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Geospatial Analysis of Amount of Biomass Loss and Carbon Released to the Atmosphere as a Result of Habitat Conversion of Ruaha – Rungwa Ecosystem, Tanzania

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Abstract
Managing unfenced protected areas (PAs) to preserve biodiversity and ecosystem services presents challenges in the face of climate change and habitat disturbance. This often forces wildlife to seek adaptation in other PAs or unprotected areas. Consequently, there is a need to include these adapted areas in the PA network. While PAs include national parks, game reserves, forest reserves, and wildlife management areas (WMAs), unprotected areas (unPAs) comprise wildlife corridors and dispersal areas that connect multiple PAs. However, residents residing near or within unPAs, particularly in developing countries, unsustainably exploit flora and fauna resources for their livelihoods. This paper focuses on the lesser-known aspect of biomass loss and carbon emissions resulting from habitat conversion in the Ruaha-Rungwa ecosystem (RRE) in Tanzania. The study estimates the annual biomass loss, carbon emissions, and conservation profit resulting from habitat conversion between 1990 and 2020. Spatial and temporal changes in land use and land cover data were analyzed to derive the desired results. The results indicate an average annual biomass loss of 0.97 million tons (above ground + below ground + deadwood) during the period of 1990-2020. Additionally, there were average annual carbon emissions of 0.46 million tons (above ground + below ground + deadwood), equivalent to a potential carbon sell revenue of US$1.84 million per year. The conservation profit from the area has the potential to counterbalance the detrimental activities of adjacent PA dwellers, provided carbon sell strategies are adopted. Looking ahead, it is necessary to incorporate adjacent PA areas into core PAs to safeguard wildlife adaptation to climate change. However, the government must incur the associated costs to protect these adaptation scenarios within core PAs. Understanding the biomass loss and carbon emissions resulting from habitat conversion in the RRE is crucial for developing effective conservation strategies and promoting sustainable management of PAs in Tanzania.

Keywords; Habitat conversion, Climate change mitigation and adaptation, Biomass, Carbon

1. Introduction

1.1 Background information

Biodiversity and ecosystem services are under threat from habitat loss and fragmentation, pollution, overexploitation, climate change, and invasive alien species (World Bank, 2010; Strange *et al.*, 2011). The impacts of climate change, such as increased atmospheric carbon dioxide, rising temperatures, and changes in precipitation patterns, have observed effects on natural ecosystems and species (World Bank, 2010; Araujo *et al.*, 2011; Fordham *et al.*, 2013). Sub-Saharan Africa's ecosystems are particularly vulnerable, leading to extinctions, altered species behavior, and shifts in distribution patterns and migrations.

Climate change exacerbates the ongoing global biodiversity loss and ecosystem degradation resulting from unsustainable practices and environmental stresses. This degradation creates opportunities for invasive alien species, further disrupting ecosystems. Climate change can be caused naturally, but human activities, including the burning of fossil fuels, deforestation, and land development, have contributed to increased carbon emissions (World Bank, 2010).

To address the impacts of climate change, there is a need for new conservation areas to bridge connectivity gaps between protected areas (PAs) and facilitate species migration within their climatic niches (Williams et al., 2005; Heller and Zavaleta, 2009). PAs provide habitats for the conservation of indigenous species, resistant to pests, diseases, environmental stress, and nutrient loss. PAs also serve as carbon sinks and contribute to environmental conservation. Effective PA conservation requires assessing hotspots, monitoring species trends, maintaining natural disturbance regimes, and limiting harmful human activities (Stohlgren *et al.*, 1999).

However, the biological effectiveness of PAs has been questioned, with some scientists advocating for strategies focusing on PA aggregation and representativeness to enhance resilience to climate change (Hodgson *et al.*, 2009). Prioritizing new conservation areas and reevaluating abandoned PAs are topics of debate, but there is limited quantitative data on the effectiveness of different PA design strategies in maintaining biodiversity over time (Pressey *et al.*, 2007; Carroll *et al.*, 2010). Studies using dynamic landscape and metapopulation models have compared the benefits of individual PAs with larger terrestrial ecosystems and assessed the effectiveness of dynamic versus static PAs in sustaining populations of focal species (Falcy and Estades, 2007; Rayfield *et al.*, 2008). However, a primary limitation has been the lack of suitable ecological modeling frameworks for quantitatively evaluating alternative habitat configuration strategies.

1.2 Problem statement

The climate is undergoing significant changes, primarily driven by increased carbon emissions into the atmosphere from human activities such as burning fossil fuels, deforestation, and land development. While natural factors have historically influenced climate change, current human activities are the primary contributors of greenhouse gas emissions, particularly carbon dioxide. These emissions result from the burning of fossil fuels and the conversion of land for agriculture, urbanization, and infrastructure development. As a response to climate change, society has recommended two sets of actions namely mitigation and adaptation. Mitigation involves reducing emissions by using alternative energy sources and adopting energy-efficient practices. Adaptation, on the other hand, focuses on adjusting and responding to the environmental changes caused by climate change (Milad *et al.*, 2011).

In the context of wildlife conservation, adaptation is crucial to enable species to respond effectively to climate change and maintain viable populations. As climate change exacerbates existing threats to landscapes and biodiversity, there is an urgent need to develop a new strategic framework for conservation. This framework should include the establishment of new protected areas that account for species' range shifts and address large-scale changes occurring across ecosystems (Li *et al.*, 2007).

Within the Ruaha-Rungwa ecosystem (RRE), it is necessary to include all formulated protected areas (PAs) within a single managed PAs network to effectively address the impacts of climate change. However, adjacent PAs and dwellers within unprotected areas often engage in unsustainable utilization of available ecological resources for their livelihoods, leading to habitat conversion. This situation calls for an urgent estimation of the amount of biomass loss and carbon emissions resulting from habitat conversion within the RRE. Such estimates are essential to plan for sustainable management strategies for the RRE.

1.3 Objectives

1.3.1 Main objective

The main objective of this study was to estimate the amount of biomass and carbon released to the atmosphere as a result of habitat conversion of Ruaha – Rungwa Ecosystem (RRE) for the period 1990 - 2020

1.3.2 Specific objectives

Specifically, the study intends to:

(i) estimate amount of biomass loss of RRE for the period 1990 - 2020

(ii) estimate amount of carbon released to the atmosphere as a result of habitat conversion of RRE for the period 1990 - 2020

(iii) estimate amount of conservation profit disposed as a result of habitat conversion of RRE for the period 1990 - 2020

2. Materials and Methods

2.1 Materials

2.1.1 Description of the study area

The study conducted in Ruaha-Rungwa Ecosystem (RRE) in Tanzania as shown in Figure 1. The study area situated in Central Tanzania (i.e., the Rungwa, Kizigo, and Muhesi (RKM) Game Reserves (GRs)) and Ruaha National Park (RNP) in Southcentral Tanzania. RNP together with the surrounding game reserves (RKM GRs) form the single continuous RRE that covers an area of roughly 45,000 square kilometres. RNP was established in 1964 and is currently the largest national park in Tanzania and East Africa. Its name is derived from the Great Ruaha River flowing along its south eastern margins. The RKM GRs are mostly located in Manyoni of the Singida Region (98%) in Central Tanzania, and 2% of this area is situated within the Chunya District of the Mbeya Region (MNRT, 2011). These three reserves are managed as one entity with headquarters based in the village of Rungwa in the Manyoni District. The reserves also border the Sikonge District (Tabora region), Iringa Rural District (Iringa region) and Chamwino District (Dodoma region) (MNRT, 2011). The three reserves cover an area of 17,340 km² (the Rungwa Game Reserve (RGR) covers 8,818 km², the Kizigo Game Reserve (KGR) covers 5,379 km² and the Muhesi Game Reserve (MGR) covers 3,143 km²) (MNRT, 2011). Three community-owned Wildlife Management Areas (WMAs), including MBOMIPA WMA, were created to provide a venue for and empower local communities to administer the management and utilization of natural resources on village lands near RRE (Nelson, 2007). However, the degradation of natural resources continues.

The area suffers from persistent consumptive use because it does not enjoy stricter conservation measures (Wilfred, 2018). As in many other rural areas in

Tanzania, the livelihoods of the local people around RRE rely fundamentally on a mixture of activities, such as keeping livestock, crop farming, fishing, hunting, beekeeping, and the harvesting of forest products (Wilfred, 2018). Rain-fed agriculture plays a central role in people's livelihoods. Popular crops grown in the area include maize, cassava, sweet potatoes and rice (Kikoti, 2009). Trophy hunting is the principal legal form of wildlife use in RRE protected areas especially in GRs and WMAs. To help win local support for conservation efforts, the government allows local communities, by permit, to carry out fishing and beekeeping activities across the entire ecosystem. Other permitted resource uses in the ecosystem are controlled extraction of fuelwood and building poles (Wilfred, 2018).

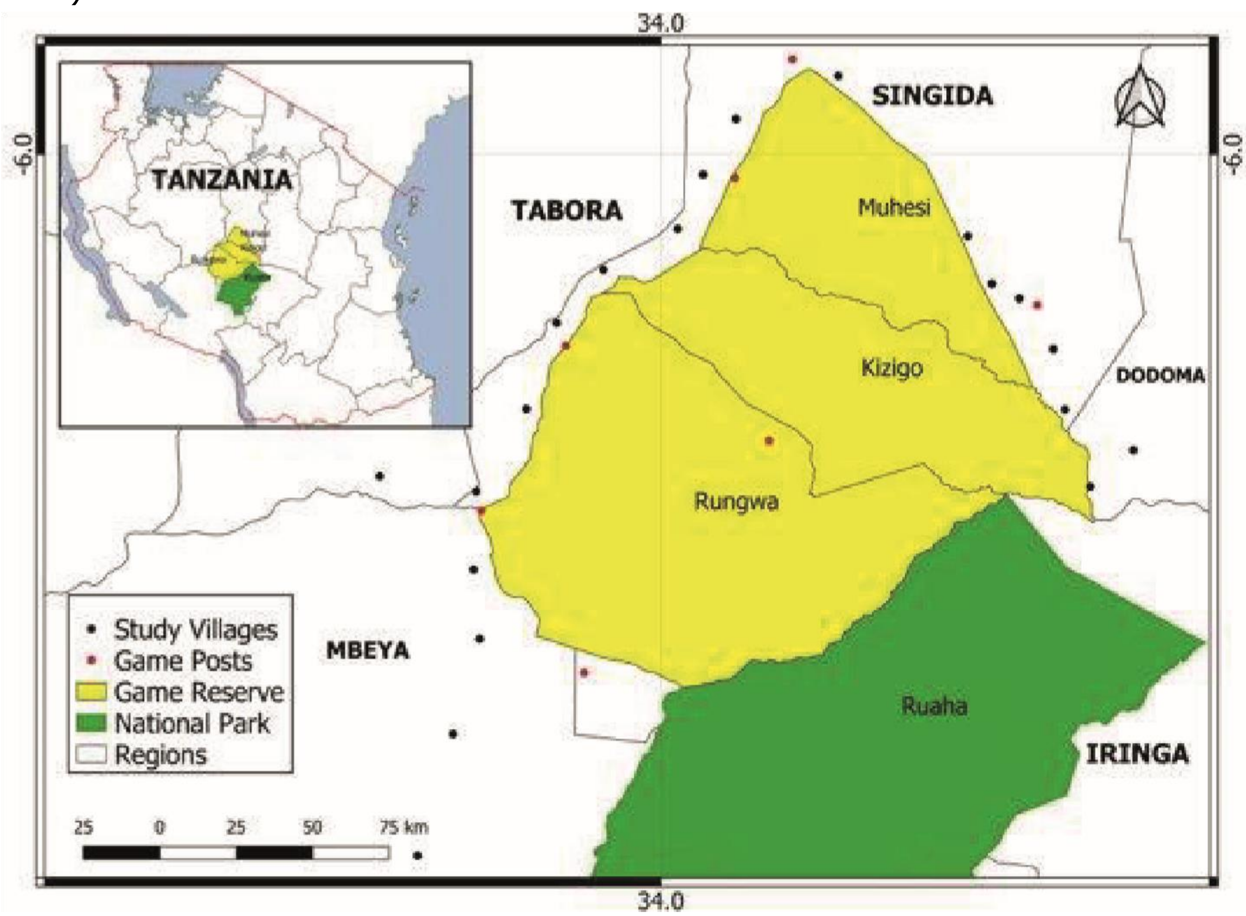

Figure 1: The Map of the study area

2.2 Methods

Datasets acquired from USGS on spatial and temporal changes in land use and land cover (LULC) of RRE for the period 1990 - 2020 was employed as indicated in Tables 1 - 3.

Table 1: Land use/cover area (ha) (%) distribution between 1990 and 2020

LULC	Forest	Bushland	Grassland	Water	Wetland	Bare soil	Total
1990	1,614,951 (35.8)	1,652,537 (36.6)	1,176,803 (26.1)	21,100 (0.5)	25,186 (0.6)	20,330 (0.5)	4,510,907 (100)
2000	1,455,963 (32.3)	1,432,159 (31.7)	1,562,176 (34.6)	10,997 (0.2)	24,299 (0.5)	25,302 (0.6)	4,510,896 (100)
2010	1,725,056 (38.2)	1,013,286 (22.5)	1,642,053 (36.4)	20,067 (0.4)	74,035 (1.6)	36,418 (0.8)	4,510,915 (100)
2020	1,261,954 (28.0)	1,524,995 (33.8)	1,671,839 (37.1)	15,084 (0.2)	9,629 (0.2)	27,414 (0.6)	4,510,915 (100)

Table 2: Land use/cover change (ha) for the period 1990 - 2020

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil
LULC (ha)	352, 997	127, 542	-495, 036	6, 016	15, 557	-7, 084

Table 3: Land use/cover classification scheme

Land cover class	Description
Forest	Area of land covered low density trees forming open habitat with plenty of sunlight and limited shade
Bushland	Area dominated with bushes and shrubs
Grassland	Land area dominated by grasses
Water	Area within body of land, of variable size, filled with water, localized in a basin, which rivers flow into or out of them (Lake/Dam)
Wetland	Area of land covered with water and plants where human activities like agriculture, livestock keeping, fishing and others take place
Bare soil	Area of land with no plants or any man made infrastructure

2.2.1 Data analysis

To estimate amount of biomass loss of RRE for the period 1990 - 2020

2.2.1.1 Biomass Stocks

2.2.1.1.1 Living Biomass Stocks

Tanzania forest Carbon can be estimated in three pools namely AGB (above ground biomass), BGB (below ground biomass) and DW (dead wood) (URT, 2015). BGB was estimated as a fraction of AGB. AGB and BGB were estimated as follows:

(i) AGB (tonnes/ha) = Tree stem volume (m^3/ha) * wood density/1000; and

(ii) BGB (tonnes/ha) = AGB * 0.25 (as default), or root to shoot ratios.

URT (2015) uses conversion factors into programmed NAFORMA analysis system by tree species or species groups to provide standards in each terrestrial ecosystem of Tanzania as shown in Table 4.

Table 4: Living tree stemwood biomass by primary vegetation type

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil
AGB(t/ha)	59.5	11	2.9	4.6	4.6	2.9
BGB (t/ha)	18.2	4.4	1.1	1.7	1.7	1.1

2.2.1.1.2 Deadwood Biomass Stocks

Dead wood (DW) biomass is estimated from the volume computed using Smalian formula multiplied by wood density of 619 kg/m^3 (Chidumayo, 2012 cited by URT, 2015). URT (2015) through NAFORMA reveals the dead wood Biomass of Tanzania (Table 5) is relatively low since most dead wood in accessible areas is collected as fuelwood. As woodlands are generally more accessible than forests, collection of deadwood for fuelwood from these areas is easier. The relatively high volume of dead wood in water is assumed to be because dead trees lying in areas with water / wetlands are difficult to access and decay slowly and because they are wet and therefore unattractive for fuelwood.

Table 5: Dead wood biomass by primary vegetation type

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil
DWB(t/ha)	4.87	0.73	0.35	1.31	1.31	0.22

To estimate amount of carbon released to the atmosphere as a result of habitat conversion of RRE for the period 1990 - 2020

2.2.1.2 Carbon Stocks

According to URT (2015), carbon in terrestrial ecosystems of Tanzania can be computed as follows:

Carbon (tonnes/ha) = Biomass * 0.47

Living tree stemwood and dead wood carbon (t/ha) by primary vegetation type are illustrated in Table 6 & 7.

Table 6: Living tree stemwood Carbon (Aboveground + Belowground) by primary vegetation type

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil

Carbo(t/ha)	36.5	7.2	1.8	3	3	1.9

Table 7: Dead wood Carbon by primary vegetation type

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil
DWB(t/ha)	2.39	0.36	0.17	0.64	0.64	0.11

To estimate amount of conservation profit disposed as a result of habitat conversion of RRE for the period 1990 - 2020

The study adopted from Jenkins (2014), and Lobora *et al.* (2017) emphasized that, the standard carbon market is US$ 4 per ton; this was used to estimate amount of money lost for the period 1990 – 2020 as a result of habitat conversion of RRE.

3. Results and Discussion

3.1 Amount of biomass loss of RRE for the period 1990 - 2020

The results in Tables 8 & 9 revealed that, about 99.87% of forests degraded compared to other vegetation type. This implies that, average amount of 0.97 million tons of biomass (above ground + below ground + deadwood) loss annually for the period 1990 - 2020. This degradation rate impacts negatively to ecosystem services offered to wildlife residing or using the area for migration or adapting to climatic change. The degraded area converted to bushland, grassland or bare soil due to increase of human population, livestock, and dependence of adjacent PAs dwellers on existing natural resources in the ecosystem for their livelihoods. These results necessitated the inclusion of the adjacent PAs and unPAs areas into core PAs or formulating sustainable management strategy which will assure the survival of wildlife without compromising livelihoods of dwellers.

Table 8: Living tree stemwood biomass loss (in millions tons) by primary vegetation type of RRE for the period 1990 - 2020

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil	Total
AGB (t)	21	1.4	-1.44	0.03	0.07	-0.2	**21.05**
BGB (t)	6.43	0.56	-0.55	0.01	0.03	-0.08	**6.47**
Total	27.43	1.96	-1.99	0.04	0.10	-0.28	**27.52**
Percentage	99.67	7.14	-7.20	0.14	0.36	-0.10	**100**

Table 9: Amount of dead wood biomass loss (in millions tons) of RRE for the period 1990 - 2020

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil	Total
DWB(t)	1.72	0.09	-0.17	0.07	0.02	-0.02	**1.67**

Percentage	103.21	5.59	-10.40	0.47	1.22	-0.09	**100**

3.2 Amount of Carbon released to the atmosphere as a result of habitat conversion of RRE for the period 1990 - 2020

The results in Tables 10 &11 revealed that, about 81.67% of forests released more Carbon to the atmosphere compared to other vegetation type; followed by bushland (52.91%). This implies that, average amount of 0.071 million tons and 0.046 million tons of Carbon (above ground + below ground + deadwood) from forest and bushland respectively loss annually for the period 1990 - 2020. This is something that we can never stay quiet; and the need to act urgently is unquestionable. Reversing releasing of Carbon to the atmosphere is a mitigation measure, but reacting now is adapting with mitigation measures which their results will be appreciated over thousands years to come. Thus, the need for sustainable utilization and management of natural resources in the area is vital. Conversely, the average total annual loss of 0.087 million tons of Carbon (above ground + below ground + deadwood) from 1987 to 2017 experienced in RRE. Since, climate change is a result of increasing greenhouse gases in the atmosphere, there are must be strategies to reverse the situation. If, we decide to include adjacent PAs and unPAs areas into core PAs network, we must incur cost that the dwellers have to accept as a compensation for releasing the area for protection. In order to officiate the process, communities should be willingly accepting the compensated cost that will be given to them or area similar to the previous one if and only if they actively participated and ensures that the benefits of protecting the area should be large compared to the cost. For Tanzania scenario, we must agree that those areas abandoned by wildlife which previously used as PAs should be recategorise by considering all species used to live in those areas have proper management plan which considered their climatic niche.

Table 10: Amount of living tree stemwood Carbon (Aboveground + Belowground) released to the atmosphere as a result of habitat conversion of RRE for the period 1990 - 2020

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil	Total
Carbo(million t)	1.29	0.92	-0.89	0.02	0.05	-0.014	**1.376**
Percentage	93.75	66.86	-64.68	1.45	3.63	-1.02	**100**

Table 11: Amount of dead wood Carbon loss of RRE for the period 1990 - 2020

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil	Total
Carbon (million t)	0.84	0.46	-0.08	0.004	0.009	-0.0008	**1.2322**

Percentage	68.17	37.33	-6.49	0.32	0.73	-0.06	**100**

3.3 Amount of conservation profit disposed as a result of habitat conversion of RRE for the period 1990 - 2020

Results in Table 12 revealed that, RRE loss an average amount of US$ 0.35 million of carbon sell annually for the period 1990 – 2020 due to degradation of the area. Forests and bushland pioneered degradation on which they loss an annual average of US$ 0.46 million per annum for the period 1990 - 2020. It seems that forests have potential hard wood species which are regarded as commercial rewarding but environmental destructive by adjacent PAs dwellers. Also, the Government earmarked those commercial rewarding tree species with their prices; but administering their utilization and their market chain are questionable. Thus, we need community centered decision making which is integrated but different from PFM (Participatory Forest Management), JFM (Joint Forest Management) and WMA (Wildlife Management Areas) because they really not fully integrate targeted population and they cannot benefit individual entity in the community. Also, all these scenarios do not consider that those individuals in the community are changing in time, thus, scientific revised community members monitoring strategy and recording system is unavoidable; and emphasis of integrative participatory approach as advocated by Pimbert and Prety (1995).

Table 12: Amount of conservation profit disposed as a result of habitat conversion of RRE for the period 1990 - 2020

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil	Total
Profit loss (Million US$)	8.52	5.52	-3.88	0.096	0.236	-0.0592	10.4328
Percentage	81.67	52.91	-37.19	0.92	2.26	-0.57	100

4. Conclusion and Recommendations

4.1 Conclusion

This study estimated amount of biomass loss and carbon released to the atmosphere as a result of habitat conversion of RRE for the period 1990 - 2020**.** The findings have revealed that, the study area has undergone notable biomass loss due to socio-economic activities performed by corridor dwellers. Also amount of carbon released to the atmosphere can contribute much to climate change and climate variability. The amount of conservation profit of the area seems to offset amount of benefit received by adjacent PAs dwellers from their destructive activities if adopted carbon sell strategies. The foreseeable future necessitates inclusion of adjacent PAs and unPAs areas into core PAs; however, there is a cost which the government must incur in order to safeguard the adaptation scenarios of wildlife suffered from climate change and variability in core PAs.

4.2 Recommendations

The study provides the following recommendations for sustainable management and conservation of RRE:

- ✓ The government and adjacent PAs dwellers should include their area in carbon sell scheme and use western paying principle scenario (i.e all vegetation species should have equal values despite of their location);
- ✓ For short and medium term strategies; the government and adjacent PAs dwellers should enhance the existing wildlife management areas (WMAs), participatory forests managements (PFMs) and joint forests managements (JFMs) so nearly 90% of their areas to be under PAs management of different categories;
- ✓ The government should formulate user friendly guidelines for protection of wildlife corridors/buffer/dispersal areas as stipulated in Tanzania Wildlife Conservation Act No. 5 of 2009;
- ✓ The government in collaboration with other stakeholders should initiate cost effective and environmental friendly source of energy different from fuelwood

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