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Research Article

An analysis of ecosystem vulnerability and management interventions in the Morogoro region landscapes, Tanzania

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Abstract

Ecosystems in sub-Saharan Africa are highly vulnerable to external perturbations. An in-depth understanding of the socio-ecological mechanisms is important for the effective management of vulnerable ecosystems. Using remotely sensed satellite imagery and social data from 335 households, the study examines how different ecological and socio-economic factors influence ecosystem vulnerability in Morogoro region, Tanzania. Remotely sensed data indicated negative patterns of change in ecosystem health both at the spatial and temporal scales. Multiple logistic regression analysis showed habitat fragmentation and forest burning as key threats ($p=0.02$). From a social point of view, low income level (54.6%) and limited knowledge of environmental conservation (18.5%) were considered major catalysts of ecosystem vulnerability. Statistical results showed livelihood diversification (45.1%), effective institutional frameworks (30.7%), and afforestation programmes (24.2%) to be key intervention measures. The methodology and policy implications of the study have a wider applicability in the long-term management of vulnerable landscapes.

Keywords: ecosystems, vulnerability, planning, management, Tanzania

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Introduction

Many factors play vital roles in increasing ecosystem vulnerability, and human-linked stresses such as population growth are critically important in the planning and management of ecosystems [1]. Ecological threats such as habitat fragmentation and fires are also major threats to these ecosystems [2-10]. Habitat fragmentation alone significantly threatens ecological functioning and biodiversity conservation [1].

A comprehensive assessment of ecosystem vulnerability is a pre-requisite for determining the relative effectiveness of conservation and management efforts [11]. Mapping ecosystem vulnerability is particularly useful in monitoring trends and predicting likely future impacts [12,13]. To date, few studies have taken into account the vulnerability status of fragile ecosystems and potential threats [14, 15]. A study by Giliba et al. [1] highlights the challenges of incorporating vulnerability into conservation planning and management due to lack of effective vulnerability data. Ecosystem vulnerability is a highly contested term. Commonly, it is used to describe a state of susceptibility to stress or harm associated with changes or disasters [16]. It often indicates an ecosystem's inability to recover from shock or stress imposed by humans or external perturbations in the natural environment [17]. An ecosystem is considered vulnerable when it displays a high level of sensitivity to change in structure and functioning. The vulnerability concept consists of the socio-economic, physical, infrastructural, political and environmental dimensions of changes in the socio-ecological systems [18]. Vulnerability has been linked directly to sensitivity to change, level of exposure to stress, and coping capacity [12, 19]. Differences in vulnerability may be driven by the geographic position, economic structure, and access to human, social, natural and financial capitals [19, 20]. Vulnerability is broadly used in different fields including climate studies [12, 21] and the social system [16].

Different system variables characterize a system's ability to develop resilience: thresholds, feedback loops, and disturbance regimes [22]. This has an important bearing on the maintenance of ecosystems [22, 23]. However, the dynamic state of most ecosystems [24], coupled with other biophysical and socio-economic factors, enhances the degree of vulnerability [16, 25]. Therefore, appropriate conservation measures for recovery of affected areas must first develop vulnerability assessments necessary for monitoring and restoration efforts [22]. In addition, incorporating regional and local stakeholders in the development of policies for collective social responsibility can support long-term management of fragile and vulnerable landscapes [26]. Up-to-date knowledge of ecological and social factors is vital to policy makers and resource managers in formulating appropriate management interventions [28].

Ecosystems in sub-Saharan African face undesirable and rapid stresses due to increased external perturbations [29-32]. Ecosystems in Morogoro region, Tanzania, are particularly sensitized by past threats and exposure to human encroachment that compromise their capacity to perform important functions [33-36]. If impacts of increased ecosystem vulnerability are not addressed, adverse impacts will likely translate into habitat losses and negative effects on important ecosystem functions. Although the decentralization policy in Tanzania has led increased local communities' knowledge by shifting planning to local governmental authorities, the system still suffers from limited access to important information on appropriate landscape management [37]. A knowledge gap on best ways to bridge science and policy can hinder effective management interventions [1]. Therefore, we argue that governments need to promote interventions that reduce the vulnerability of ecosystems. This however requires widespread vulnerability assessments, including potential threats and feedback mechanisms [16, 18]. Such information can be acquired from up-to-date geographic and region-specific data [16], such as that provided in this paper.

We apply a combination of social and ecological indicators to assess vulnerability of ecosystems and management interventions in biodiversity hotspots in Morogoro region, Tanzania. Specifically, we investigate: (1) the vulnerability status of natural forests in Morogoro based on satellite imagery and socio-economic indicators; (2) the forces that drive ecosystem vulnerability; and (3) feasible management interventions for future natural ecosystem protection. Our paper contributes to the on-going debate about vulnerability assessments needed for effective conservation and management interventions, particularly in complex and dynamic environments with inadequate geographic data [22]. We combine time series satellite imagery and empirical data from 335 households as a reference point for policy recommendations for habitat management of fragile landscapes. Lack of region-specific policy and management guidelines is a major impediment to conservation and management efforts, particularly in sub-Saharan Africa, where there are multiple drivers of change [1, 28]. We address unresolved management issues and knowledge gaps, providing leverage points for resource planners and managers in developing policy guidelines for long-term management of vulnerable landscapes.

Methods

Study area

The Morogoro region is one of the twenty main regions in Tanzania. It lies between 5°58' and 10°00' South and 35°25' and 38°30' East (Fig. 1). The oceanic climate of the region translates into a bimodal rainfall distribution characterized by two rainfall peaks per year, with a dry spell separating the short rains (October–December) from the long rains (March–May). Rainfall exceeds 1,000 mm per annum in high altitudes of the Eastern slopes of the Uluguru Mountains and decreases in a gradient to 600 mm per annum in the low altitude plains. The area receives average rainfall between 800-1,000 mm per year. Moderate temperature of around 25°C is experienced throughout the year. August is the coldest month (average of 18 °C), and the hottest is February (32 °C).

Natural ecosystems in Morogoro region have been subjected to forest fragmentation over the years [38-42]. Between 1955 and 2000 for instance, Burgess et al. (33) notes that natural forest cover decreased from 300 km^2 to 220 km^2 and the rate of endemism and extinctions increased due to increased settlements and farming activities in the region. Morogoro region is made up of five districts: Morogoro rural, Morogoro urban, Ulanga, Kilombero and Kilosa districts (Fig. 1). The Morogoro region has an estimated total population of 2,218,492 and 157 villages. The study was conducted in 11 randomly selected villages (located in four districts). We randomly selected villages from those located adjacent to the forest sites including Uluguru, Nguru ya Ndege and Kitulanghalo forests.

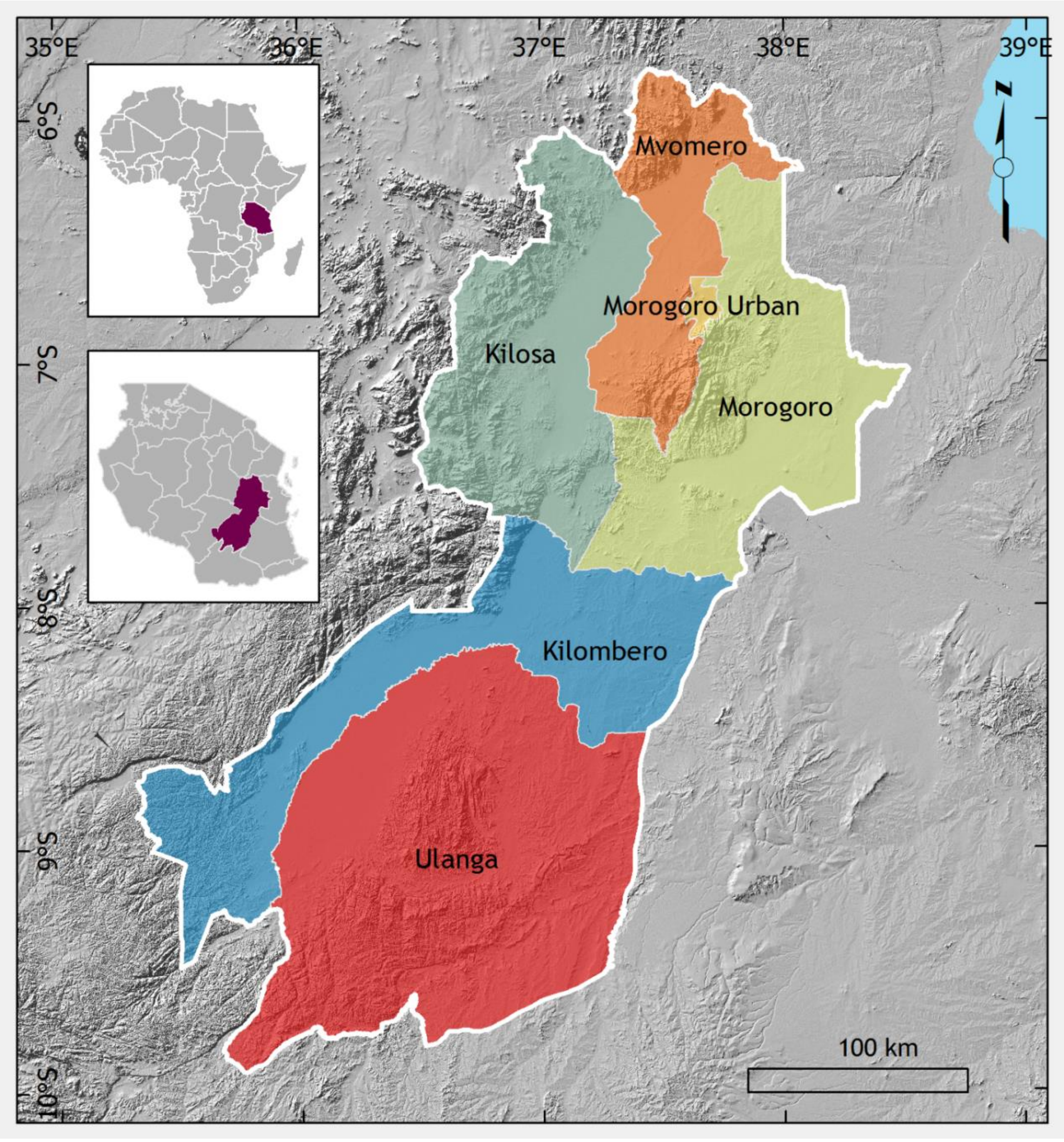

Fig. 1. Location of the five districts within Morogoro region, Tanzania.

An analysis of indicators of vulnerability based on spatial patterns

We used satellite imagery to assess regions considered ecologically vulnerable to changes in total habitat coverage. Landsat TM (30/09/1995) and Landsat ETM+ (20/07/2012) were utilized. Supervised image classification using the maximum likelihood classifier was adopted as it is the most popular parametric classification technique [43-46]. It is based on the Bayes theorem, using a discriminant function that assigns pixel values to the category with the highest likelihood [47-49]. The images were classified into natural intact forest cover and developed areas. A total of 82 field ground data points were used to validate the classified 2012 image.

Spatial data analysis

Three temporal image analyses were conducted for 1975, 1995 and 2012. The annual rate of forest change was calculated in each of the years. Change difference in forest cover between 1995 and 2012 were conducted using the land change modeler. All images were then converted to ASCII format in ESRI [50].The ASCII format scenes were then imported into Fragstats [51], and ASCII built-in-algorithm selected for running analyses in the Fragstats model, which is relevant in forest fragmentation studies. In accounting for temporal and spatial patterns, patch metrics were effective indicators of vegetation fragmentation. Mann-Whitney U-test was useful in the detailed assessment of differences among patch areas over the years using STATA version 10.1 [52]. Games-Howell tests were conducted to investigate any significant trends in the mean perimeter area ratio over the years.

Social data collection

Household data were collected between July and October 2012 from 335 households randomly sampled from 11 villages. Twenty-minute household interviews were conducted after obtaining the consent of every single individual interviewed. The identity of the respondents was marked using roman numerals as respondent i, ii, iii etc. In total, 335 respondents were interviewed in 11 villages with approximately 39.4% females and 60.6% males, aged above 18 years. The villages included Kitulanghalo (8.3%), Mikese (9.9%), Ruvuma (8.2%), Mbete (9.8%), Tangeni (8.8%), Mafuta (9.9%), Ubiri (9.3%), Tulo (8.8%), Chanzema (9.3%), Kwelikwiji (9.7%), and Choma (8.0%). To ensure relevance of responses to the research questions, only villages adjacent to the natural cover sites were sampled. Interviews were administered by the primary investigator and three trained research assistants, and all interviews were administered in Swahili, the widely spoken national language in Tanzania. Interviews sought information on household socioeconomic characteristics, on-going development activities in the region, perceptions regarding forest cover changes in the past 20 years, and appropriate strategies for management of fragile landscapes. Secondary data were collected from local government extension officers and leaders in districts within Morogoro region.

Social data analysis

A multiple logistic regression model was used to investigate factors associated with ecosystem vulnerability. These were classified into three groups: (i) household socioeconomic characteristics (such as age, gender, education); (ii) economic development activities (farming, charcoal production, timber sawing, firewood collection, settlement, infrastructure development); and (iii) perceptions of change in forest cover (i.e., whether there is a decrease in size of forest cover). The following model was developed to understand how different factors influenced ecosystem vulnerability in the Morogoro region.

$$Vulnerability = f(Householdcharacteristics + humanactivities + perceptionsonforestcoverchanges) \text{Equation}$$

Variables with a strong relationship ($p<0.01$) on univariate (used here to mean a single covariate) analyses were included in a backwards, stepwise regression model and rejected at the $p \geq 0.05$ level based on likelihood ratio tests. Selection of variables was based on literature and expert knowledge. One-Way ANOVA was used for testing significant differences associated with driving forces and management interventions. Duncan post-hoc tests were used to assess significant differences ($p \leq 0.05$) within and between group means.

Results

Temporal and fragmentation patterns - an indicator of ecosystem vulnerability

Temporal map analyses were produced for 1975, 1995 and 2012 (see Figures 2, 3, and 4). Natural forest cover decreased at an annual rate of 1.6% between 1975 and 2012. We found a decrease from 64,813.68 hectares (17.70%) in 1975 to 27,742.68 hectares (7.60%) in 1995 and 26,137.98 hectares (7.10%) in 2012. Our results further showed the largest patch number and mean patch area in dense forest. Games-Howell showed a high significance in fragmentation trends ($p=0.01$). There was an increase in patch frequency by 412 in the forest cover between 1995 and 2012 ($p=0.0001$). Mann-Whitney tests showed distinct differences in patch area ($p=0.007$) between 1975 and 1995. Overall, the patchy nature of forest fragments was a very good indicator of a vulnerable ecosystem.

Based on the logistic regression results, changes in forest size and burning were considered as key forces driving increased ecosystem vulnerability ($p=0.0001$ and $p=0.021$, respectively, Table 1). An expansion in development is a major contributing factor to ecosystem dynamics throughout the region (Figs. 2, 3, 4).

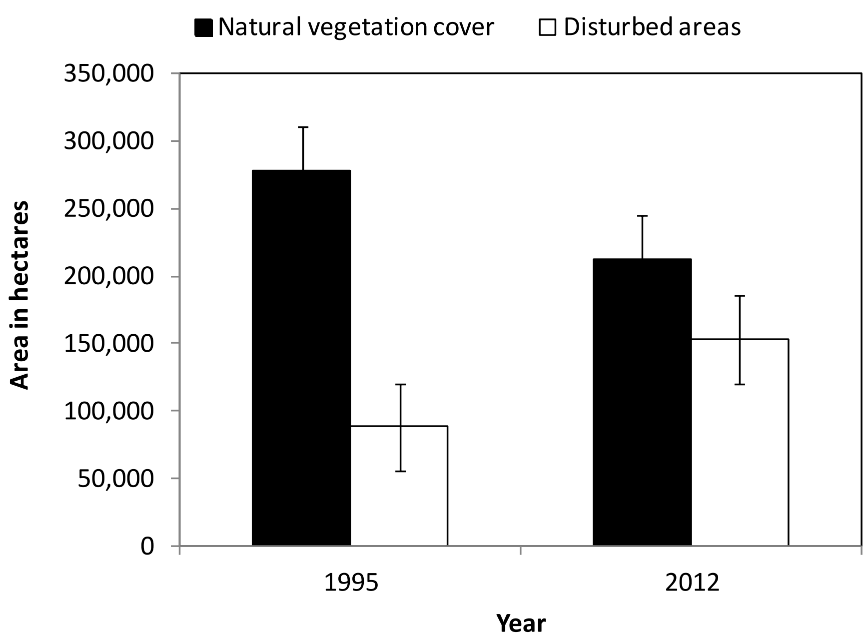

Fig. 2. Temporal change patterns in natural cover in forest landscapes between 1995 and 2012 representing natural forests landscapes within Morogoro region (Uluguru, Nguru ya Ndege and Kitulanghalo).The bars represent the standard error.

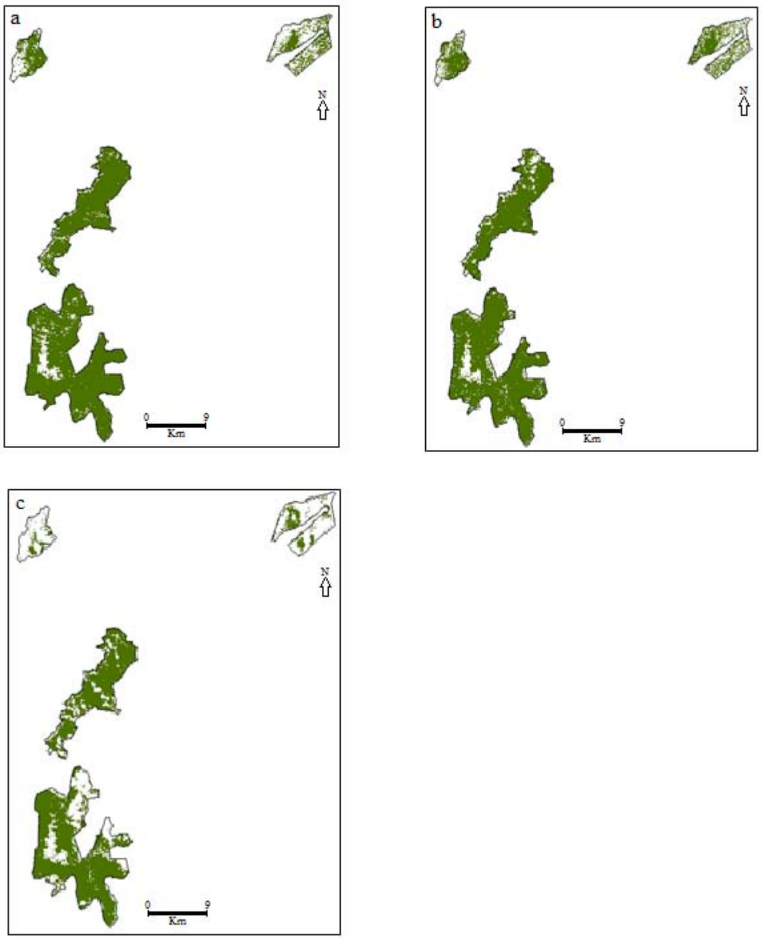

Fig. 3. Forest cover maps based on Landsat images representing a (1975); b (1995); c (2012) representing all natural forests landscapes within Morogoro region (Uluguru, Nguru ya Ndege and Kitulanghalo).

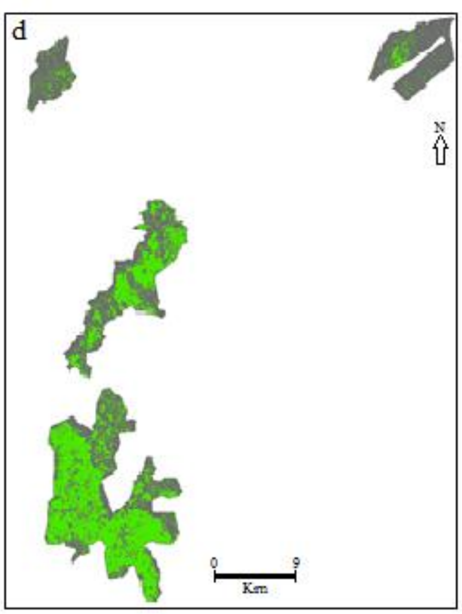

Fig. 4. Forest changes analysis between 1995 and 2012 with forest patches (green) and developed areas (grey) based on Landsat images representing natural forests landscapes within Morogoro region (Uluguru, Nguru ya Ndege and Kitulanghalo).

Ecosystem vulnerability as perceived by respondents

Approximately 32.8% (95% CI: 27.8-38.1%) of respondents indicated the high extent of ecosystem vulnerability. Vulnerability of ecosystems in Morogoro region significantly varied among villages (p=0.03). The greatest vulnerability was significant among respondents in Mbete, Mafuta, Ubiri and Kwelikwiji villages compared to the rest of the villages (Table 1).

Table 1. A logistic regression model showing ecosystem vulnerability

Variable	Odds ratio	95% CI	P-value
Villages			
Kitulangalo	1	_	_
Mikese	0.51	0.19-1.37	0.183
Ruvuma	0.85	0.15-4.97	0.859
Mbete	0.24	0.06-1.00	0.049
Tangeni	0.70	0.12-3.99	0.688
Mafuta	0.19	0.06-0.60	0.005
Ubiri	0.13	0.03-0.57	0.007
Tulo	0.40	0.09-1.78	0.230
Chanzema	1.41	0.44-4.53	0.563
Kwelikwiji	0.29	0.10-0.84	0.023
Choma	0.30	0.03-3.41	0.333
Forest size decrease	8.12	3.89-16.92	0.001
Forest burning	0.33	0.13-0.85	0.021

Note: Kitulanghalo lacks 95% CI and p-value as it was used a reference level

Socio-economic factors influencing ecosystem vulnerability

The majority (50 %) of the respondents were in the middle age group between 35-55 years. Approximately 16.7% of the participants did not have any formal education, 76.7% had primary education and 6.6% had secondary education. All respondents reported farming as the most commonly practiced economic activity. The main activities associated with forest loss included charcoal production (35.4%), farming (26.8%), timber sawing (17.0%), forest burning (13.4%), and settlement (5.5%). Forces driving habitat loss and fragmentation included poor income (54.6%) and lack of capacity building on conservation (18.5%). Duncan post-hoc tests showed statistical significance within and between group differences among different villages (Fig. 5). Tangeni and Ubiri village respondents seem to be more knowledgeable on major drivers of change than respondents in the rest of the villages.

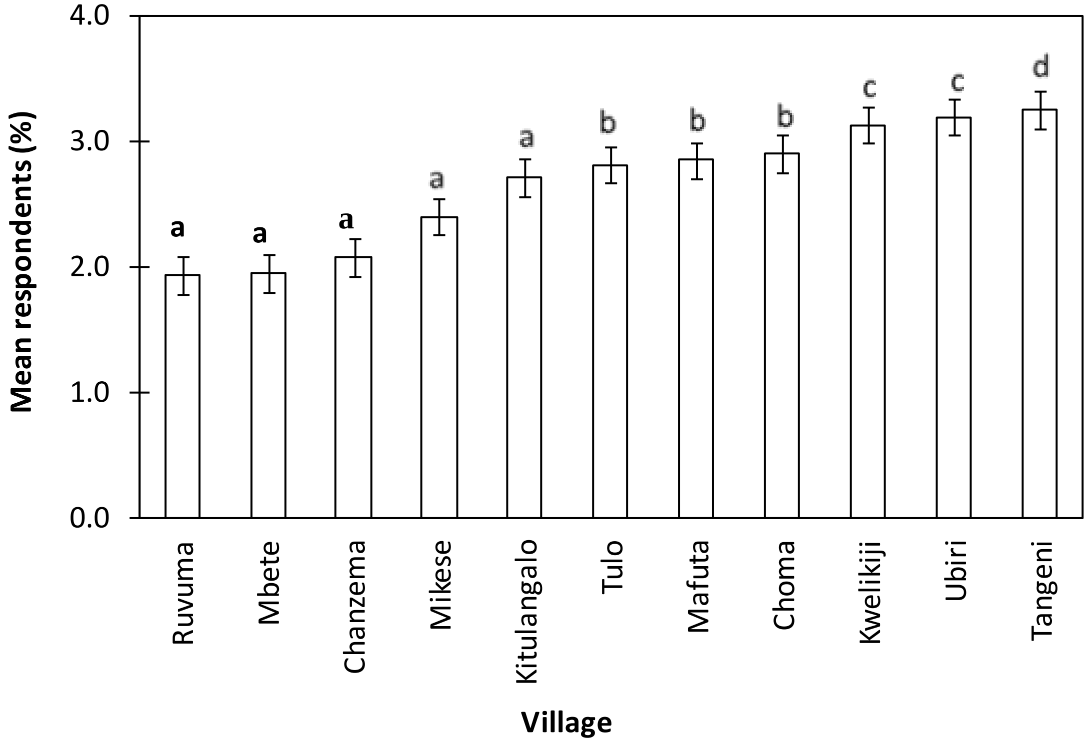

Fig. 5. Mean percent respondents in each village who perceived poor income and lack of capacity building on conservation as driving forces to habitat loss. Bars (standard error) with similar letters are not significantly different (p≤0.05) based on Duncan post hoc test.

Management interventions

Respondents prioritized livelihood diversification (45.1%) as essential in effective management of vulnerable ecosystems in Morogoro region. The significance of institutions (30.7%) and afforestation programmes (24.2%) emerged as useful intervention measures. Furthermore, one way ANOVA test indicated a high level of significance ($F=5.72$; $df = 10$; $p=0.005$) at a 5% level of significance for the mean between villages and management intervention measures. Duncan post-hoc test results showed statistical significance within and between group differences among different villages (Fig. 6). Mikese and Ubiri villages had the highest appreciation of the need to integrate livelihood diversification and important role played by institutions as key intervention strategies.

Population trend statistics in the region

Statistics obtained from secondary data show an increasing population trend in the region (Table 2).

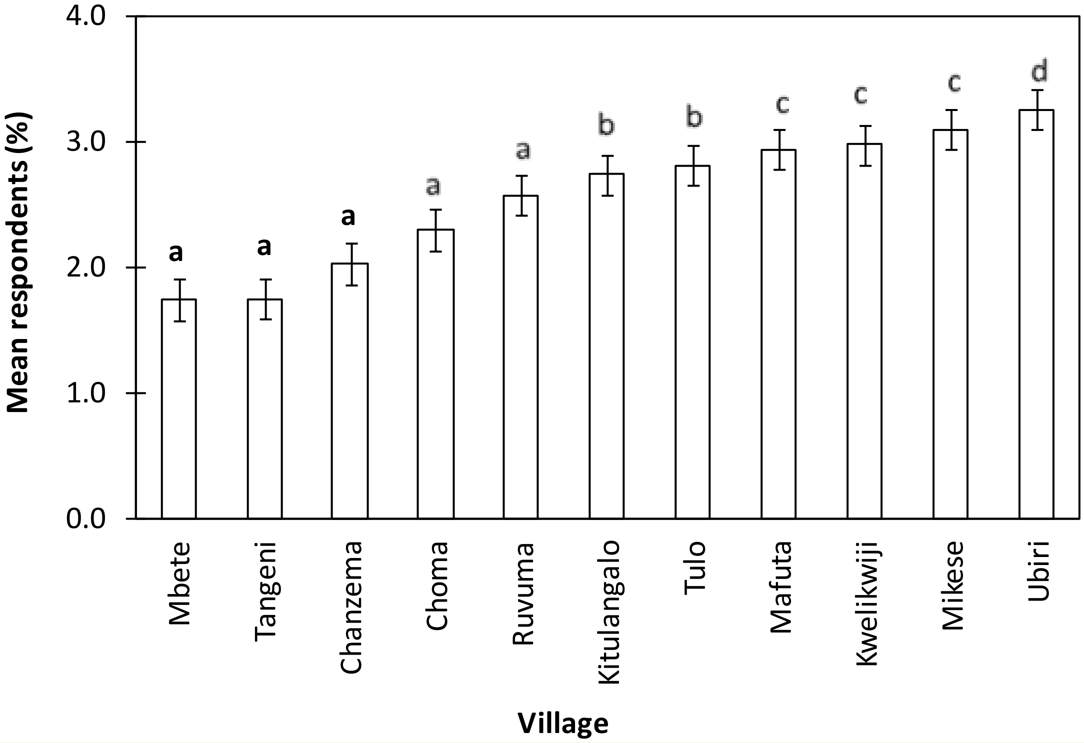

Fig. 6. Mean percent respondents in each village who appreciate livelihood diversification, institutional frameworks and afforestation programmes as useful intervention measures. Bars (standard error) with similar letters are not significantly different (p≤0.05) based on Duncan post hoc test.

Table 2. Population trends in Morogoro region between 1967-2013

District	1967	1988	2002	2013
Morogoro Urban	24,999	117,601	227,921	315,866
Morogoro rural	291,373	430,202	263,012	286,248
Mvomero	*	*	259,347	312,109
Kilosa	193,810	346,526	488,191	631,186
Kilombero	74,222	187,593	321,611	407,880
Ulanga	100,700	138,642	193,280	265,203
Total in Morogoro	685,104	1,220,564	1,753,362	2,218,492

Note: *Represents missing data. Source: [70;71].

Discussion

Important results emerge from the study. First, changing spatial and temporal patterns in natural forest cover are good indicators of the high level of vulnerability. We also investigated important issues to be considered in the conservation agenda of fragile landscapes. Two socio-economic factors -- low economic capacity and poor knowledge of environmental conservation -- stand out as major drivers of the high level of ecosystem vulnerability in the study area. However, this varied considerably among the study villages, with the highest significance evident among Tangeni and Ubiri villages. It is important to note that appropriate management of landscapes is heavily driven by socio-economic factors. Results showed Ubiri and Mikese villages to be leading in prioritization of livelihood diversification and the role played by local institutions. To account for significant differences among the different villages, we present our discussion and policy implications of our results.

Ecosystem fragmentation and temporal dynamics

Landsat satellite imagery and fragstats metrics showed the profound magnitude of change and trend patterns. Primarily, human encroachment activities leading to fragmentation and habitat modification are projected to lead to negative effects on biological conservation. In the long term, species and ecological functions of ecosystems will diminish. Satellite imagery indicates the spatial relevance in computing the patterns and the magnitude of fragmentation. Consistent monitoring procedures based on better remote sensing techniques are essential to the successful development of better conservation and management plans for the forest remnants.

Wilson et al. [11] characterize areas exposed to past threats based on quantitative spatial models to predict the extent of future vulnerability. The increased threats could be attributed to habitat transformation by human activities such as agriculture and built-up areas [33-35]. An increase in settlements and farmlands may have led to a decline in natural land cover [53, 54]. In addition, most people in Morogoro region are subsistence farmers who rely heavily on rain-fed agriculture, which could be a principal cause of natural forest cover loss [55]. The extent of deforestation in most woodlands in Tanzania makes conservation very challenging [56], and some studies find farming and urban sprawl to be leading causes of natural forest loss [57-58]. It is also possible that dynamic spatial patterns may have heightened as a result of high population growth in the region (as shown by results in Table 2).

Impacts of poor economic capacity and conservation knowledge

Income and improved conservation capacity are critical in shaping the behavior of communities in supporting conservation efforts. Our results showed poor income (54.62%) and lack of conservation capacity (18.51%) as the leading factors in the increased ecosystem vulnerability in Morogoro region. Respondents from Tangeni and Ubiri villages were more knowledgeable on forces driving ecosystem vulnerability than those in the rest of the villages. Differences in perceptions of the extent of vulnerability could partly be attributed to better knowledge of conservation's significance in Tangeni and Ubiri than in the rest of the villages. Another possible reason could be better access to conservation programmes in Morogoro urban and rural districts. The presence of conservation support programmes initiated by Sokoine University, Morogoro Tanzania and the Eastern Arc Mountains Critical Ecosystem Partnership Fund (CEPF) programmes in Morogoro urban districts, for instance, may offer better access to information on environmental conservation. In addition, access to such institutions introduces development programmes to low income households, providing unique growth and development opportunities. These findings are in agreement with Dolisca et al. [28], who found that participatory management of ecosystems could be enhanced by socio-economic factors such as increased annual income and increased awareness. Other studies have also established how communities with better income levels and environmental capacity had more concern for environmental conservation activities [59].

The role of livelihood diversification and effective institutional frameworks

The concept of livelihood diversification emerged as a critical management intervention avenue (45.1%). Livelihood diversification as a key, urgent intervention measure was more appreciated in Ubiri and Mikese than in the rest of the study villages, reflecting the prevailing scenario in Morogoro region, where most communities live under poor economic conditions [60, 61]. This poverty constrains conservation efforts in the region [4]. Many individuals living adjacent to natural forest ecosystems are subsistence farmers who practice small-scale farming [33, 34]. Increased incidences of poverty and high population growth rates in Morogoro region (see Table 1) are major causes of habitat loss and fragmentation in Tanzania [56, 62, 63]. It is important therefore that resource managers and policy makers first develop policy measures for sustainable livelihood options. Raising levels of human and social capital are critical to any intervention strategy [64, 65]. Appropriate legislative measures need to be consonant with available natural forest resources and socio-economic patterns of the local people living adjacent to natural forest sites in the case study area.

In addition, communities need more incentives to encourage their full participation in the conservation agenda. Supporting alternative community projects can help resolve the social-ecological crisis facing environmental conservation [26, 66]. For instance, sustainable livelihood options hold greater promise for local communities in the long term [67]. The social and capital elements need to be considered in such an approach [68]. Our results support previous studies which showed the need to strengthen the significance of institutions and livelihood diversification programmes in sustainable conservation and management efforts (69). Furthermore, our study adds to arguments made by Neufeldt et al. [70], who assert that development programmes need support both the economic capacity of communities and livelihood diversification.

The study showed that approximately 30.7% of the respondents in Morogoro region prioritize effective role played by local institutions as a key intervention in management. Though the United Republic of Tanzanian government is the main provider of extension services, several non-governmental organizations (NGOs) have, over time, supplemented these services [71]. Local communities in the region generally lack confidence in their national governments' policy planning and management [37]. Our results show a great opportunity for positive change if programmes and policies are developed and implemented along with local institutional arrangements to ensure effective decision-making. Encouraging community participatory initiatives was considered key in shaping future conservation planning and management efforts. Approximately (24.2%) of respondents in the region showed the need for long-term re-afforestation programmes, including designation of forest management by local communities [53]. Indeed, involving local people who directly or indirectly benefit from conservation projects may increase their participation in such projects [72].

In conclusion, a better understanding of the socio-ecological mechanisms responsible for ecosystem vulnerability is critical for the effective management of such ecosystems. This is particularly important for the dryland dynamic environments of sub-Saharan Africa where there are multiple drivers of change. Our research tests how science-based interpretation could guide policy makers in ameliorative decision-making procedures. A combination of remotely-sensed data and socio-ecological factors were successful in meeting this objective, providing a better understanding of the potential drivers of ecosystem vulnerability. Importantly, our results highlight the influence of forest fragmentation and fires on the vulnerability of natural ecosystems in Morogoro region, Tanzania, and show that major socio-economic factors driving ecosystem vulnerability are low income levels and poor knowledge of environmental conservation in the studied villages. One key result is that different villages within the same geographical location may perceive different factors driving ecosystems vulnerability, demonstrating the need for policy makers to design region-specific policies and programmes for reducing ecosystem vulnerability.

Implications for conservation

Despite the challenges associated with management of vulnerable ecosystems, our results suggest the potential for positive change by emphasizing the need to strengthen livelihood diversification needs and institutions. Our study will be useful for resource and conservation planners in the long term conservation and management agenda against external perturbations. It is of utmost importance that managers of vulnerable landscapes align policy guidelines with effective institutional and livelihood diversification programs. The methodology and findings from this paper may have wider applications for the management of vulnerable ecosystems in Tanzania and other dryland ecosystems in sub-Saharan Africa.

Furthermore, it would be useful in future if more resource protection studies integrated higher spatial resolution satellite data in the detailed assessment of external impacts on natural ecosystems, as we did not cover this important aspect. In addition, future research work on ecosystem vulnerability may consider integrating interviews on ecosystem management from regional leaders and planners.

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QUESTIONNAIRE

Dear respondent,

I am carrying out a study on forest use, conservation and management. I request for your honest opinion on the following questions and appreciate your support. I confirm that I will not reveal your identity. This work plays an important role in future planning and forest conservation.

GI Use of forest resources and their conservation

Village name			
Name of enumerator		Date	

Section 1: General information (GI)

G11 Respondent's Characteristics:

GI1a Name of respondent ……………………………………………

GI1b Age of respondent …………….

GI1c Education ……….. 0. None ❒ 1. Primary School ❒ 2. Secondary School ❒ 3. Tertiary ❒

GI1d Sex ………………… 1. Female ❒ 2. Male ❒

GI1e Village ……………………………………………

Section 2: Forest Use and Conservation (FUC)

FUC1: Is the forest conserved or not?

(1) Conserved (2) Not Conserved (3) Partially Conserved (4) Do not Know

FUC2: Please state any human developmental activities in the area?

HUMAN ACTIVITY	DESCRIPTION
FUC2a Farming	(1) Yes (2) No (3) Do not Know
FUC2b Charcoal production	(1) Yes (2) No (3) Do not Know
FUC2c Timber sawing	(1) Yes (2) No (3) Do not Know
FUC2d Firewood collection	(1) Yes (2) No (3) Do not Know
FUC2e Settlement	(1) Yes (2) No (3) Do not Know
FUC2f Brick making	(1) Yes (2) No (3) Do not Know
FUC2g Infrastructure development	(1) Yes (2) No (3) Do not Know

FUC3: In comparison to previous years, has the size of the forest increased in the past 20 years compared to now?

(1) Yes (2) No (3) Do not know (Please specify)…………………………………………………………………

FUC4: What are the causes of forest losses in the region?

(1)Timber sawing (2) Settlement (3) Farming (4) Charcoal Production (5) road construction (6) forest burning

FUC5. What could be the factor (driving forces) leading to forest decrease?

(1) Lack of education (2) Poor income (3) Poor farm productivity (4) Farm preparation for cultivation (5) Others (please specify………………………………………….)

FUC6. What should be done to conserve our forests?

(1)Afforestation activities (2) Education and awareness activities enhanced with institutions (3) Create job opportunities (4) Diversify livelihoods