSF) consolidated two colonial sisal estates (Rudewa and Kisangata) with a total area of 6,900 ha to produce and export roughly-processed sisal fibers to China. By 2018, CSF has rehabilitated 2,300 ha sisal plantation, creating the second-largest sisal fiber producer and exporter in Tanzania (Fig. 1).

Located in the central-northern part of Kilosa, the KSB area comprises three wards, Moswero, Rudewa, and Madoto, covering 1,433 km^2 at elevations ranging from 368 to 1,802m above sea level. Three major landscapes constitute KSB's territory, each supplying different ecosystem services supporting distinct livelihoods (Fig. 2). A forested highland dominates the northwestern part of KSB, which descends southeastward into the second landscape––a sparsely-vegetated lowland plain. The majority of the KSB population practices subsistence activities and the estates operate in this space. This plain stretches to the east and south from B127 Road, where it meets the third landscape––a vast woody savanna––providing support for Maasai nomadic herding, one of few human activities undertaken in this space. In contrast, the forested land and lushly vegetated floodplains of the Wami River and its branches are exploited for various purposes, such as timber, firewood and charcoal, and hunting.

The CSF sisal fields intersect with the three wards, and sisal operations provide smallholders from 12 neighboring villages with an additional means of employment. Smallholders typically cultivate maize and beans on their land for subsistence, and increasingly, rainfed rice for the market. CSF, by contrast, relies

on smallholder labor to maintain its operations. The wage labor opportunity poses a distinct attraction for migrant laborers, causing the KSB population to have nearly tripled over the past two decades. To expand sisal production, CSF plans to enter into outgrowing schemes in which the adjacent smallholders are encouraged and subsidized to produce sisal on their own land. The outgrowers are paid through a division of proceeds after the CSF sells the fibers. Some pilot smallholder outgrowers have planted sisal in their fields since 2016. This scheme is expected to propagate outgrowing production when the stable monetary returns made by pilot outgrowers are demonstrated.

In addition to livelihoods, the estate-smallholder interactions may also have significant ecological impacts from the landscape dynamics at play. In the past two decades, lowland and mountain forests have been converted into cultivated land, posing threats to maintaining multiple ecosystem services, especially those regarding water, soil, and carbon. Hence, fostering local economy while maintaining a healthy landscape has been emphasized in local policies and development goals. Within KSB, however, inadequate farming practices, conversion of native land covers to cultivated land, and large-scale estate investments are underway, generating ecosystem-service and socioeconomic trade-offs among different stakeholders.

4. Material And Methods

4.1. Dataset

The key dataset used in our research is a 2018 land-use land-cover (LULC) base map created from Google Earth Engine (GEE, https://earthengine.google.com) remote sensing and classification algorithms based on the synergistic use of Sentinel-1 and Sentinel-2 image collection (Fig. 2: 2018 baseline map). Nine LULC classes were identified in Table 1, informed by local knowledge about phenology.

Table 1
LULC Classes

Class ID	LULC class	Description
1	Sisal	Standardized sisal monocropping in CSF estates
2	Mix-crop	Intercropped maize and pigeon pea; one or, in a few cases, two yields annually
3	Rice	The primary smallholder cash crop in the sisal belt
4	Residential	Built-up rural settlements
5	Savanna	Sparsely-vegetated grassland; transitional space between forest and cropland
6	Water	Wami River and its tributaries, most of which are seasonal, and some ponds
7	Forest	Highland densely-vegetated woodland
8	Abandoned sisal	Deserted old sisal fields, usually intergrowing with tree/shrubs
9	Outgrowing sisal	Sisal planted by smallholder outgrowers under contract

InVEST (below) contains a suite of modules that use LULC maps to evaluate the environmental and economic values of ecosystem services provided by a landscape (Sharp et al. 2018). Our research ran a subset of InVEST modules to predict changes in land uses with a specific focus on water quality and annual yield, carbon storage, and the value of several marketed commodities across three different stakeholder-defined LULC scenarios for KSB. Other datasets required to run InVEST are listed in Table S1-3. All datasets were projected into UTM 37S WGS 1984 geographic coordinate system with the raster datasets resampled to 30m resolution. Importantly, climate change is not considered given the complexity of the model and the temporal proximity of the projection year, 2030, to the current average conditions, foremost precipitation, in Kilosa.

4.2. Scenario development and storylines

The InVEST model is based on scenarios that consider drivers, such as policy shifts, socioeconomic effects (e.g., population growth), and landscape dynamics. Our approach used a participatory scenario development method to create stakeholder-defined scenarios to represent alternative estate-smallholder nexuses and the consequent land-use and local development visions in KSB for 2030. This date constitutes the termination of CSF's short-term plan, Sustainable Development Goals (SDGs; of the state) and 2030 Tanzania Implementation Agenda, and many other state/regional development policies and strategies (e.g., SAGCOT; Intended Nationally Determined Contributions––INDC). We proceeded with this work in three steps.

Step One was initiated by a review of the literature related to the state/regional land-use and development policies and strategy papers related to the relevant economic and environmental sectors, informed by consultative advice from local experts. Step Two involved extensive interviews with 80 smallholders engaged in estate labor and household agricultural production and with the entirety of the Chinese managerial staff of the estates. This effort clarified current trends in resource use, livelihoods, and commodity production, and led to the development of visions of the land system dynamics and the resulting social-environmental consequences in KSB by the year 2030. These visions were built on plausible underlying estate-smallholder relationships and included three contrasting scenarios: *Business-as-Usual*, *Formal Wage Labor*, and *Outgrowing Scheme*.

Business-as-Usual (BAU) refers to continued population growth and insufficient protection of existing natural resources. This scenario assumes that by 2030 development follows its current trajectory, with most smallholder households maintaining a livelihood combination of estate labor, subsistence, and rice cultivation, CSF adding sisal at the current rate (80 ha annually), and weak governance along with few financial incentives for sustainable development in KSB. A rapidly growing population (average annual growth rate for Kilosa, 5%), ongoing resource exploitation, and non-implementation of nature conservation plans at any meaningful scale lead to land-use/cover conversion, environmental degradation, and slow-to-moderate growth in estate revenue and family income.

Formal Wage Labor (FWL) represents the desired scenario by most landless smallholders who hope to work in the sisal estate full-time under a formal contract. There are two direct results of this estate-smallholder relationship. First, the population grows at a remarkable rate––6%, consistent with that of the past sisal boom periods, largely owing to migrants seeking wage opportunities on the estate. Second, the costs of CSF to operate the estate increase significantly as a result of the rising payment for employment and expedited estate expansion. CSF estimates that it needs to add at least 200 ha new sisal fields into production every year to provide enough jobs for the growing wage seekers, part of their agreement with Tanzania, and to maintain a profitable operation. Cropland increases extensively to meet the rising subsistence demands, whereas rice expansion is constrained due to the restructuring of intrahousehold labor allocation, where fixed labor forces are directed from household fields to the estate. United Nations Strategic Plan for Forest 2017–2030 (3% increase in forest stock––UNSPF) is conditionally implemented.

Outgrowing Scheme (OGS) reflects an optimistic scenario of the future, where KSB meets all its stated policy goals to alleviate poverty and manage natural resources sustainably. Existing forest resources are conserved and committed to increasing 10% by 2030, following the aim of AFR100––the African Forest Landscape Restoration Initiative (Gizachew et al. 2020; Owusu et al. 2021). The population continues to grow, but slowly, at the growth rate stated by INDC, 1.5%. Some larger smallholder landholders (households with six or more acres of land; acres not hectares are locally used) are engaged in the outgrowing scheme initiated by CSF, allocating uncultivated landholdings to grow sisal under contract. They are expected to receive monetary returns from the outgrowing sisal produced and sold to the estate five to six years subsequent to seeding. Cropland declines moderately to the quantity that meets the basic

subsistence requirements with bare crops remaining. Essentially, per household land uses for rice cultivation largely stagnate, as an increasing number of labor forces are channeled into the outgrowing scheme.

Based on the three draft scenarios, several storylines about socioeconomic and environmental dynamics were developed. The various storylines were discussed in group interviews with representatives of a broad range of stakeholders (Step Three), including smallholders and estate staff, local policymakers, researchers, and members of NGOs. The informants were asked to evaluate the likelihood that each storyline would take place, and if occurring, the extent to which each storyline would impact LULC and various ecosystem services across the region. Based on the responses, new storylines were added if necessary, and others were eliminated if deemed unlikely to occur. Finally, we ranked the likelihood of each of the storylines and the magnitude of their impacts on ecosystem services. The top-ranked storylines were compiled and finalized for each draft scenario (see Table S4 for details).

Group interviews with major land users, especially smallholders, also helped create rules reflecting constraints for specific land conversions (Table S5). In line with the land-use plans under various scenarios, storylines, and local practices, these rules were evaluated to measure the extent to mimic land change reality using the MCE tool in TerrSet (Clark Labs 2015). We averaged these evaluations and performed pairwise comparison procedures (Saaty, 1977) to derive the best-fit set of weights for each land conversion (Table S6). We lastly factored these derived weights into LULC projections by using Future Land Use Simulation (FLUS), an integrated software application based on coupled system dynamics and cellular automata algorithms for land change analysis and prediction, to quantify and map the LULC patterns for the three estate-smallholder relationship and scenarios (see Liu et al. 2017).

4.3. InVEST models

Ecosystem services and commodity production values are a function of land characteristics and landscape patterns (Nelson et al. 2009). Using the three scenarios and required datasets (Table S1-3), we employed InVEST tools to evaluate three critical ecosystem services and the commodity production outcomes, and evaluated each scenario based on four metrics with contrasting beneficiary groups: (*i*) carbon storage/sequestration (metric tons C/ha) as a critical global benefit related to climate change mitigation; (*ii*) water yield (m^3/ year), measured as the flood control capacity, affecting the safety and livelihoods of communities living in the study region; (*iii*) water quality, focused on the total dissolved phosphorous export from watersheds (kg) as the proxy for pollution, given the proximity of the agricultural lands to water bodies, and (*iv*) market value of commodity production (constant year US$2018), constituting the majority of support from governments, international agencies, and promises from CSF for local poverty reduction and rural development.

Carbon storage and sequestration

We tracked the carbon stored in above- and below-ground biomass, soil, and dead organic matter using standard carbon accounting methods (Lubowski et al. 2006; Nelson et al. 2008; Sharp et al. 2018). The

InVEST model aggregated the amount of carbon stored in these pools according to the LULC projections. Land management strongly affects the total carbon stock in the terrestrial system, with implications for soil fertility and CO_2 emissions (Li et al. 2021). The amount of carbon sequestered in an area for a particular period is determined by subtracting the carbon stored in the area at the beginning of the time from that stored in the area at the end time.

Water service models: annual water yield and water quality

The InVEST annual water yield model computes spatial indices that quantify the relative contribution of a parcel of land to the generation of both base- and quick-flow (Kienzle and Mueller 2013). This model estimated the volume of freshwater that runs off in unregulated watersheds, which has significant implications for the equilibrium of local agricultural economy, land use, and hydraulic systems, especially annual flows for surface water.

In this application, we also used the discharge of dissolved phosphorus (P) into the local watershed to measure water pollution. Although this single measure ignores other sources of water pollution, it provides a proxy for non-point-source pollution. Slope, soil depth, and surface permeability were the major indexes used to define potential runoff by location (Nelson et al. 2009). Areas with more potential runoff, less downhill natural vegetation for filtering, greater hydraulic connectivity to water bodies, and LULC associated with the export of phosphorous (e.g., agricultural land, and more significantly, the sisal fields in this case) have greater rates of phosphorus discharge.

Commodity production value

The market value of commodities is represented as the aggregate net present value of commodities produced in the area. We focus on the production of three major crops: maize, the primary source of subsistence, commercial rice, and sisal. We excluded the value of local rural-residential housing due to local data unavailability. Livestock raising, aquaculture, timber logging, hunting, and charcoal production exist but were also excluded from this assessment because they either account for only a minimal section of the local economy or are largely prohibited in current community resource administration settings. The estimate of the net present value of crops depends on the crop type, productivity, market prices, and production costs. We derived these variables for 2018 estimates and 2030 projections from field surveys and international assessments (Table S7). In cases of missing local data, such as local crop production costs, data for the same product elsewhere in Tanzania were substituted. We used a discount rate of 5% per annum to compute the net present values of commodity production across time (Moner-Girona et al. 2016).

5. Results

5.1. From scenarios to LULC projections

The storylines of the scenarios determined plausible trends and magnitude of LULC changes. For example, the increase of residential area essentially corresponds to the population growth under all three scenarios, as does household cropland but as determined by per household subsistence requirements. If the present deforestation rate continues (1.2% per annum, 2019 field data), KSB will lose approximately 13.5% of forest for other uses by 2030 under BAU. In contrast, a 3% and 10% increase would follow from the stricter forest management and restoration guidance by UNSPF and AFR100 under FWL and OGS conditions, respectively. Rice expansion may reach its cultivation cap, 125% of the 2018 scale based on smallholders' assessment that 80% of such land was already used in 2018 and could not increase under BAU, whereas FWL and OGS only gain moderate increases in rice fields, primarily constrained by labor capability and the emerging new labor division plans. For example, a tendency exists for households to divert more laborers from commercial rice to estate as the latter has become a more profitable livelihood option since 2016 (2019 field data), and the emerging opportunities for outgrowing sisal production.

Mappings shown in Fig. 3 reveal that KSB would experience substantial LULC changes relative to baseline conditions (BSL, mapped in Fig. 2) under all three scenarios between 2018 and 2030. KSB under BAU lost large parcels of forest to cropland, most of which occurred in the bordering area between the core sisal belt and the forestland in the northwest of the KSB due to its relatively lower elevation and proximity to the most populated region, whereas the forest under FWL and OGS gained in alignment with corresponding forest restoration guidelines[1]. The decreases in savanna represented the most extensive native land losses in the KSB area. Under BAU, KSB lost 6.5% of the savanna primarily to cropland and rice fields as the population grew and sought to expand subsistence cultivation and maximize the profits from commercial crop sales. In addition to smallholder farm enlargement, savanna loss also resulted from the increases in the estate (FWL) and outgrowing (OGS) sisal cultivation. Despite the substantial land gains for cropland in response to the rapidly increasing subsistence demands under BAU and FWL, the cropland areas under OGS declined to the amount only sufficient to meet the base needs, owing to portions of household labor switched to rice cultivation and outgrowing sisal production. The rice field expanded remarkably under BAU and reached its limits of heat-moisture suitable lands. In contrast, FWL and OGS gained moderate rice field increases. While estate sisal expansion only took place within CSF-prescribed territory, sisal outgrowers prioritized rehabilitating abandoned sisal on their smallholder farms before converting other uncultivated landholdings, provided physical conditions (e.g., moisture, slopeness, and altitude) were suitable. Such land conversion for outgrowing sisal mainly occurred around the northern and southern ends of the core sisal belt, particularly marked in the areas along the major roads, where accessibility to smallholder settlements, CSF fiber processing plant, and other facilities was relatively good (Fig. 3).

5.2. Trade-offs between ecosystem services and commodity production for the KSB region

Based on the projected mappings, we illustrate the modeling outcomes of ecosystem services and commodity production value under BAU, FWL, and OGS relative to BSL conditions in the metrics shown in Fig. 4 and Table 2. The market value of commodity production increased in many areas under all three

scenarios as a result of increased unit present value for both commercial rice and sisal fibers. Although the market value of commodity production declined in some areas under BAU and FWL due to devalued subsistence crops (Table S7), the aggregate market value of commodity production summed over the whole region increased because of the high value of commercial crops (rice and sisal) more than compensated for the losses elsewhere. Consequently, all scenarios considered in this analysis generated positive net present outcomes and greatly exceeded the value of approximately $13 million projected for BSL (Table 2). Specifically, BAU generated the highest net present value of $17.5 million. The FWL generated a net present value of $16.5 million, and the OGS generated $16.6 million. In addition to the rapidly growing estate revenue, most increases in commodity production values came from household monetary wealth growth. Though BAU and FWL outperformed the total net present values, per household income declined relative to BSL because of the increasing number of households; comparatively, OGS generated the largest CSF revenue and per household income[2]. The majority change in the market value of commodity production occurred in the core sisal belt, with the values outside of the developing areas largely unchanged (Fig. 4).

Table 2
Comparison of ecosystem services and commodity production values between future scenarios and BSL conditions

Estate-smallholder relationship scenario		2018 BSL	2030 BAU	2030 FWL	2030 OGS*
Selected ecosystem services	Carbon storage (mt C/ha)	210	188	209	222
	Change from BSL (%)	-	**-10.5**	**-0.5**	**5.7**
	Annual water yield (m^3/ha/year)	1,492	1,562	1,549	1,513
	Change from BSL (%)	-	**4.7**	**3.8**	**1.4**
	Water quality (kg (P)/year)	27,697	31,986	32,490	30,795
	Change from BSL (%)	-	**15.5**	**17.3**	**11.2**
Commodity production value	Total (US$2018)	13,340,267	17,477,677	16,451,132	16,590,810
	Change from BSL (%)	-	**31.0**	**23.3**	**24.4**
	CSF Revenue ($)	1,390,813	2,042,225	2,995,793	3,436,288
	Change from BSL (%)	-	**46.8**	**115.4**	**147.1**
	Ttl. household income ($)**	11,949,455	15,435,453	13,455,339	13,154,522
	Population	68,719	123,409	138,276	82,162
	Household	17,180	27,424	30,728	18,258
	Per household income ($)	696	563	438	720
	Change from BSL (%)	-	**-19.1**	**-37.1**	**3.4**

*Under the OGS scenario, CSF suggests that the proceeds after sisal sales be allocated between the estate and outgrowing smallholders at a fixed division ratio of 6:4––CSF earns 60% of the proceeds outgrowers receive 40%. This is the tentative plan by CSF and has not yet reached a consensus with the smallholders interested in the outgrowing scheme.

**This part only counts the household income from crop production (e.g., maize, rice, and outgrowing sisal).

Increases in land devoted to agriculture exacerbate various ecosystem disservices, other than provisioning ones. (Fig. 5. A-C). The greatest carbon sequestration increases currently are found in the afforested regions and the largest losses in the capacity to sequester carbon today follow from the loss of forest and the new lands taken to cultivation (Fig. 3, 4). As such, BAU produced the largest carbon reductions relative to BSL (10.5%), owing to its fast-expanding agricultural areas and reducing forest stocks. For FWL and OGS, substantial native land losses for carbon-intensive uses notwithstanding, on-site carbon reductions were repaid by following stricter forest restoration strategies, generating a slight decrease (0.5%, FWL) and moderate increase (5.7%, OGS) in carbon sequestration, respectively (Table 2).

Water services scores declined under all three scenarios (Table 2), but OGS exhibited the smallest decline (Table 2 and Fig. 5. D-F). Increases in water yield (indicative of increased flood risk at the catchment outlets on Wami River) were greatest under BAU, which had the largest removals of downhill and floodplain vegetation of any of the scenarios. For water quality, sisal field-caring and fiber production are the predominant sources of pollution in the study area because of the use of herbicide and fiber bleach discharge of large amounts of dissolved phosphorous into the water (FAO, 2012)[3], with the increasing application of phosphate fertilizer in the agricultural fields also of concern. Water quality declined most sharply with FWL (17.3% increase in P export), and then BAU (15.5%), as a result of the largest increases in estate sisal production and smallholder agricultural areas, respectively (Table 2). Phosphorous export also increased under OGS, although less steeply (11.2%), mainly because of offset effects by the increments of native vegetation mitigating the water pollution (Table 2 and Fig. 4).

[1]. The forest restoration in this study follows the natural vegetation succession from woody shrubland to woodland, most of which occurs around the transitional areas between the savanna and forestland.

[2]. Given the tendency of more involvement in estate work since 2016 and the potential establishment of work under formal contract (FWL), the actual per household income on average generated under BAU and FWL scenarios may exceed BSL if we add the off-farm wages to aggregate household income calculation.

[3]. The most widely used herbicides are 3, 5, 6-trichloro-2-pyridinyloxyacetic acid and N-phosphonomethyl-glycine (Glyphosate) applied to leaves, stems, rhizomes, and cut plants (Weber 2017).

6. Discussion

Human uses of landscapes may increase some ecosystem services but most invariably degrade others. Such is the case identified through the use of the InVEST model applied to the KSB. Provisioning services increase under the scenarios presented but at the cost of all other services examined. Hence, trade-offs between maintaining landscape functions in the KSB and improving the livelihoods of the inhabitants are at play. BAU, as the long-term continuation of BSL conditions, generated the greatest carbon reduction, flood risk, second-greatest water quality decline, and the smallest increase in estate revenue. Per

household income growth largely stagnated due to the unchanged intrahousehold labor and income structure. These results suggest that BAU is not an outcome favorable to most stakeholders in the KSB.

FWL and OGS represent two alternative scenarios that redefine estate-smallholder relationships. FWL illustrates the vision in which the estate provides sufficiently secure employment and realizes the various promised benefits to the local people. Socioeconomically, this scenario involves estate standardized sisal fiber production at an unprecedented production scale, creating an enlarged group of off-farm smallholder wage laborers. The local rural economy restructures significantly under this scenario. It fosters the emergence of a large class of off-farm wage workers and incubates subsidiary businesses involving labor support and legal services. Adverse effects are conspicuous, however. First, a complete switch from casual to formal employment means the estate confronts the market and economic uncertainties alone, which increases the operational risks and restrains most estates from making such a move. Secondly, the influx of wage work-seekers increases local-level subsistence demands and consequently expedites the land conversion from native landscapes to smallholder farms, exacerbating the issues of local food provisions and ecosystem services losses.

Of the three scenarios, OGS produces the largest gains (or the smallest losses) in ecosystem services and aggregate market value of commodity production. Carbon sequestration, estate revenue, and per-household income increase substantially. Water services decline, but only slightly compared to BAU and FWL, which also increase the net present aggregate value of commodity production with the trade-off of carbon reductions. These losses of ecosystem services could be reversed by, for instance, de-phosphorizing the wastewater after sisal fiber processing prior to discharge into rivers and creating vegetation buffers around watersheds and agricultural areas––well-established practices that have proven useful elsewhere to increase carbon storage and improve water services (e.g., Correll 1997). These actions might come with trade-offs of increased commodity production costs and land taken out of agricultural and other profitable uses, however, resulting in reduced financial return. More so, neither carbon nor water services currently have a direct price in the study region, meaning that decisions about whether to establish wastewater treatment plants and/or vegetation buffers hinge on the value assigned by decision-makers to the carbon- and water-service improvements relative to a financial penalty.

The economic restructuring in the OGS also provides challenges. These include the rigidities in the contract terms, which favor the estate over outgrowers; lack of transparency in the weighing and measuring of products; the fixing of prices of inputs and products and harvesting delays; broken guarantees of a ready market for products, and the loss of time for subsistence production. Even more fundamentally, the outgrowing scheme exposes farmers to the vicissitudes of global markets, while tying them to the bottom of the value chain. These drawbacks are consistent with the critical discussions of the extensive literature on contract farming (e.g., Oya 2013; Smalley 2013; Hall et al. 2015), and constitute most of the concern among potential outgrowers, being repeatedly debated in the group interviews with smallholders. Though we have not included the effects of these adversities in the modeling approach and analysis presented here, such concerns may increase the reluctance among smallholders to implement this scheme. More importantly, even though most potential outgrowers hope to maintain their own

farming activities while participating in the scheme, this is only feasible for larger landholders (households with six or more acres of land in this study) and would have excluded most smallholders at the very beginning.

7. Limitations And Implications

Various challenges limit the robustness of our results and point to implications for future research. First, although our models can include biophysical drivers besides LULC change, we have not included them in this analysis due to data issues and the inadequacy of the model to incorporate such data at the scale of the analysis. Furthermore, there may be essential feedback effects, such as the amenity value of conserved land, that increase development pressure on land near the conserved area. Including changes in climate, soil, technology, and feedback effects––all of which are likely to drive the socioeconomic and ecological relationships that determine the value of ecosystem services in the future––is an essential next step in the application of InVEST. It must be recognized, however, that increasing the complexity of the model likely increases the uncertainties involved.

The second limitation is the exclusion of the market value of commodities generated in urban areas in any scenario. Although KSB remains mostly rural, larger villages, such as Msowero and Mvumi, have grown extensively and developed businesses, most of which are linked to the estate sisal production, including, for instance, credit cooperatives, transportation hubs, and sisal leaves storehouse.[4] Since urban market returns tend to be higher than those for other land uses, we may have underestimated the aggregate value of marketed commodities for scenarios in which urban markets increase by 2030. The development values produced on that land lost to the urbanized area may overwhelm the ecosystem services values generated by conserving that land. Therefore, market evaluation services might not always favor conservation, especially in high-value urbanized and urban-like areas.

Thirdly, the ecosystem services evaluated here do not reflect all the concerns of a particular stakeholder group or may mismatch with the expectations among various stakeholders on the same service. Our use of carbon sequestration, following the state and international concerns, was not highly important to local stakeholders, for example. Likewise, benefits at the local level may enable negative impacts elsewhere. For instance, the creation of our scenarios only considered the profit-maximizing demands of a single stakeholder group––smallholders favor FWL, and the estate prefers OGS. Both smallholders and the estate saw the increase in water yield as a critical threat to their production, but neither of them took the decline in water quality as a pressing issue, despite its potential negative impacts on the livelihoods of inhabitants living in the broader catchment areas of the lower Wami River.

In general, as to the trade-offs involving a choice between development and conservation, the essences of making reconciliation or coping strategies are the presence of markets for the vital ecosystem services, which are not in place in most cases. Before payments for these ecosystem services are instituted, however, clear links need to be made between their biophysical provision and their ultimate use by people. The crucial next step is to determine how much of this production is actually of value to people and

where that value is captured. Eventually, the use-values of ecosystem services will be determined by local landscape patterns and population needs––which could be place-specific and market-dependent across various stakeholders.

[4]. These facilities are primarily serving those adjacent smallholders who have partially rehabilitated some deserted sisal parcels in former estate land since 2005-2006, producing low-end (quality) sisal leaves sold to CSF at a much lower price.

8. Conclusions

Nature provides a range of benefits, collectively called ecosystem services, essential for human wellbeing and the functioning of the environment (Metzger et al. 2006). Maintaining these “services” while improving human welfare based on different human-environment relationships is critical for sustainable development (Clark and Harley 2021), and of increasing interest to landscape sustainability science (Wu and Hobbs 2002; Wu 2013, 2019, 2021). Such efforts require empirical calculations of the trade-offs between human and environmental wellbeing. These calculations, in turn, are difficult to address quantitatively, that format on which science tends to supply to decision-makers. KSB, Tanzania, is exemplary of these needs and challenges. Here, large-scale estate investments are underway, bringing about significant impacts on local smallholder agriculture and state/regional sustainable development efforts for climate change mitigation, food production, poverty alleviation, and diversifying rural economic opportunities. Like many rapidly developing regions globally, KSB is a microcosm of different forces at play, intensifying pressure on land for competing uses. In response, recent policy initiatives involving KSB have emphasized the adaptation to climate change, mitigation of excessive resource exploitation, food and energy security, and the role of foreign-owned estates in meeting these ends to address sustainability challenges. At the core of this effort, argued in this paper, is a reconciliation of the needs of major stakeholders, especially the estate and adjacent smallholders, for land-use development and its landscape consequences.

This paper demonstrates one approach. It coordinated major stakeholders’ needs and expectations to develop three contrasting scenarios and related storylines based on likely estate-smallholder relationships, policies of land-use plans, and local development visions up to the year 2030. Integrated land-change projection (FLUS) and ecosystem service modeling (InVEST) methods were employed to convert the storylines through modeling rules to project the amount and location (mapping) of the outcomes in question. In doing so, the trade-offs and synergies between the provision of ecosystem services and the market value of major commodities across space and time are illustrated, providing insights for future land use and policy decision-making.

We found adequate evidence of trade-offs between ecosystem services and agricultural commodity economy for the KSB. All scenarios that enhance commodity production have reductions in the provisions of various ecosystem services to varying extents. Concerns that the co-development of the estate and smallholder agriculture will fail to reconcile conservation goals were mostly supported. A

positive correlation between carbon and water services is the one clear synergy we found. The increase in forest stock has significant mitigation effects on the decline in water services, as demonstrated in the OGS scenario.

Despite several limitations, our approach offers a means to engage major stakeholders in a region to address possible decisions about future social-environmental conditions in which their participation moves from qualitative to quantitative status. The projected scale of socioeconomic and environmental change is linked to the locations in which the changes are likely to take place. This kind of analysis makes the trade-offs between ecosystem services and market returns transparent, building up the platform that engages stakeholders and policymakers to make environmental governance and natural resource decisions more collaboratively, effectively, and efficiently.

Declarations

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Figures

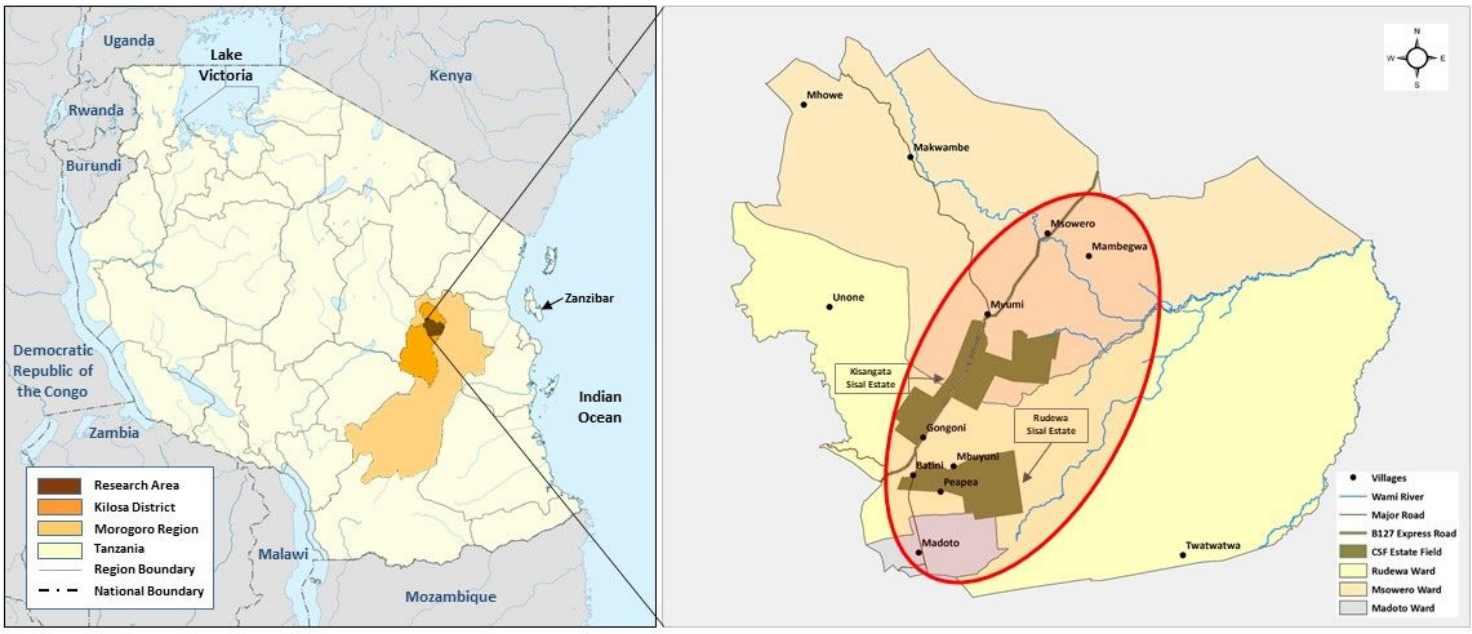


Figure 1

Maps of the Kilosa Sisal Belt and its core region (red circled area)

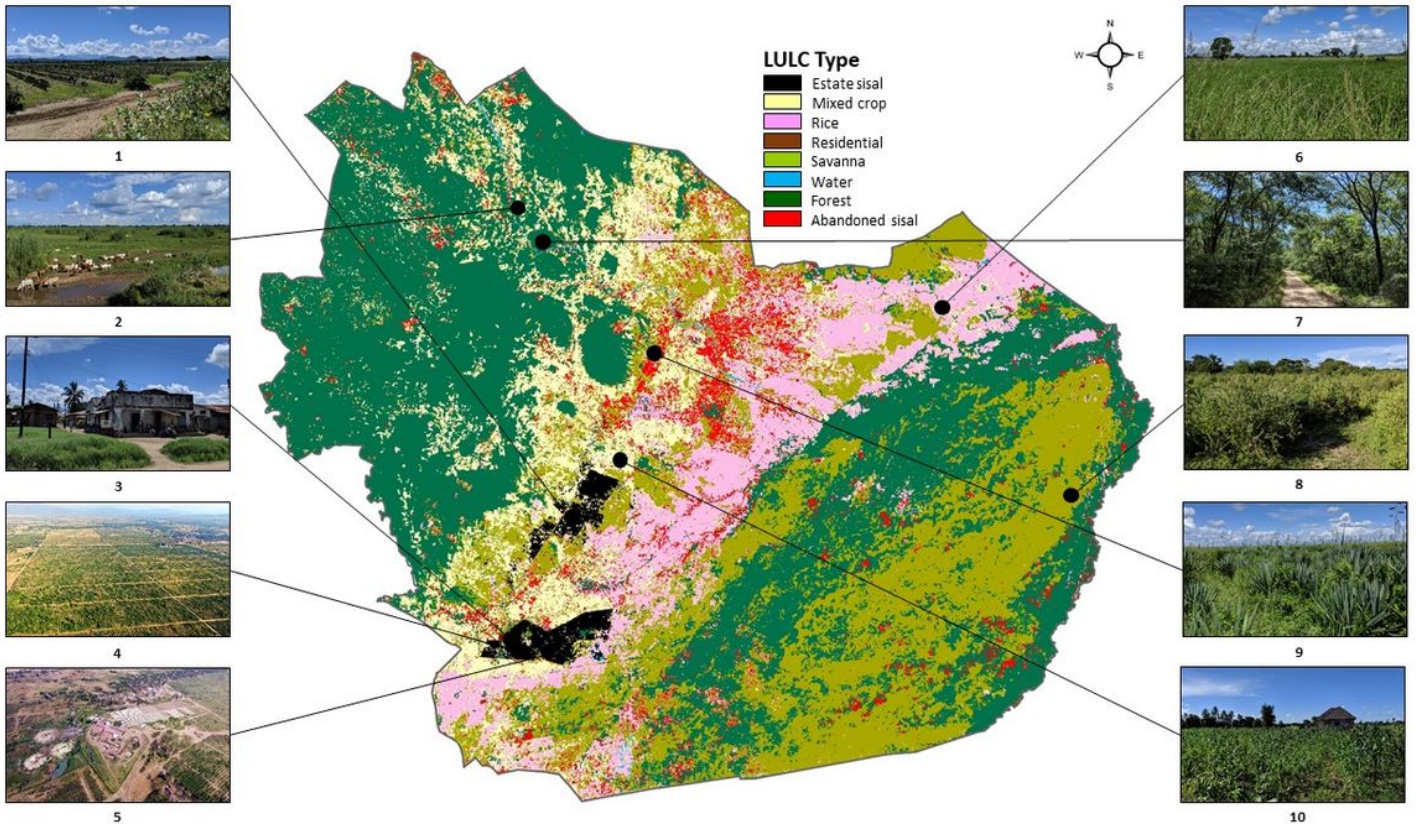
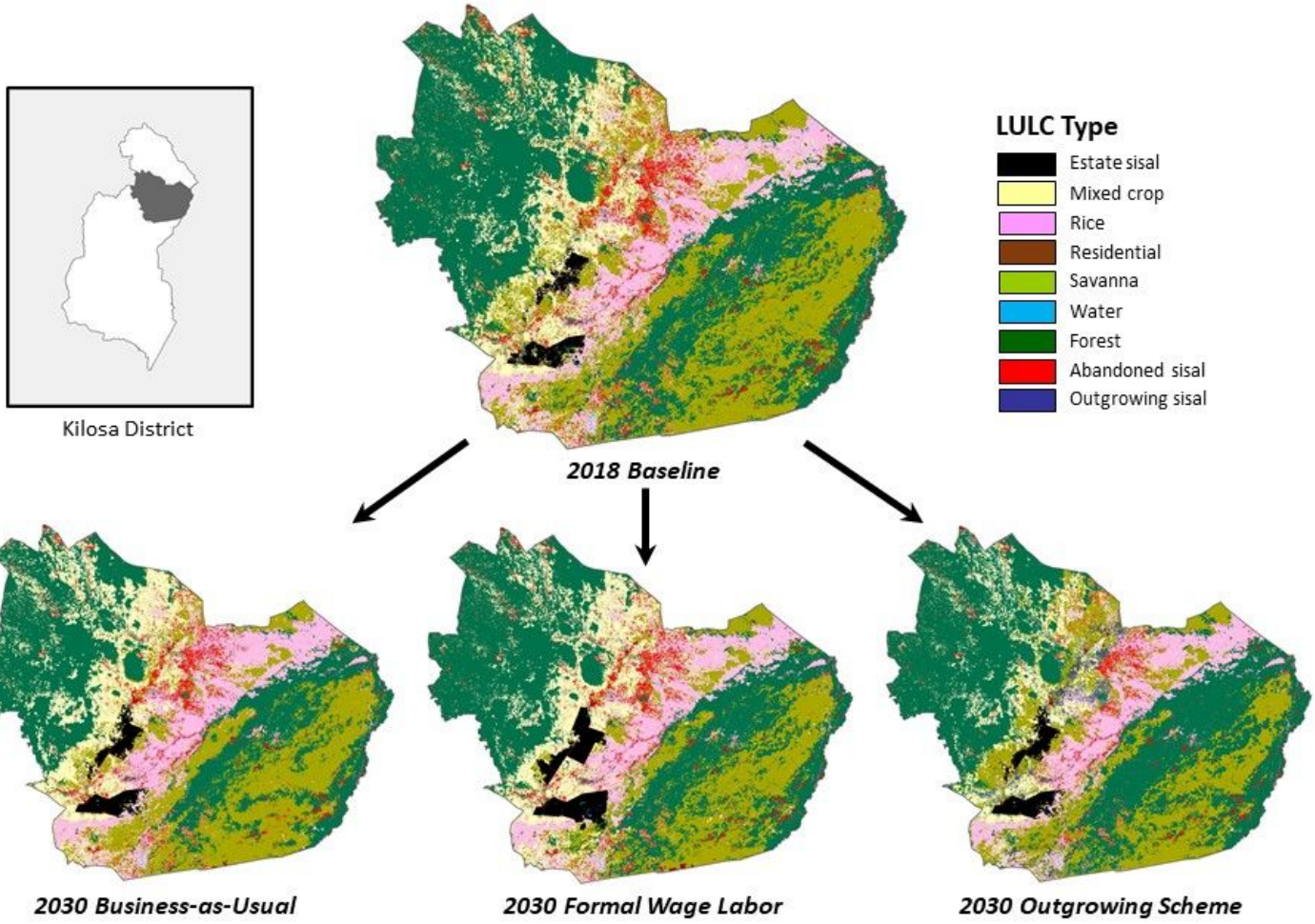


Figure 2

Map of LULC types in 2018 KSB and the distinct ecosystems they provide*

*Fig. 2-1: newly-rehabilitated sisal in Kisangata estate; 2-2: Wami River in dry seasons––the major water source supporting Maasai herding; 2-3: residential settlements of Batini; 2-4: sisal plantation in Rudewa estate; 2-5: sisal fiber processing plant at Peapea; 2-6: rainfed rice fields; 2-7: forestland in the northwest Mvumi; 2-8: typical savanna landscape; 2-9: abandoned sisal parcels dispersed in savanna; 2-10: subsistence crop (maize). Image courtesy: authors



LULC changes of BAU, FWL, and OGS relative to 2018 BSL conditions (ha)

LULC Type	2018 Baseline (BSL)	2030 Business-as-Usual (BAU)	2030 Formal Wage Labor (FWL)	2030 Outgrowing Scheme (OGS)
Estate sisal	2,125	3,084	4,524	3,809
Mixed crop	19,027	24,131	23,658	14,057
Rice	16,803	21,004	17,643	18,483
Settlement	268	481	539	320
Savanna	38,183	35,716	28,260	33,798
Water	257	257	257	257
Forest	59,392	51,382	61,174	65,331
Abandoned sisal	7,572	7,572	7,572	4,687
Outgrowing sisal	0	0	0	2,885
Total	143,627	143,627	143,627	143,627

Figure 3

Projected LULC maps in 2030 under BAU, FWL, and OGS scenarios, in comparison with 2018 BSL conditions

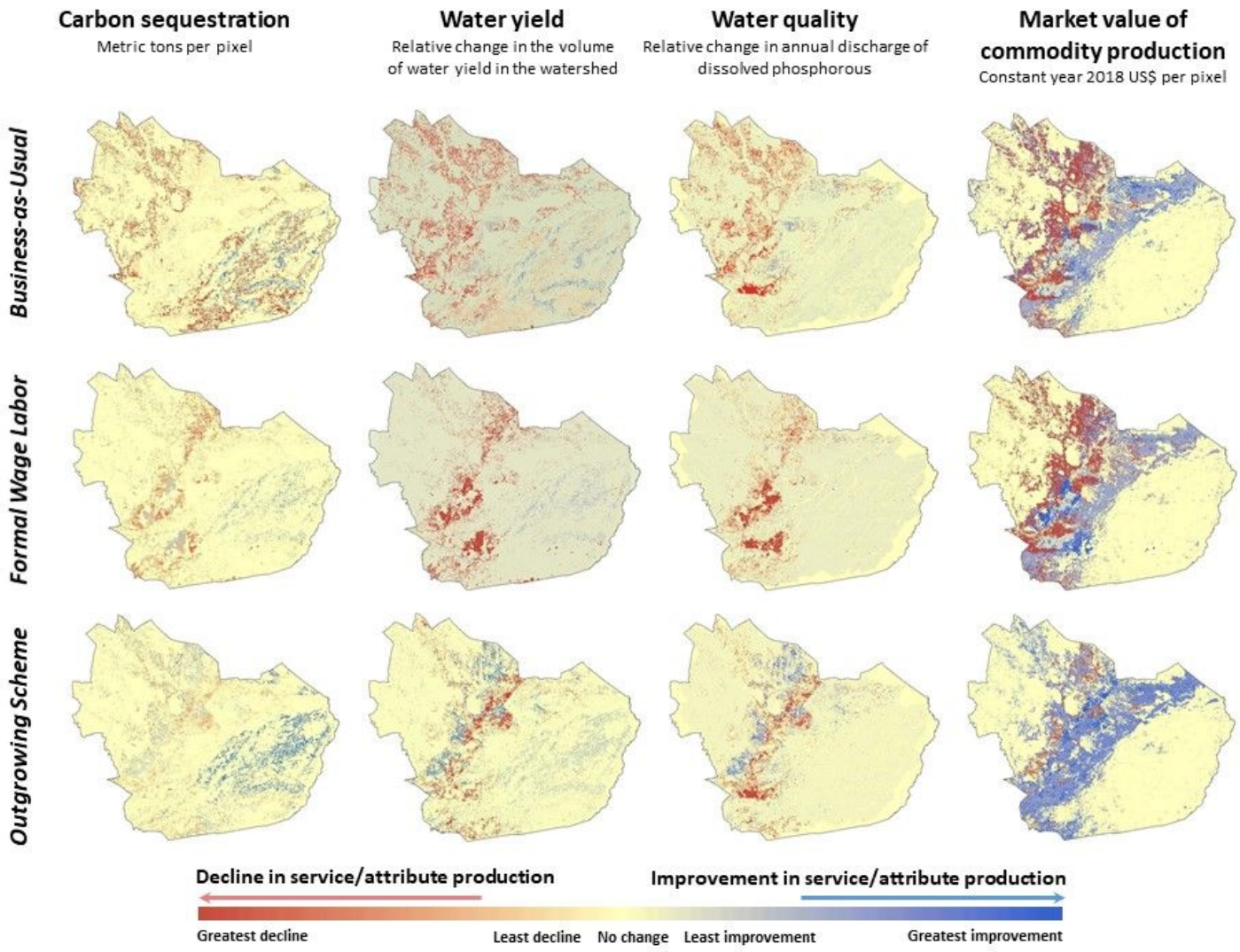


Figure 4

Maps of change in ecosystem services and market value of commodity production from 2018 to 2030 for the three estate-smallholder relationship scenarios

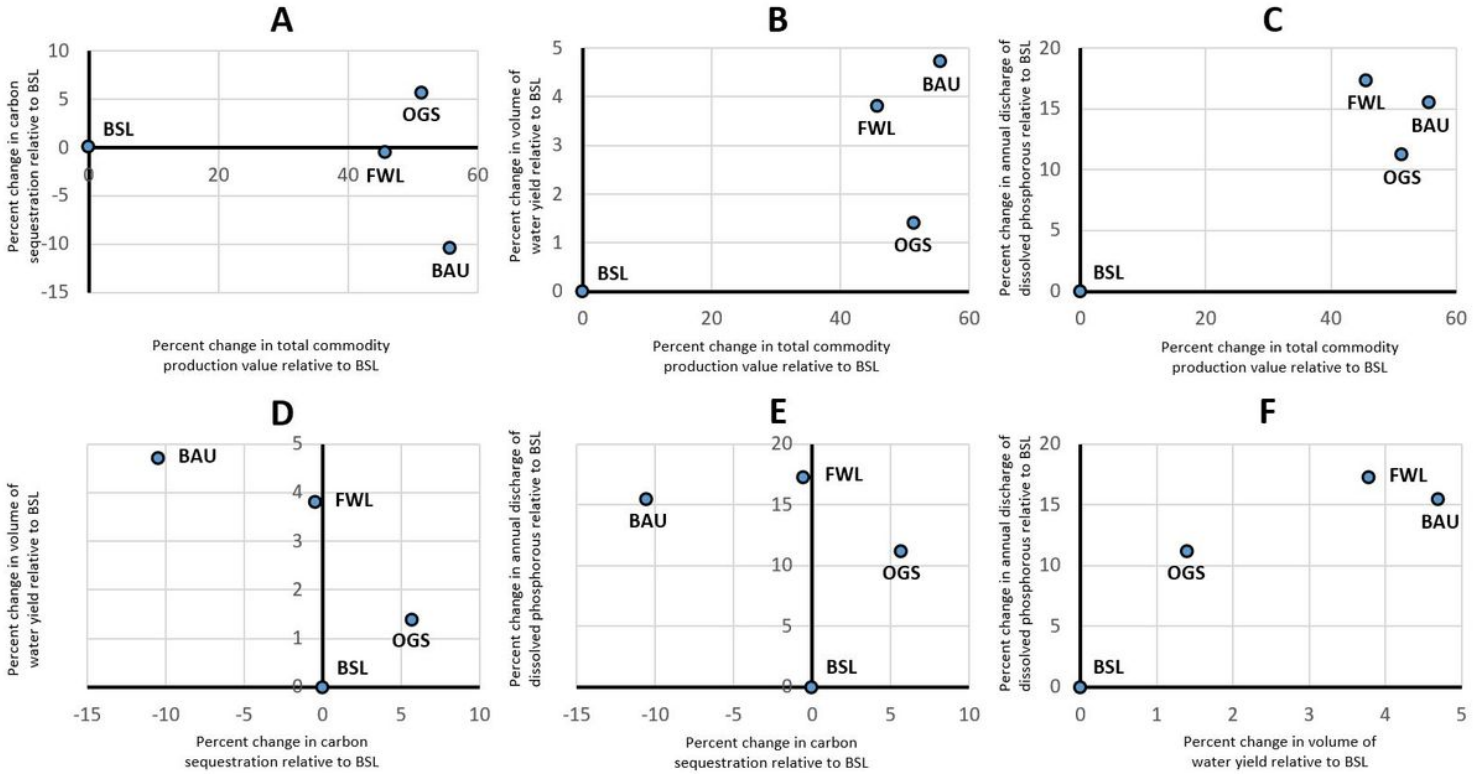


Figure 5

Trade-off comparison of the improvement or decline in ecosystem service and commodity production value metrics relative to the BSL for KSB. (A) Carbon sequestration vs. commodity production value; (B) Water yield vs. commodity production value; (C) Water quality vs. commodity production value; (D) Water yield vs. carbon sequestration; (E) Water quality vs. carbon sequestration; (F) Water quality vs. water yield.

Supplementary Files

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