Grassland loss in Tanzania: Causes, Consequences and Control

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Abstract
Grasslands are an important component of rangelands. The work presented in this paper is based on spatial statistical analysis of grassland change between 1995 and 2010 using land use and land cover maps covering the whole of mainland Tanzania and GIS techniques. Further arguments for discussion in the paper are sourced from literature review. Results show that grasslands are lost at an alarming rate of almost 1 million hectares annually. Between 1995 and 2010 Tanzania lost more than 14 million hectares of grassland. Main direct causes of grassland loss are conversion to cultivation and to forest cover, almost at an equal rate of more than 6 million hectares over the 15year period (about 400,000 ha annually). Bush encroachment is also an important direct driver of grassland loss. Indirect causes of grassland loss include population growth, economic growth, challenges in grassland governance and management and globalization. Consequences of grassland loss include reduced areas for grazing, increased soil erosion, floods, increased land use conflicts and their repercussions including loss of property and life. Control measures include those addressing the direct and indirect drivers of change. However, most of the control measures are ineffective and hence the observed trend of

grassland loss is increasing with time. The paper concludes by suggesting some topics for further research into ways to improve the effectiveness of the control measures against grassland loss in terms of potential and possibility of more agricultural intensification, improvements of markets and profits to cultivators, nature of grassland loss to forest cover, ways to apply existing extensive research on bush encroachment and, the role of formal and informal institutions that control grassland loss.

Keywords: *cultivation, bush encroachment, population growth, management challenges, land use conflicts, soil eroding floods.*

Introduction

A simple, all-encompassing definition of grasslands is surprisingly difficult to come by, and grasslands have been defined and distinguished from other biome types in many different ways (Blair et al., 2014). One defining feature of grasslands is that they are dominated or codominated by graminoid vegetation, including the true grasses (family Poaceae) and other grasslike plants including sedges (Cyperaceae) and rushes (Juncaceae) (Blair et al., 2014). Defined narrowly, grasslands are ecosystems characterized by a relatively high cover of grasses and other graminoid vegetation in an open, often rolling, landscape with little or no cover of trees and shrubs (Blair et al., 2014). However, the term grassland can also be used in a broader sense to encompass ecosystems with a significant grass cover interspersed with varying degrees of woody vegetation, including relatively open savannas and woodlands (e.g., the cerrados of South America) and some deserts and shrub grasslands (also referred to as steppes) that include a significant cover of grasses interspersed with succulent plants and/or shrubs

(Blair et al., 2014). In this context, grasslands can vary in the relative abundance of grasses and other plant life forms, such as trees and shrubs (Blair et al., 2014). In fact, the cover of woody vegetation is increasing in many grasslands globally, and there is often disagreement about how to delimit grasslands from other vegetation types that include significant grass cover mixed with other herbaceous and/or woody vegetation (Blair et al., 2014).

Grasslands are particularly important to Tanzania ecologically, socially and economically due to a number of reasons. One of the reasons is that Tanzania has a large number of grazers both domestic and wild and ranks the third in number of livestock in Africa (Zarei et al., 2021). Globally, grasslands and other grass- and graminoid-dominated habitats (e.g., savanna, open and closed shrubland, and tundra, usually a mixture of grass, clover and other leguminous species, dicotyledonous, herbs and shrubs) occur on every continent except Antarctica (though some grasses do occur there) and occupy about 30–40 % of Earth's land surface (Blair et al., 2014; Carlier et al., 2009). They cover more terrestrial area than any other single biome type (Blair et al., 2014).

Ecological and economic importance of grasslands at local, regional and global scales is associated with the extent and diversity of grasslands and related habitats (Blair et al., 2014). For example, grasslands provide critical habitat for a diverse array of plants and animals (Blair et al., 2014; Peeters, 2009). Grassland soils store tremendous quantities of carbon and other key nutrients and play a major role in global biogeochemical cycle (Blair et al., 2014). Grasslands contribute to a high degree to the struggle against erosion and to the regularizing of water regimes, to the purification of fertilizers and pesticides and to biodiversity and they have aesthetic role and recreational function as far as they provide public access that other agricultural uses do not allow (Carlier et al., 2009). There is also a long and complex relationship between grasslands and humans (Aune et al., 2018; Blair et al., 2014). Modern humans are thought to have originated in the open grasslands and savannas of Africa, and grasslands have provided the habitats and biological raw material for the development of modern agriculture and associated human societies (Blair et al., 2014). The fertile soils that developed under many grasslands have been plowed and the nutrients mined to support agricultural production (Aune et al., 2018; Blair et al., 2014). Domesticated grasses, such as corn, rice, wheat, oats, and sorghum, have become some of our most important agricultural crops, and barley was used by Neolithic humans to produce one of the first known alcoholic drinks (Blair et al., 2014). Grasses are not only consumed directly by humans, but they also support the production of domestic livestock for human use through outfields grazing or harvesting of folder for indoor feeding (Aune et al., 2018; Blair et al., 2014). More recently, several species of grasses are being widely used or considered as feedstock for biofuel production (e.g., *Panicum virgatum, Miscanthus* spp.) (Blair et al., 2014). It is estimated that as many as 800 million people worldwide rely directly on grasslands for their livelihoods, and virtually everyone uses grassland products (food, fiber, fuel) in their daily existence (Blair et al., 2014). In total, it is clear that grasses and grasslands have played an important role in the history of humans and will continue to do so in the future (Blair et al., 2014).

Another aspect of importance of grasslands is its role in the development and testing of ecological theory, such as assessing relationships between species richness and ecosystem function and as model systems for assessing the impacts of global changes, including responses to chronic N deposition, elevated CO^2 concentrations, landscape fragmentation, and climate change (Blair et al., 2014; Collinge, 2000; Shaffer et al., 2018). This is due, in part, to the relative ease of performing manipulative experiments in grasslands, the sensitivity of grasslands to perturbations, and the relatively rapid responses they often exhibit to these manipulations (Blair et al., 2014). In fact one of the longest running field experiments in the world is the Park Grass Experiment at the Rothamsted Experimental Station in England (Blair et al., 2014). This experiment was established in 1856 with the original goal of assessing the effects of various nutrient amendments on grass yields (Blair et al., 2014). The experiment has since been used to address a broad range of fundamental questions in ecology and evolutionary biology (Blair et al., 2014).

Some of the most endangered ecosystems on the planet are grasslands (Blair et al., 2014). These include the tallgrass prairies of North America and other temperate grasslands (Blair et al., 2014). In addition to the historical loss of grasslands to agricultural expansion, grasslands today are threatened by a broad array of environmental changes, including climate change, elevated atmospheric carbon dioxide concentrations, increased nitrogen deposition, invasive species, habitat fragmentation, degradation due to overgrazing, change in natural disturbance regimes (e.g., fire suppression), and woody plant expansion (Blair et al., 2014; Collinge, 2000; Shaffer et al., 2018). Conserving and in some cases restoring these ecosystems require a solid foundation of ecological and socioeconomic knowledge (Blair et al., 2014; Kikula, 1999).

Many studies have been conducted on grasslands in Tanzania on various aspects for different parts of the country or for the whole country (Bamford et al., 2008; Zarei et al., 2021). One study reported of grassland loss along with deforestation and loss of bushland for the whole of the mainland Tanzania in the period 1995-2010 (Nzunda & Midtgaard, 2019). However, the focus of the study was mainly deforestation for both presentation and discussion of the results (Nzunda & Midtgaard, 2019). Although the drivers of land use and land cover changes may be the same for different categories of land use and land cover, it may not necessarily always be the case. Thus the purpose of the current paper is to specifically focus on assessment of land use and land cover changes pertaining to grasslands in Tanzania. Specifically, the objectives of the paper are: (1) to quantify changes in grassland cover in relation to other land use and cover categories; (2) to examine the causes of changes in grassland cover and; (3) to assess the consequences of grassland loss, and; (4) to assess control measures taken to address grassland loss.

Methodology

Study area

The study covered the whole of mainland Tanzania (excluding water bodies). Tanzania has tropical climate (URT, 2013). The hottest period spreads between November and February (25–31 °C) while the coldest period occurs between May and August (15–20 °C) (URT 2013). The mean annual rainfall is about 874 mm (Nzunda & Midtgaard, 2017, 2019).

This paper presented socioeconomic data here in the description of study area that are relevant for the period 1995-2010, rather than the latest data. This is because those are the data that are relevant for the land use and cover changes assessed. The human population for mainland Tanzania was 33,461,849 in 2002 and 43,625,354 in 2012 (URT, 2013). The national (mainland Tanzania) population density was 50 people per square kilometre in 2012 and the intercensal population growth rate was 2.7 (URT, 2013). Per capita gross domestic product (GDP) was estimated at TZS 698,990 in 2010 (URT, 2013). Agriculture is the foundation of the Tanzanian economy (URT, 2013). It accounts for about half of the national income, three quarters of merchandise exports and is source of food and provides employment to about 80% of Tanzanians (URT, 2013). Agriculture is dominated by smallholder farmers (peasants) cultivating an average farm size of 0.9–3.0 hectares each (URT, 2013).

Land use and cover maps used

The land use and cover map for 1995 was produced by Hunting Technical Services and published by the Ministry of Natural Resources and Tourism of the United Republic of Tanzania. For 2010, the land use and cover map was produced by NAFORMA (National Forest Resources Monitoring and Assessment) of the Ministry of Natural Resources and Tourism of the United Republic of Tanzania.

Although the two land use and cover maps were produced by different projects, the 2010 map was deliberately made comparable to the 1995 map (URT, 2010). The land use and cover classification scheme used by the NAFORMA 2010 map is mainly adopted from Hunting Technical Services (1995) map with few modifications to reflect actual ground conditions that are noticeable in the map (URT, 2010). Most of the details of the minor modifications made for the NAFORMA 2010 map (URT,

2010) are irrelevant to describe for this paper because they concern details of subclasses of the classes used in here. Furthermore, both the 1995 map and the 2010 map were obtained as geo-referenced and co-registered digital vector maps with a minimum mapping unit of 1 ha, which were rasterized to spatial resolution of about 1 km (=1,090.79 m) (Nzunda & Midtgaard, 2017). Both the 1995 and 2010 land use and cover maps have been used previously for other studies (Capitani et al., 2016; Nzunda & Midtgaard, 2017; Runsten et al., 2013; Swetnam et al., 2011; Willcock et al., 2016).

The strength of the 1995 and 2010 land use and cover maps is that a lot of effort to correctly identify the details of land use and cover was employed especially using on-the-ground information (URT, 2010). The weakness and limitation is that the maps have not been popularly published unlike the regional and global maps (see for example (Hansen et al., 2013; Mayaux et al., 2004; Sophie, Pierre, & Eric, 2010)). Thus if you search for them on the internet they are hardly accessible unlike some of the regional and global maps. Furthermore, if you contact the authorities that may give you the data you will get the data not as a finished product with full documentation but only as partial data with some important information missing (e.g. accuracy assessment of the land use and cover classification for the maps will be missing). The reference to the Hunting Technical Services 1995 map is not available on the internet although this reference is mentioned by several studies (FAO, 2010b; URT, 2010; Willcock et al., 2016). The 2010 map is only mentioned and its land use and cover classes described in the NAFORMA manual and report but the map itself is not published (URT, 2010, 2015).

Although there are regional and global maps of land use and cover that cover Tanzania as well, it was decided to use the maps that were prepared specifically for Tanzania because inconsistent results were obtained when other maps were used. For instance, using a regional map for Africa (Mayaux et al., 2004) as source for 2000 land cover and a global land cover map (Sophie et al., 2010) as a source for 2009 land cover both based on the globcover project classification scheme, forest area increased between 2000 and 2009 instead of decreasing as expected on the basis of studies specific to Tanzania (FAO, 2010b, 2016). This is not surprising because regional and global maps of land cover and land use are characterised by lower accuracy than national maps (Estes et al., 2018). One of the reasons for low accuracy is that the regional and global maps are mainly signal-based and have relatively little on-the-ground input compared to the vast region or globe mapped (Hansen et al., 2014; Tropek et al., 2014).

Analysis of land use and cover changes

The 1995 and 2010 maps were reclassified to make the land use and cover classes comparable (Table 1). This was achieved by either aggregating the 1995 subclasses into the 2010 class they belonged to or vice versa (Table 1). The reclassification was performed in GRASS GIS version 6.4.2 using the recoding function. Change detection was performed in SAGA GIS version 2.1.2. Gains and losses for each land use and cover class were identified using the appropriate off-diagonal entries of the cross-tabulation matrix of the LUCC (Schulz et al., 2010). The annual rate of change for each class was calculated with the formula proposed by Puyravaud (Puyravaud, 2003) and used by Schulz et al. 2010:

$$r = ((1/t_2 - t_1)) \times \ln (A_2/A_1)$$

where A_2 and A_1 are the land use and cover class areas at the end and the beginning, respectively, of the period being evaluated, and t is the number of years spanning that period (i.e. 2010-1995 = 15).

Table 1. Land use and cover classes nomenclature for 1995, 2010 and that used in this study

1995 land use and cover class name	2010 land use and cover class name	Land use and cover class name used in this study
Natural forest	Montane and lowland forest	Forest
Mangrove forest	Mangrove forest	Forest
Woodland	Closed woodland	Forest
	Open woodland	Forest
Forest plantation	Forest plantation	Forest
Bushland	Bushland	Bushland
	Thickets	Bushland
Grassland	Grassland	Grassland
Cultivated land	Cultivated bushland	Cultivation
	Cultivated woodland	Cultivation
	Grains and other crops	Cultivation
	Wooded crops	Cultivation
Bare soil	Open land	Other land use and cover
Rock outcrops		Other land use and cover
Salt and crusts		Other land use and cover
Airport	Built-up area	Other land use and cover

Airstrip		Other land use and cover
Urban area		Other land use and cover
Ice	Ice	Other land use and cover
Permanent swamp	Wetland	Other land use and cover
Water	Fresh water	Water[a]
	Salt water	Water

[a]Water was not included in analysis of land cover changes.
Source: Nzunda and Midtgaard 2019

Persistence and changes for each land use and cover class were analysed in a spatially explicit manner as advised by Pontius and colleagues (Pontius et al., 2004). Simple logic was used to create maps showing persistence and changes for each land use and cover class. Land use and cover codes for 1995 and 2010 were 0, 1, 2, 3 and 4 for forest, bushland, grassland, cultivation and other land use cover respectively. To identify the changed areas, land use and cover classes for 2010 were reclassified to 20, 30, 40, 50 and 60 respectively for forest, bushland, grassland, cultivation and other land use and cover using the "reclassify grid values" function in SAGA GIS 2.1.2. Subtraction of the 1995 map from the 2010 map resulted in, for example, 20 (i.e. 20-0), 19 (i.e. 20-1), 18 (i.e. 20-2), 17(i.e. 20-3) and 16 (i.e. 20-4) for changes pertaining to forest cover. Thus for the resulting difference map, 20 would mean unchanged forest (i.e. forest in 1995, code = 0; forest in 2010, code=20), 19 would mean a change from bushland to forest (i.e. bushland in 1995, code =1; forest in 2010, code=20), 18 would mean a change from grassland to forest (i.e. grassland in 1995, code=2; forest in 2010, code=20), etc. The same logic was used for analysis of persistence and changes pertaining to bushland, grassland, cultivation and other land use and cover. Any numbers could have been used provided the logic is maintained. The subtractions were performed in SAGA GIS 2.1.2 using the grid calculator. The resulting maps were formatted for presentation in QGIS 2.14.0.

Regression analysis of spatial statistical relationship between grassland loss and explanatory variables

To be able to use multiple linear regression, grassland loss was defined as the number of pixels within a 9x9 kernel that lost grassland between 1995 and 2010. Thus, if all the pixels lost grassland the number would be 81 while if none lost the number would be 0. The calculation was performed in GRASSS 7.8.2 using the neighbourhood analysis tool. All changes to other land use and cover from grassland were defined as grassland loss. The reclassification was done in GRASS 7.8.2 using the recoding function.

Topographic information (that is, elevation, slope and aspect) was obtained from a digital elevation model (EVC, 2010). Aspect was transformed using Beer's transformation whereby transformed aspect = cos(45-Aspect)+1 (Beers et al., 1966). Spatial data on towns, rivers, and roads were obtained from Africover digital maps for Tanzania (FAO, 2010a). Digitised map layers of mean rainfall, boundaries of game reserves and human population density were obtained from the International Livestock Research Institute (ILRI) GIS database (ILRI, 2010). Average population density was calculated for windows covering about 200 km^2. Shape files of protected areas were obtained from the World Database on Protected Areas (WDPA) website (WCMC, 2013).

Regional Gross Domestic Product (GDP) map was produced using data from the National Accounts of Tanzania Mainland 2000-2010 report (URT, 2011) and boundaries of regions defined in the 2002 map of population density. Multiple linear regression was performed using raster maps in GRASS 7.8.2.

Results

Area and rate of change of grassland in relation to other land use/cover classes

While grassland had the second largest cover in 1995, it was reduced to the second least cover in 2010 (Table 2, Figure 1). Grassland had the highest total area lost and the rate of change is significantly higher (Table 2). The total area lost for grassland was more than three-fold of the total area lost for forest and bushland land cover classes individually. It was also more than the sum of the total area lost for forest and bushland, which amounted only to about two thirds (actually only 65%) of the total area of grassland lost. Grassland, forest and bushland lost areas whereas cultivation and other land use and cover gained areas (Table 2, Figure 2). Cultivation increased more than three-fold whereas other land use and cover increased more than two-fold (Table 2, Figure 1).

Table 2. Area and rate of change for each land use and cover class

Land use and cover class	Area (ha)[a] 1995	Area (ha)[a] 2010	Total changed area 2010-1995 (ha)	Changed area per year (ha/yr)	2010 area as a percentage of 1995 area	% Annual rate of change[b]
Forest	38,097,662	33,296,651	-4,801,010	-320,067	87.4	-0.9
Bushland	17,372,207	12,666,025	-4,706,182	-313,745	72.9	-2.1
Grassland	20,606,711	6,056,976	-14,549,735	-969,982	29.4	-8.2
Cultivation	9,764,073	31,967,393	22,203,320	1,480,221	327.4	7.9
Other land use and cover	1,715,590	3,569,198	1,853,608	123,574	208.0	4.9

[a]The total area and the area for each land cover for each year excludes 514,594 ha that were unclassified for the 2010 land cover map.
[b]Calculated using the formula for annual rate of change proposed by Puyravaud (2003)
Source: Nzunda and Midtgaard 2019

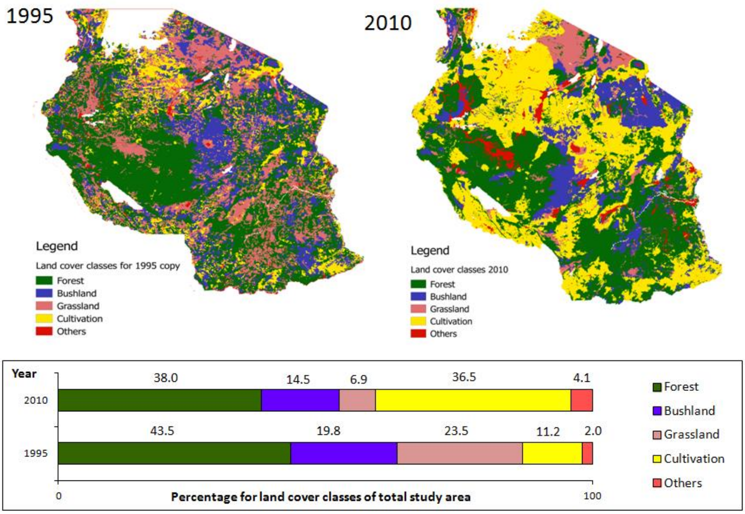

Figure 1. Spatial distribution and percentages of land use and cover classes for mainland Tanzania in 1995 and 2010. Source: Nzunda and Midtgaard 2019.

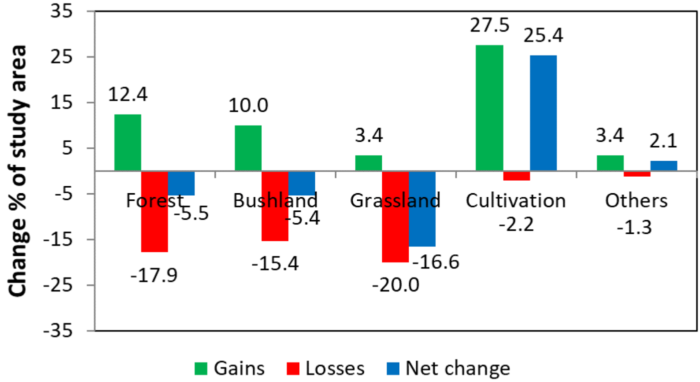

Figure 2. Gains, losses and net change for each land use and cover class for mainland Tanzania 1995-2010. Source: Nzunda and Midtgaard 2019.

Persistence and trajectories of grassland changes in relation to other land use/cover changes

Unchanged grassland had the second least cover area of all the changes involving grassland (Table 3). The highest grassland loss was toward forest and cultivation land, which was approximately equal (Table 3). Each of the grassland area losses to forest and cultivation was about twice the area of unchanged grassland. Needless to state that this also means that summing up the area of grassland lost to forest and cultivation gave an area about four-fold as large as that of unchanged grassland. Grassland also lost to bushland and others (Table 3). The area of grassland lost to bushland was about twice that lost to others (Table 3).

Table 3. Trajectories of changes: Land use and cover class area in 1995 that was converted to different land use and cover classes in 2010

Land use and cover class in 1995	Land use and cover class in 2010		
		ha	% study area
Forest	Forest	22,433,905	25.62
	Bushland	4,506,175	5.15
	Grassland	926,745	1.06
	Cultivation	9,645,092	11.02
	Other land use and cover	585,744	0.67
	TOTAL	38,097,662	43.51
Bushland	Bushland	3,889,139	4.44
	Forest	3,684,729	4.21
	Grassland	1,624,807	1.86
	Cultivation	7,909,037	9.03
	Other land use and cover	264,495	0.3
	TOTAL	17,372,207	19.84
Grassland	Grassland	3,105,766	3.55
	Forest	6,049,480	6.91
	Bushland	3,507,566	4.01
	Cultivation	6,053,169	6.91
	Other land use and cover	1,890,730	2.16
	TOTAL	20,606,711	23.54
Cultivation	Cultivation	7,847,286	8.96
	Forest	822,398	0.94
	Bushland	601,807	0.69
	Grassland	252,597	0.29
	Other land use and cover	239,985	0.27
	TOTAL	9,764,073	11.15
Other land use and	Other land use and	588,243	0.67

cover	cover		
	Forest	306,139	0.35
	Bushland	161,339	0.18
	Grassland	147,061	0.17
	Cultivation	512,809	0.59
	TOTAL	1,715,590	1.96

Source: Nzunda and Midtgaard 2019.

Spatial distribution of grassland persistence and changes

There was a large area of grassland persistence in the northern part of the country that is within the Serengeti Ecosystem (Figure 3(C)). Conversion of grassland to forest was mostly in the central southern part corresponding to the Selous Ecosystem. Conversion of grassland to bushland was in three main areas: north east, west and central southern parts of the country. Close examination of these areas shows that they are adjacent to areas of conversion of grassland to forest. Conversion of grassland to cultivation was scattered throughout the country. However, some parts appear to have relatively large contiguous areas of conversion than others, which have more scattered patches. Notable among these are the lake zone, central zone and southern highlands. Some parts of western and central southern Tanzania had large contiguous areas of grassland loss to other land use and cover.

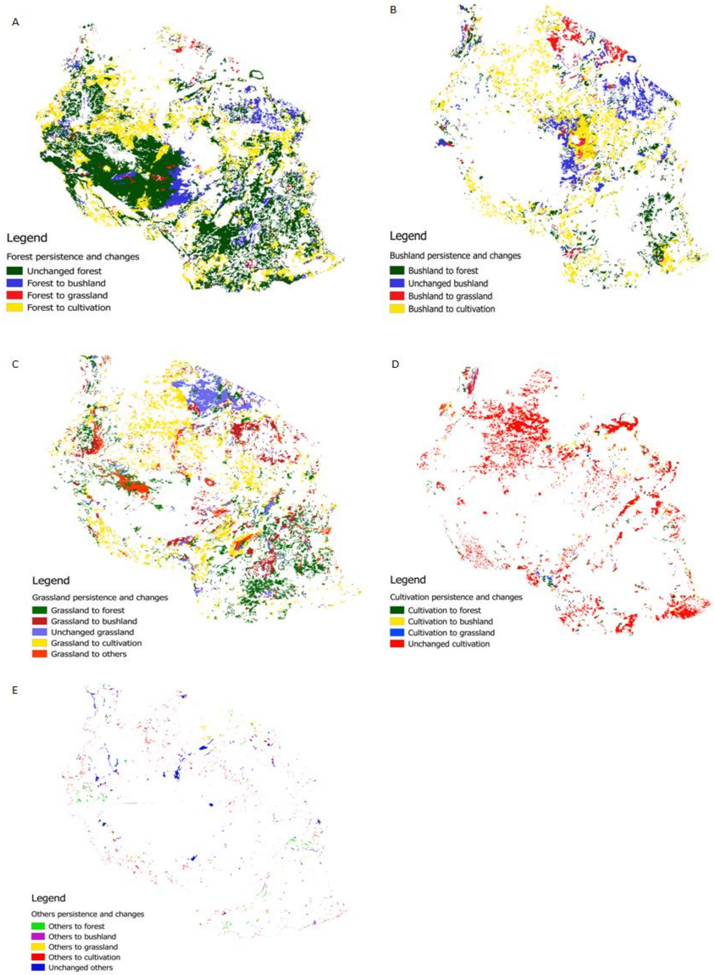

Figure 3. Spatial distribution of persistence and changes for land use and cover classes studied for mainland Tanzania 1995-2010. Forest (A), Bushland (B), Grassland (C), Cultivation (D) and other land use and cover (E). Percentages are with reference to the whole study area (Table 3). Changes of forest, bushland and cultivation to other land use and cover are not shown due to their relatively small magnitude. Source: Nzunda and Midtgaard 2019

Spatial statistical relationship between grassland loss and selected factors

Grassland loss was lower for protected areas, areas with higher slope, further from rail and with higher population density (Table 4). The higher the grassland loss the higher the GDP, elevation, distance to road and rainfall. All the factors explained very little variation in grassland loss as indicated by very small values of R^2. Even the overall model explained only about 2% of the total variation in grassland loss. However, all relationships were statically significant due to large sample sizes used.

Table 4. Results of multiple linear regression analysis of spatial statistical relationship between grassland loss and selected factors

Overall R^2	F	Intercept	B	Factor R^2	F	B	Factor R^2	F
	Overall			Protected area			GDP	
0.022	1208.09	18.52	-1.43	0.00067	359.82	0.000003	0.0004	216.09
n				Distance to road			Population density in 2002	
527,694			0.000050	0.0011	595.44	-0.05	0.0044	2374.40
				Elevation			Slope	
			0.000096	0.0000040	2.31	-0.29	0.0035	1889.74
				Distance to river			Rainfall	
			-0.000064	0.00083	447.98	0.0052	0.0043	2293.93
				Distance to rail			Aspect	
			-0.000027	0.01	5561.43	-0.27	0.000068	36.65

Source: Data analysis by the author.

Discussion

Direct anthropogenic drivers of land use and cover changes in relation to area, rate, persistence, trajectories and spatial distribution of grassland use and cover changes

Grassland loss reported in this study may be explained in terms of direct anthropogenic drivers, indirect anthropogenic drivers and bio-physical drivers of land use and cover changes (Geist et al., 2006; Jaimes et al., 2010; Lambin et al., 2003). Direct anthropogenic drivers are further classified into agricultural expansion (including expansion of cultivation) and infrastructure extension (Geist & Lambin, 2001; Jaimes et al., 2010).

The data in this study show that expansion of cultivation was associated with the largest proportions of grassland loss (Table 3) and these losses were distributed more or less evenly throughout the country (Figure 3(a)-3(e)). In mainland Tanzania, total area planted with annual and permanent crops increased from 4,824,710 ha in 2002/03 cropping season to 5,500,303 ha in the 2007/08 cropping season (URT, 2013). Production of annual and permanent crops increased from 9,620,068 tonnes in the 2002/03 cropping season to 12,459,886 tonnes in the 2007/08 cropping season (URT, 2013). These data show a similar trend to the increase in area under cultivation observed in the current study (Table 3, Figure 3(a)-3(e)).

In Africa, including mainland Tanzania, most of the cultivation responsible for land cover and use changes between 2000 and 2005 was due to small-scale permanent agriculture (FAO, 2009) unlike in South America where its mainly due to commercial agriculture (Freitas et al., 2010; Jaimes et al., 2010). The permanence of agriculture is shown by the largest proportion of what was under cultivation in 1995 remaining under cultivation in 2010 (Table 3, Figure 3(d)). The permanence of agriculture may be because shifting cultivation declined in mainland Tanzania during the period covered by this study (Kilawe et al., 2018). Higher rate of increase in cultivation (7.9%, Table 2) than in population size (2.7%, URT 2013) indicates more land used per farmer. This in turn could indicate an increase in production efficiency and/or a decrease in land fertility.

Infrastructure (including roads, railways and settlements) was the least important direct anthropogenic driver of land use and cover changes during the study period given the low proportions of LUCC associated with other land use and cover (Table 3, Figure 3(e)). People in areas surrounding urban centres are involved in agriculture leading to grassland loss rather than being employed in off-farm occupations in mainland Tanzania (Kashaigili et al., 2013; Lupala et al., 2014; Muzzini & Lindeboom, 2008; Nzunda & Midtgaard, 2017). Despite of little notable direct effects of infrastructure, roads and railways facilitate access to grassland areas for cultivation and activities which indirectly facilitated grassland loss. However results obtained from analysis of distance to road and railway suggest that railways relatively contributed to grassland loss when compared to roads. This may not be true because roads are mainly used for transportation in Tanzania when compared to railways. The notable findings could also mean that the types and levels of roads analysed are not detailed enough to capture the significance of the roads. Under this study only major roads were used and little access roads were included in the analysis. On the other hand, the minimum mapping unit of 1 ha used for the land use and cover maps and the resolution of 1 km used in this study could not capture narrower infrastructural features like roads and railways (Figure 3(a)-3(e)). On the other hand, mining has not been captured, though it was expected to contribute to grassland loss. One study reports of grassland loss in the short term after mining followed by grassland gain after a longer period at the expense of bushland and forest cover (Kahangwa et al., 2020).

Grassland loss to bushland is called bush encroachment and may be caused by many reasons including overgrazing (Tobler et al., 2003). Grassland loss to forest may be due to natural succession or due to establishment of forest plantations including woodlots. The former may be more relevant in the Selous ecosystem whereas the latter may be more relevant in the southern highlands. Unlike for the Serengeti ecosystem where fire is used to maintain grasslands at the expense of forests and bushlands (Hassan, 2007), there are no reports of using fire for maintenance of grasslands in the Selous ecosystem. In the southern highlands, some of the forest plantations are established on what were grasslands, leading to grassland loss (Green Resources Limited, 2011).

Indirect anthropogenic drivers of land use and cover changes in relation to area, rate, persistence, trajectories and spatial distribution of grassland use and cover changes

Indirect drivers are factors which influence direct drivers, and can be divided into five major categories: (i) demographic factors, (ii) economic factors, (iii) technological factors, (iv) policy, institutional and cultural factors and, (v) globalization (Geist & Lambin, 2001; Jaimes et al., 2010; Nzunda & Midtgaard, 2019). In mainland Tanzania, population increased from 22,584, 000 in 1988 to 33,462,000 in 2002 to 43,625,000 in 2012 (URT, 2013).

Population density increased from 26 people/km^2 in 1988 to 39 people/km^2 in 2002 to 51 people/km^2 in 2012 (URT, 2013). Thus the grassland loss and increase in cultivation and other land cover is probably to cater for larger population and its density. On the contrary, the loss of grassland was not associated with higher population density in this study. This could probably means that people from areas with higher population density may have a way of causing grassland loss in areas with low population density. One such way is cultivation away from areas of high population density, which is common practice in Tanzania. Refugees were also an important component of human population in mainland Tanzania that was somehow involved in grassland loss whereby there were about 1,282,638 refugees by 1999 (Jones et al., 2009; UN, 1999).

As for economic drivers of land use and cover changes for mainland Tanzania, quantities of major export agricultural crops marketed increased from 472,000 tonnes in 2006 to 711,000 tonnes in 2010 (URT, 2013). The value of exports of forest products rose from 4 to 16 million US$ from 1995 to 2007 respectively at the 2007 price and exchange rates (FAO, 2008). Out of more than 18 million economically active people in mainland Tanzania, only 1,276,982 people were employed in the formal sector in 2010 (URT, 2013). The remaining portion of the economically active population was employed in the informal sector mainly in livelihood activities particularly cultivation leading to grassland loss. Poverty as measured as percentages of people below food needs line and basic needs line was 21.6% and 38.6% respectively in 1992 and 16.6% and 33.6% respectively in 2007 (URT, 2013). The impacts of aggravated poverty due to economic crises in mainland Tanzania in the 1970s and 1980s that necessitated reforms in the late 1980s and early 1990s were still in effect during the time covered by this study (Gabagambi, 2013; Wobst, 2001). Higher poverty is associated with farming systems that may lead to grassland loss (Mnenwa & Maliti, 2010).

Poor farming technology and resultant low productivity coupled with low returns to inputs necessitated agricultural expansion rather than intensification in mainland Tanzania (Angelsen & Kaimowitz, 2001; Gabagambi, 2013; Lambin et al., 2003). This led grassland loss and more than three-fold expansion of land under cultivation during the study period (Figure 1 & 2; Table 2 & 3).

With regards to policy, institutional and cultural factors (Jaimes et al., 2010; Lambin et al., 2003), there were explicit strategies to increase cultivation in mainland Tanzania (URT, 2002). Efforts to protect grasslands as part of rangeland against destruction and loss have involved, among other things, setting aside some tracks of land as protected areas in the form of national parks, nature reserves, game reserves, game controlled and wildlife management areas (Kideghesho et al., 2013). However, these areas and adjacent lands have long been subjected to a number of emerging issues and challenges, which complicate their management, thus putting the resources at risk of over exploitation and extinction (Kideghesho et al., 2013). These issues and challenges include, among other things, government policies, failure of conservation (as a form of land use) to compete effectively with alternative land uses, habitat degradation and blockage of wildlife corridors, overexploitation and illegal resource extraction, wildfires, human population growth, poverty, HIV/AIDS pandemic and human-wildlife conflicts (Kideghesho et al., 2013). Protected areas is one of the policy, institutional and cultural factors and it was found to be associated with reduced likelihood of grassland loss (Table 4 (Pelkey et al., 2000)). The main cultural force affecting land use and cover in mainland Tanzania may be degradation of traditional cultural values and systems that protected and conserved grasslands. Such systems that still survive to some extent include 'Olopololi/Alalili' for Maasai, 'Ngitili' for Sukuma and 'Milaga' for Gogo are important in conservation of grasslands Mwilawa et al., 2008; Safari et al., 2019).

In mainland Tanzania, most of the agricultural expansion due to investment from industrialized countries (a part of globalization) (Achard et al., 2005)) during the study period was in the form of biofuel projects, which acquired about 120,969 ha of land (Mwamila et al., 2009; Nelson, Sulle, & Lekaita, 2012; E. Sulle, 2013; Sulle & Nelson, 2009). These biofuel farms could have occupied areas that would be pasture land including grassland leading to grassland loss (Mandari, 2010).

Bio-physical drivers of land use and cover changes in relation to area, rate, persistence, trajectories and spatial distribution of grassland use and cover changes

Biophysical drivers of land use and cover changes include drought, destructive animals, disease and insect outbreaks, fires, floods, slope, elevation, aspect and distance to river (Geist & Lambin, 2001; Jaimes et al., 2010; Lambin et al., 2003). As reported in this study, drought in the form of lower rainfall would favour grasslands over cultivation (Aune et al., 2018). However, closer to rivers people access water easily for irrigated cultivation and hence grasslands would be lost more, as reported. Steeper slopes are not suitable for cultivation and hence grassland loss was lower for areas with higher slope (Table 4). In the tropics, animals would cause bush encroachment especially where there is overgrazing (Tobler et al., 2003) although high grazing pressure favours grasslands in Europe (Aune et al., 2018). Fires and floods favour grasslands over other vegetation types such as forests and bushlands (Eva & Lambin, 2000). For instance, the Serengeti National Park area showed persistence of grassland (Figure 3(c) and was burnt consistently for maintenance of grassland (Hassan, 2007). Disease and insect outbreaks may not be important in influencing changes in grassland cover.

Consequences of grassland loss

Direct consequences of grassland loss are ecological in terms of changes in ecosystem goods and services value of a landscape or its component. The goods and services may be in the hydrological, biodiversity or climate amelioration dimensions. The indirect consequences are in the socioeconomic dimension. One example of these consequences is presented for the transboundary Mara River basin around the Kenya-Tanzania border where grassland loss alongside loss of bushland and forest led to sharp increases in flood peak flows by 7%, and an earlier occurrence of these peaks by 4 days between 1973 and 2000; increased soil erosion in the upper catchments, and expansion of Mara wetland by 387%, which adversely affected riparian agriculture (Mati et al., 2008). In another instance, loss of grassland was more important than disease (in particular trypanosomiasis spread by tsetse flies) in leading to the closure of Mkwaja Ranch in Tanzania in 2000 after operating for 48 years (Tobler et al., 2003). Grassland loss leads to landscape fragmentation resulting in lower or loss of connectivity which reduces insect and avian diversity (Collinge, 2000; Shaffer et al., 2018). Loss of grasslands may also lead to conflicts over land use especially farmer-herder conflicts. For example, in Kilosa District, Tanzania there were farmer-herder conflicts as a result of many political-ecological reasons including grassland loss (Benjaminsen et al., 2009). In turn, the conflicts led to loss of property and life (Benjaminsen et al., 2009).

Control of grassland loss

Protected areas strategies, agricultural intensification, permanent agriculture and rangeland management are some of the control measures taken (Kideghesho et al., 2013). To deal with institutional constraints, the most common interventions are stakeholder involvement using participatory approaches, tenure and rights regularisation and policy and governance reform (Kideghesho et al., 2013). Usually a combination of interventions is used to address the drivers: for instance, agricultural intensification is often combined with zoning, protected areas or rehabilitation of degraded lands to prevent further degradation (Kikula, 1999). There are also efforts to address the root cause of grassland loss, which is high rate of population growth, using the whole spectrum of approaches from population control policies to techniques, although this is so far not successful due to various reasons (Robinson, 2016). There are also interventions to address economic and market drivers of grassland loss especially those related to improving profitability of agriculture (Gabagambi, 2013; URT, 2002).

Conclusions and recommendations

The net change was grassland loss although there were also changes of other land cover classes to grassland. Grassland loss had the highest rate of all the changes in land cover. Expansion of cultivation was scattered throughout the country and was associated with the largest areas of grassland loss. The highest grassland loss was to forest and cultivation, which was approximately equal. Each of the grassland area losses to forest and cultivation was about twice the area of unchanged grassland. Bush encroach was also an important cause of grassland loss. Protected areas reduced grassland loss and thus there was grassland persistence in protected areas such as the Serengeti ecosystem. Conversion of grassland to cultivation was scattered throughout the country although there were areas with more contiguous patches than others. The higher the grassland loss the lower the slope, the distance to rail, the population density but the higher the GDP, elevation, distance to road and rainfall. Direct consequences of grassland loss are ecological in terms of changes in ecosystem goods and services value of a landscape or its component. The goods and services may be in the hydrological, biodiversity or climate amelioration dimensions. The indirect consequences are in the socioeconomic dimension. Control of grassland loss would be achieved through addressing the drivers of grassland loss.

Further research should investigate the potential and possibility of improvements in agricultural technology to achieve more agricultural intensification than expansion of areas under cultivation so as to reduce or completely reverse grassland loss. Along the same lines, research should be conducted on improved markets and profits to cultivators so as to reduce grassland loss as a result of less need for expansion of area under cultivation due to higher profitability of farming per unit area. The nature of grassland loss to forest cover should also be researched into.

Ways to apply existing extensive research on bush encroachment should be explored. Furthermore, research should focus on the role of formal and informal institutions that protect grasslands against expansion of cultivation and other changes discussed in this paper.

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