Drivers and their influences on variation of aboveground carbon removals in miombo woodlands of mainland Tanzania

CURRENT STATUS: UNDER REVIEW

Carbon Balance and Management BMC

Bernardol John Manyanda
Sokoine University of Agriculture

bernardoljohnm@gmail.com*Corresponding Author*
ORCiD: https://orcid.org/0000-0001-8796-2752

Emmanuel Fred Nzunda
Sokoine University of Agriculture Faculty of Forestry and Nature Conservation

Wilson Ancelm Mugasha
Sokoine University of Agriculture Faculty of Forestry and Nature Conservation

Rogers Ernest Malimbwi
Sokoine University of Agriculture Faculty of Forestry and Nature Conservation

10.21203/rs.3.rs-18917/v1

SUBJECT AREAS

Environmental Policy

KEYWORDS

Drivers, aboveground carbon, emissions, miombo, removals

Abstract
Background
Removals caused by both natural and anthropogenic drivers such as logging and fire causes substantial carbon emissions. Better insights into drivers and their variations of aboveground carbon removals is therefore needed. We assessed the drivers of aboveground carbon (AGC) removals and quantified the dynamics of removals-induced carbon emissions due to drivers using the National Forest Resources Assessment and Monitoring (NAFORMA) data sets in R software. Miombo woodlands which is the largest forest formations covering about 93% of forest land in mainland Tanzania was the case study.
Results
Drivers of AGC removals in miombo woodlands of mainland Tanzania in order of importance were; timber, fire, shifting cultivation, charcoal, natural death, firewood collection, poles, grazing by wildlife animals, carvings, grazing by domestic animals, and mining. The average AGC removals by drivers range from 0.0–1.273tCha^{-1}year^{-1}.
Conclusions
Increased mitigation efforts in addressing removals by timber, fires, shifting cultivation, charcoal and natural death would be effective in addressing forest degradation in the REDD + process in Tanzania. Since NAFORMA provides national picture on drivers and their variation on AGC removals, site-specific studies need to be conducted to bring information that would be used for local forest management. This kind of study need to be conducted in other vegetation types like Montane and Mangrove forest in Tanzania.
Background
Managing the carbon stocks of the land use sector is currently a key focus for climate change mitigation in developing countries [1, 2, 3]. In terrestrial ecosystems, forests and woodlands play a major role for the mitigation and adaptation to climate change via carbon storage [4, 2]. After oceans, forests are the world’s largest storehouses of carbon and they provide ecosystem services that are important to human wellbeing [5]. Tropical forests alone store a quarter of a trillion tons of carbon in above and below ground biomass [6]. Notwithstanding their contribution to the climate change

mitigation, Tanzania’s forests face enormous challenges including deforestation and forest degradation [7].

Deforestation and forest degradation are amongst the major anthropogenic sources of greenhouse gas emissions (GHG), contributing about 17 per cent globally [8]. Of the total emissions, degradation is responsible for at least one-fifth in the Brazilian Amazon [9], two-thirds in Indonesian forests [10], and almost half in African tropical forests [11]. Forest degradation also leads to forest fragmentation and can contribute to deforestation [12]. While deforestation refers to a permanent or long-term conversion of forest to non-forest land [13, 14], forest degradation is the changes within the forest that negatively affect the structure or function of the stand and/or site, and thereby lower the capacity to supply products and/or services [15, 16].

The changes within the forests involves removals of trees and hence contributing to carbon emissions. The drivers of carbon removals are multifaceted and cannot be reduced to a few variables; rather they operate at different levels and scales in the human-environment linkage [17]. These drivers are divided into two broad categories: proximate and underlying causes. Proximate causes are typically human activities operating at the local level. They include shifting cultivation and cattle ranching, wood extraction through logging or charcoal production, and infrastructural development such as transportation, markets and settlements. On the other hand, underlying causes do not directly cause removals but influence the proximate causes. This category includes a complexity of economic issues, policies and institutions, technological factors, socio-cultural, and demographic factors [11, 17, 18].

Aboveground biomass (AGB) is not static, but rather spatially and temporally highly variable, particularly in the tropics with the same factor likely having different results [19, 20, 21]. This makes its quantification challenging. It is generally assumed that about half of AGB consists of carbon in different vegetation types including miombo woodlands in Tanzania. Miombo woodlands are the largest vegetation types in Tanzania covering about 93% of the forest area of 48.1 million ha [22]. As in other tropical forest landscape, complex matrices of low to high AGC removal densities can be expected in entire miombo woodlands in Tanzania and its management categories due to varying drivers. Additionally, which drivers contribute more to the variations of AGC removals in the entire miombo woodlands and its management categories is to a large extent unknown. This has been due to lack of appropriate assessment mechanism. Nevertheless, the Mainland Tanzania National Forest Inventory (NFI) data source which is commonly referred as NAFORMA, have recently become available based on country REDD + readiness activities that allow assessment of AGC removals and their amount of AGC emissions in miombo woodlands [3]. The objective of the present study was to identify the drivers of AGC removals and assess which of the identified drivers contribute more to the variation of AGC in miombo woodlands of Tanzania mainland. Specifically the study sought to: (1) identify drivers of AGC removals (2) quantify the amount of AGC removals by each driver and, (3) Ranking the identified drivers in order of their contribution to the variations of AGC.

Understanding the drivers of AGC removals and their amount of AGC removed is fundamental for better design of REDD + strategy. In some cases, REDD + incentives would be channeled directly to affect drivers. Moreover, a better understanding of drivers of AGC removals are required as part of developing mitigation interventions at sub-national levels to ensure improved land-use change. This kind of understanding is also crucial for subsequent development of management plans in order to tackle each driver in response to the amount of AGC emissions caused.

Results

Drivers and their corresponding number of stems and aboveground carbon removals

We identified eleven drivers for tree cutting and these were, forest fires, firewood collection, grazing by both wildlife, domesticated animals, carving, poles, shifting cultivation, timber, and mining activities (Table 1).

Drivers and their variations on the number of stems and AGC removals

Table 1 also shows the contribution of the drivers in terms of the number of stems and AGC removals per hectare per year for miombo woodlands in Tanzania. Higher number of stems/ha/year were removed by shifting cultivation, followed by charcoal, natural death, firewood collection and poles. In terms of biomass however, we observed higher AGC removals by timber followed by fire, shifting cultivation, charcoal and natural death (Table 1).

The contribution of the drivers with regards to number of stems and carbon removals were further expressed on the basis of different management categories and subcategories of miombo woodlands. Considering Tanzania Forest Services Agency (TFS) administrative zones, large number of stems were removed by charcoal followed by firewood collection and shifting cultivation whereas grazing was the least in the central zones (Table 2). Onn the other hand, charcoal removed more AGC followed by firewood collection, natural death and shifting cultivation while grazing had the least removals. In the other zones, the drivers seem to change leading positions between charcoal production, timber and fire (Table 2).

Considering vegetation types, natural death, timber production and shifting cultivation appear to be leading causes of removals interchangeably in the closed woodlands, open woodlands and Woodlands with scattered cropland for both number of stems and AGB (Table 3). Grazing, mining and carvings are among the least contributors to removals in the three vegetation types. Regarding ownership types, higher number of stem removals were observed due to natural death followed by fire, poles and timber in the central government land (Table 4). While the least number of stems removals per hectare per year was observed due to carving followed by grazing domestic and charcoal. The highest AGC was removed as timber followed by natural death, fire and charcoal. Carvings, grazing domestic and shifting cultivation accounted for the least AGC removals in this ownership types (Table 4). The contribution of the drivers of removal in terms of number of stems and AGC removals appear to be changing leading positions in other ownership types i.e. general land, local government land, private land and village land (Table 4).

Table 5 indicates drivers and the variations of number of stem and carbon removals in the different land use types. Regarding protection forestland, the highest number of stems removed were due to natural death followed by poles, firewood collection and timber (Table 5). In terms of AGC, the highest AGC were removed as timber followed by charcoal, natural death, poles and fire. Grazing by domestic animals, carvings and grazing by wild animals accounted for the least AGC removals in protection forest. In other land use types such as production forest, grazing land, shifting cultivation, water bodies or swamps and wildlife reserves, drivers of removals appear to be changing leading positions in terms of the number of stems and AGC.

Table 1
Drivers and their corresponding number of stems and AGC removals in mainland Tanzania

Drivers	Stemsha^{-1}yr^{-1}	Stem %	AGBtha^{-1}yr^{-1}	AGCtCha^{-1}yr^{-1}	Agb%
Timber	0.780	7.000	0.244	0.119	20.173
Fire	0.845	7.581	0.196	0.096	16.235
Shifting cultivation	2.741	24.595	0.191	0.093	15.788
Charcoal	1.747	15.672	0.182	0.089	15.085
Natural death	1.233	11.061	0.160	0.079	13.268
Firewood collection	1.376	12.343	0.089	0.043	7.331
Poles	1.588	14.250	0.078	0.038	6.494
Unknown	0.472	4.233	0.047	0.023	3.871
Grazing wild	0.256	2.294	0.014	0.007	1.192
Carvings	0.050	0.450	0.004	0.002	0.350
Grazing domestic	0.053	0.471	0.002	0.001	0.203
Mining	0.006	0.051	0.000	0.000	0.010

Table 2
Drivers and their corresponding number of stems and AGC removals in zones of mainland Tanzania

Zone names	Drivers	Stems/ha/yr	Stem%	Agbt/ha/yr	AgctC/ha/yr	AgctC%
Central	Charcoal	3.687	28.472	0.187	0.092	49.202
	Firewood collection	3.653	28.213	0.055	0.027	14.429
	Timber	1.334	10.303	0.046	0.023	12.215
	Shifting cultivation	1.808	13.961	0.042	0.020	10.969
	Natural death	0.693	5.351	0.027	0.013	7.131
	Fire	0.870	6.722	0.018	0.009	4.662
	Poles	0.820	6.332	0.003	0.001	0.787
	Grazing domestic	0.019	0.148	0.001	0.001	0.380
	Grazing wild	0.065	0.498	0.001	0.000	0.225
	Total	12.949	100	0.380	0.186	100
Eastern	Timber	5.812	12.466	0.746	0.366	30.732
	Charcoal	11.014	23.625	0.655	0.321	26.979
	Natural death	7.904	16.954	0.405	0.198	16.670
	Shifting cultivation	5.151	11.050	0.189	0.092	7.772
	Firewood collection	8.157	17.497	0.178	0.087	7.337
	Poles	5.137	11.019	0.097	0.048	4.004
	Fire	1.022	2.193	0.079	0.039	3.258
	Grazing wild	2.201	4.722	0.069	0.034	2.844
	Carvings	0.199	0.426	0.010	0.005	0.396
	Grazing domestic	0.023	0.048	0.000	0.000	0.008
	Total	46.62	100	2.428	1.19	100
Lake	Fire	0.515	6.604	0.089	0.044	33.115
	Poles	2.303	29.520	0.049	0.024	18.096
	Firewood collection	2.555	32.755	0.042	0.021	15.674
	Timber	0.379	4.862	0.035	0.017	13.031
	Charcoal	0.663	8.495	0.023	0.011	8.555
	Natural death	0.782	10.023	0.023	0.011	8.720
	Shifting cultivation	0.417	5.347	0.005	0.003	1.901
	Grazing wild	0.187	2.394	0.002	0.001	0.909
	Total	7.801	100	0.268	0.132	100
Northern	Charcoal	8.040	21.454	0.331	0.162	22.579
	Shifting cultivation	13.459	35.915	0.324	0.159	22.145
	Timber	1.257	3.355	0.301	0.147	20.525
	Poles	6.117	16.325	0.209	0.102	14.248
	Natural death	4.459	11.898	0.166	0.081	11.301
	Firewood collection	2.881	7.688	0.103	0.05	7.006
	Fire	1.092	2.915	0.030	0.015	2.072
	Grazing wild	0.168	0.449	0.002	0.001	0.124
	Total	37.473	100	1.466	0.717	100

Table 2
cont….

Southern highlands	Natural death	2.397	25.501	0.332	0.163	59.949
	Poles	3.026	32.2	0.08	0.039	14.403
	Timber	0.649	6.908	0.075	0.037	13.576
	Firewood collection	2.294	24.407	0.052	0.026	9.44
	Shifting cultivation	0.621	6.61	0.008	0.004	1.401
	Grazing domestic	0.091	0.964	0.004	0.002	0.731
	Charcoal	0.258	2.741	0.002	0.001	0.421
	Grazing wild	0.063	0.67	0	0	0.079
	Total	9.399	100	0.553	0.272	100
Southern	Fire	4.143	14.368	0.586	0.287	36.115
	Timber	2.149	7.455	0.304	0.149	18.729
	Shifting cultivation	7.009	24.309	0.293	0.144	18.049
	Natural death	7.122	24.7	0.183	0.09	11.257
	Poles	4.477	15.528	0.112	0.055	6.923
	Charcoal	0.885	3.07	0.064	0.031	3.916
	Firewood collection	1.54	5.342	0.048	0.024	2.961
	Grazing wild	0.884	3.067	0.019	0.01	1.199
	Carvings	0.311	1.078	0.011	0.006	0.702
	Grazing domestic	0.233	0.809	0.002	0.001	0.121
	Mining	0.079	0.273	0	0	0.028
	Total	28.832	100	1.622	0.797	100
Western	Timber	1.782	11.582	0.163	0.08	27.946
	Shifting cultivation	5.317	34.564	0.127	0.062	21.766
	Natural death	1.592	10.348	0.073	0.036	12.584
	Firewood collection	1.866	12.128	0.065	0.032	11.195
	Charcoal	1.364	8.866	0.059	0.029	10.053
	Fire	0.922	5.993	0.059	0.029	10.169
	Poles	2.419	15.726	0.031	0.015	5.366
	Grazing domestic	0.025	0.163	0.005	0.002	0.794
	Grazing wild	0.097	0.632	0.001	0	0.128
	Total	15.384	100	0.583	0.285	100

Table 3
Drivers and their corresponding number of stems and AGC removals in miombo woodlands vegetation subtypes of mainland Tanzania

Vegetation types	Drivers	Stems/ha/yr	Stems %	Agbt/ha/yr	AgctC/ha/yr	Agct/ha/yr%
Closed woodlands (crown cover > 40%)	Natural death	2.070	28.528	0.251	0.123	26.309
	Timber	0.847	11.680	0.250	0.122	26.236
	Shifting cultivation	0.782	10.782	0.183	0.090	19.174
	Unknown	0.384	5.297	0.069	0.034	7.243
	Fire	0.642	8.843	0.063	0.031	6.657
	Poles	1.041	14.350	0.044	0.022	4.662
	Firewood collection	0.675	9.297	0.040	0.020	4.219
	Charcoal	0.414	5.707	0.040	0.020	4.192
	Grazing wild	0.338	4.658	0.010	0.005	1.091
	Carvings	0.027	0.366	0.001	0.001	0.122
	Grazing domestic	0.036	0.492	0.001	0.000	0.094
	Total	7.255	100	0.953	0.467	100
Open woodlands (Crown cover between 10–40%)	Timber	11.005	51.300	0.262	0.128	20.443
	Fire	0.903	4.210	0.246	0.121	19.225
	Charcoal	1.454	6.779	0.193	0.095	15.070
	Natural death	1.686	7.860	0.167	0.082	13.061
	Shifting cultivation	2.448	11.409	0.158	0.078	12.360
	Firewood collection	1.550	7.226	0.101	0.049	7.882
	Poles	1.538	7.168	0.086	0.042	6.702
	Unknown	0.499	2.328	0.042	0.021	3.297
	Grazing wild	0.245	1.142	0.017	0.008	1.288
	Carvings	0.055	0.258	0.005	0.003	0.419
	Grazing domestic	0.061	0.284	0.003	0.002	0.241
	Mining	0.008	0.037	0.000	0.000	0.013
	Total	21.453	100	1.282	0.628	100
Woodlands with scattered cropland	Shifting cultivation	16.587	58.998	0.735	0.360	47.938
	Charcoal	1.751	6.228	0.241	0.118	15.713
	Timber	0.382	1.360	0.180	0.088	11.715
	Firewood collection	2.032	7.228	0.127	0.062	8.259
	Poles	4.994	17.764	0.121	0.059	7.914
	Natural death	0.858	3.051	0.073	0.036	4.759
	Fire	0.912	3.244	0.039	0.019	2.541
	Unknown	0.452	1.606	0.011	0.005	0.700
	Pole	0.063	0.225	0.006	0.003	0.383
	Carvings	0.083	0.297	0.001	0.001	0.080
	Total	28.114	100	1.533	0.751	100

Table 4
Drivers and their corresponding number of stems and AGC removals in ownership types of miombo woodlands in Mainland Tanzania

Ownership types	Drivers	Stems/ha/yr	Stems %	Agbt/ha/yr	AgctC/ha/yr	AgctC %
Central Government	Timber	0.507	10.511	0.114	0.056	26.306
	Natural death	1.503	31.143	0.103	0.050	23.651
	Fire	0.695	14.409	0.079	0.039	18.124
	Charcoal	0.284	5.888	0.037	0.018	8.604
	Grazing wild	0.561	11.617	0.037	0.018	8.467
	Firewood collection	0.331	6.851	0.026	0.013	6.040
	Poles	0.551	11.406	0.020	0.010	4.652
	Shifting cultivation	0.372	7.704	0.016	0.008	3.792
	Carvings	0.011	0.218	0.001	0.000	0.232
	Grazing domestic	0.012	0.254	0.001	0.000	0.132
	Total	4.827	100	0.434	0.213	100
Local Government	Natural death	1.684	23.388	0.310	0.152	33.885
	Charcoal	1.738	24.134	0.217	0.106	23.743
	Timber	0.988	13.719	0.210	0.103	23.032
	Firewood collection	2.315	32.141	0.140	0.068	15.288
	Fire	0.225	3.128	0.031	0.015	3.446
	Shifting cultivation	0.118	1.634	0.004	0.002	0.471
	Poles	0.106	1.476	0.001	0.000	0.080
	Grazing domestic	0.019	0.269	0.000	0.000	0.054
	Grazing wild	0.008	0.111	0.000	0.000	0.002
	Total	7.201	100	0.914	0.448	100
Village land	Fire	1.000	7.911	0.315	0.154	22.305
	Timber	0.841	6.654	0.278	0.136	19.694
	Natural death	2.000	15.815	0.227	0.111	16.082
	Charcoal	1.363	10.779	0.177	0.087	12.550
	Shifting cultivation	3.038	24.024	0.160	0.079	11.366
	Poles	2.337	18.479	0.122	0.060	8.678
	Firewood collection	1.755	13.882	0.115	0.056	8.156
	Grazing wild	0.170	1.347	0.008	0.004	0.564
	Carvings	0.066	0.522	0.004	0.002	0.300
	Grazing domestic	0.063	0.499	0.004	0.002	0.288
	Mining	0.011	0.087	0.000	0.000	0.017
	Total	12.645	100	1.411	0.691	100

Table 4

cont....

Private Land	Shifting cultivation	11.128	59.113	1.102	0.540	60.139
	Charcoal	2.466	13.101	0.355	0.174	19.388
	Timber	0.625	3.320	0.135	0.066	7.344
	Firewood collection	1.913	10.160	0.116	0.057	6.348
	Poles	1.991	10.577	0.059	0.029	3.216
	Natural death	0.374	1.987	0.046	0.023	2.517
	Fire	0.278	1.478	0.016	0.008	0.872
	Pole	0.033	0.175	0.003	0.001	0.167
	Grazing wild	0.016	0.088	0.000	0.000	0.009
	Total	18.825	100	1.832	0.898	100
General land	Timber	1.577	13.068	0.807	0.395	48.146
	Natural death	2.719	22.537	0.247	0.121	14.754
	Charcoal	2.163	17.925	0.226	0.111	13.470
	Fire	1.911	15.838	0.155	0.076	9.268
	Shifting cultivation	1.308	10.839	0.086	0.042	5.127
	Poles	0.854	7.080	0.085	0.042	5.059
	Carvings	0.256	2.124	0.034	0.017	2.056
	Firewood collection	0.721	5.976	0.027	0.013	1.586
	Grazing wild	0.260	2.153	0.006	0.003	0.344
	Grazing domestic	0.297	2.461	0.003	0.002	0.191
	Total	12.065	100	1.675	0.821	100
Unknown	Firewood collection	1.051	68.394	0.010	0.005	69.823
	Natural death	0.486	31.606	0.004	0.002	30.177
	Total	1.536	100	0.014	0.007	100

Table 5

Drivers and their corresponding number of stems and biomass removals in land use types of miombo woodlands in mainland Tanzania

Ownership types	Drivers	Stems/ha/yr	Stems %	Agbt/ha/yr	AgctC/ha/yr	AgctC %
Production forest	Fire	1.144	10.354	0.390	0.191	26.726
	Timber	1.086	9.831	0.380	0.186	26.061
	Charcoal	1.426	12.903	0.203	0.099	13.925
	Natural death	2.294	20.764	0.167	0.082	11.473
	Poles	1.968	17.815	0.108	0.053	7.385
	Firewood collection	1.582	14.318	0.106	0.052	7.284
	Shifting cultivation	0.668	6.046	0.048	0.024	3.313
	Unknown	0.450	4.077	0.031	0.015	2.104
	Grazing wild	0.230	2.082	0.010	0.005	0.717
	Carvings	0.097	0.874	0.010	0.005	0.653
	Grazing domestic	0.089	0.810	0.005	0.002	0.339
	Mining	0.014	0.127	0.000	0.000	0.020
	Total	11.049	100	1.458	0.714	100
Protection forest	Natural death	3.749	40.101	0.176	0.086	44.792
	Timber	0.936	10.012	0.090	0.044	22.917
	Fire	1.754	18.761	0.069	0.029	15.104
	Grazing wild	1.567	16.761	0.045	0.022	11.458
	Poles	0.457	4.888	0.010	0.005	2.604
	Firewood collection	0.671	7.177	0.008	0.004	2.083
	Charcoal	0.083	0.888	0.004	0.002	1.042
	Unknown	0.052	0.556	0.002	0.000	0.000
	Grazing domestic	0.061	0.652	0.001	0.000	0.000
	Shifting cultivation	0.019	0.203	0.000	0.000	0.000
	Total	9.349	100	0.405	0.192	100

Wildlife reserve	Natural death	1.985	38.544	0.213	0.104	40.532
	Timber	0.364	7.079	0.121	0.059	23.125
	Fire	0.903	17.534	0.079	0.039	15.010
	Grazing wild	0.932	18.091	0.060	0.029	11.398
	Unknown	0.282	5.473	0.021	0.010	4.080
	Poles	0.184	3.572	0.014	0.007	2.605
	Firewood collection	0.367	7.131	0.010	0.005	1.992
	Charcoal	0.069	1.343	0.005	0.003	0.994
	Grazing domestic	0.052	1.005	0.001	0.001	0.235
	Shifting cultivation	0.012	0.229	0.000	0.001	0.030
	Total	5.149	100	0.525	0.257	100
Shifting cultivation	Shifting cultivation	21.885	61.492	1.664	0.815	61.559
	Timber	0.985	2.768	0.310	0.152	11.486
	Charcoal	2.368	6.652	0.187	0.092	6.930
	Firewood collection	2.463	6.920	0.150	0.073	5.543
	Poles	4.520	12.700	0.134	0.066	4.973
	Unknown	1.471	4.133	0.118	0.058	4.382
	Natural death	0.952	2.675	0.094	0.046	3.462
	Fire	0.870	2.445	0.044	0.022	1.630
	Carvings	0.077	0.216	0.001	0.000	0.035
	Total	35.591	100	2.703	1.324	100
Agriculture	Shifting cultivation	12.914	49.747	0.884	0.433	46.721
	Firewood collection	4.776	18.399	0.411	0.201	21.685
	Charcoal	2.107	8.116	0.217	0.107	11.484
	Unknown	1.173	4.519	0.105	0.051	5.547
	Fire	0.807	3.107	0.093	0.046	4.932
	Timber	0.405	1.559	0.072	0.035	3.817
	Poles	2.669	10.282	0.065	0.032	3.447
	Natural death	0.962	3.706	0.036	0.018	1.906
	Pole	0.068	0.261	0.006	0.003	0.332
	Grazing domestic	0.034	0.130	0.002	0.001	0.101
	Grazing wild	0.045	0.174	0.001	0.001	0.027
	Total	25.959	100	1.893	0.928	100
Grazing land	Grazing domestic	1.830	17.790	0.606	0.297	43.763
	Charcoal	2.339	22.742	0.410	0.201	29.570
	Shifting cultivation	2.754	26.783	0.101	0.049	7.280
	Poles	1.405	13.657	0.080	0.039	5.767
	Firewood collection	1.281	12.454	0.078	0.038	5.652
	Fire	0.297	2.888	0.055	0.027	3.944
	Timber	0.153	1.492	0.037	0.018	2.669
	Unknown	0.171	1.667	0.014	0.007	0.985
	Carvings	0.017	0.162	0.003	0.001	0.201
	Natural death	0.022	0.216	0.002	0.001	0.121
	Grazing wild	0.015	0.149	0.001	0.001	0.049
	Total	10.284	100	1.385	0.679	100
Built up area	Firewood collection	7.798	100	0.319	0.156	100
	Total	7.798	100	0.319	0.156	100
Water body/swamp	Timber	12.758	66.667	2.599	1.273	95.994
	Poles	6.379	33.333	0.108	0.053	4.006
	Total	19.137	100	2.707	1.327	100
Other land	Fire	1.371	27.861	0.085	0.042	35.878
	Poles	0.415	8.435	0.045	0.022	19.128
	Firewood collection	0.605	12.289	0.041	0.020	17.176
	Natural death	1.102	22.398	0.033	0.016	13.793
	Charcoal	1.105	22.464	0.031	0.015	13.159
	Grazing wild	0.138	2.808	0.001	0.001	0.558
	Shifting	0.184	3.744	0.001	0.001	0.309

	cultivation					
	Total	4.920	100	0.238	0.116	100

Discussion

The overall objective of this paper was to identify the drivers of AGC removals and to quantify the contributions of each driver to the variation of AGC removals and hence carbon emissions in miombo woodlands in Tanzania using NAFORMA data set. In this study, drivers and their corresponding estimates of AGC and number of stems removals have been reported. The carbon stored in the aboveground biomass (AGB) pool is typically the largest among the Intergovernmental Panel for Climate Change (IPCC) carbon pools for REDD + reporting purposes. It is understood that while removals by shifting cultivation fire, firewood collection and charcoal, results immediately into carbon emissions, it is not the case with removals for timber, carvings and poles which may end up in construction and furniture whose emissions may be delayed. Nonetheless, timber in the form of furniture, carvings or construction is more in the process of contributing to emissions although delayed. Due to the uncertainty of time taken for timber to act as stored carbon all removals are assumed to eventually to contribute to emissions.

Drivers of aboveground carbon and number of stems removals

Several drivers contributed number of stems and AGC removals in mainland Tanzania. These drivers included charcoal, wildfire, firewood collection, grazing by both wildlife and domesticated animals, carving, poles, shifting cultivation, timber, and mining activities. Since drivers of AGC removals are similar to drivers for forest degradation in the woodlands meant for both protective and production purposes, comparison across studies were based on studies conducted to determine forest degradation drivers. The result found in the present study is comparable to results found in miombo woodland in Masito forest in western Tanzania and Liwale district southern Tanzania [23, 24, 25]. These studies documented only six drivers responsible for forest degradation. Sites specific and the methodologies applied on these studies explains fewer documentation of drivers. On the other hand, [26] documented ten drivers for forest degradation in Philippines that agrees with results from the present study. The methodology employed, particularly on the sampling procedures could explain the similarity.

In terms of the contribution of drivers on the number of stems and AGC removals nationally, removals by shifting cultivation, natural death, poles and charcoal production account for the highest number of stem removals. The reason could be attributed by high demand of charcoal in the country for cooking energy in which small diameter trees are involved. Tanzania’s annual consumption of charcoal is 1,658,000 tons [27]. About 85% of the total urban population depends on charcoal for household cooking and energy for small and medium enterprises [28]. Additionally, more than 40% of the tree removals can be attributed to charcoal use alone in Tanzania [29]. Higher removals by shifting cultivation is probably due to intensification of shifting cultivation in Tanzania. Shifting cultivation in Tanzania occupies 7.6% of the total country land area and 33% of area classified as woodlands in Tanzania [22]. Other scholars [30, 31] asserted that shifting cultivation contribute more to forest degradation due rising demand for agricultural products, dietary changes, agricultural trade and adjustment. Firewood collection and poles on the other hand, rank third and fourth in taking large amount of stems in the woodlands. This is probably because; firewood is the main source of energy rural areas [32]. The same author noted that, lack of alternative and affordable sources of energy dependence of communities on forests. Construction purposes both in the rural and urban areas probably account for higher removals of trees as poles. Furthermore, climate change impacts like diseases eruptions and severe drought naturally kills trees. These effects have recently increased tremendously. Mining and grazing by domesticated animals appeared as the least drivers responsible for stems removals. This is because of the smallest area subjected into mining and carvings activities. In terms of AGC removals, timber and fire accounts for the highest AGC removals. This may be explained by the large trees removals that comprises of the largest biomass. According to [33], large trees tend to account for a large proportion of the AGB in mature forests; often between 30 and 40% of the AGB can be found in trees with diameters greater than 70 cm. Elsewhere in miombo [34], found that most miombo had been heavily disturbed because of local benefits attached to them like dry-season fodder for large livestock populations, fuelwood for domestic use and rural industry and construction materials for farm structures and homes for millions. Higher AGC removals in miombo woodlands due to fire is because of its roles as the management tools. When fire is frequently and uncontrolled, it could kill trees and eventually cause carbon emissions.

Considering administrative zones, charcoal and timber account for higher AGC removals in the Eastern zone. Conversely, charcoal and firewood collection account for higher number of stem removals in this zone. This is due to the highest charcoal and timber consumption that may be linked to the closeness to Dar es Salaam city. Dar es Salaam, Tanzania's largest city, accounts for more than 50% of all charcoal consumed in the country [35]. Moreover, higher timber consumption in this zone could be attributed to high demand of timber for furniture and infrastructure development particularly houses in the Dar es Salaam city. Dar es Salaam is the primary destination of timber and timber products (including all round and sawn timber) and accounting for 87% of timber felled in southeast Tanzania [36]. Other important domestic markets of timber and wood products from the zone are Zanzibar, Mafia and Arusha [25]. Shifting cultivation and charcoal account for the largest number of stems and AGC removals in the northern zone probably due to intensification of shifting cultivation. In the lake zone, fire, firewood collection and pole account for the large stems and AGC removals probably due to heavily dependence trees for cooking energy and constructions purposes. Furthermore, presence of dry litter that foster fire occurrence explains the removals due to fire in this zone. The regular fires in the miombo region can, if too frequent or intense, cause mortality of large and small trees and prevent regeneration [37]. Likewise, long-term plot-scale experiments had shown that under annual burning miombo woodland is converted to grassland [38, 37], and that in the absence of fire, miombo starts to form closed canopy forest [37].

Regarding vegetation types, shifting cultivation, charcoal, timber poles, and firewood collection accounted for the highest AGC and number of stems removals in the woodland with scattered woodland. Shifting cultivation type of farming in the country is practiced by more than 70% of the population. Other scholar [25] found that shifting type of Agriculture is common and practiced for all annual crops grown in Tanzania. The most cited reasons for shifting their plots are; invasion of weeds and evading wild animals. On the other hand, natural death, timber and shifting cultivation accounts for the largest AGC removals in the closed woodland. Natural death is more prominent in this vegetation probably because protection forest and wildlife area comprises most of this vegetation where by no harvesting is allowed. Regarding timber, most of the timber is removed illegally.

In terms of ownership types, fire, timber charcoal and natural death account for higher number of stems removals in all the categories of ownership. This may be attributed to population growth and inadequate presence of alternative sources of energy for cooking and construction purpose that ultimately forces people to heavily depend on charcoal and timber. Irrespective of the fact that, forest under general land is almost open access in which free movement of people take products [39], its contribution to the total removals is low as opposed to private and village land. On the other hand, shifting cultivation accounts for the highest AGC removals in the shifting Agriculture and Agricultural land probably because shifting cultivation type of agriculture characterize the ownership types. Considering land use types that miombo woodlands falls, it was revealed that shifting cultivation and charcoal account for the highest number of stem removals in grazing and shifting cultivation land. This is because large numbers of stems are removed during land preparation in the shifting cultivation. Likewise, charcoal making and firewood collection characterize the land. Furthermore, natural death, poles, charcoal and firewood collection causes more stems cut in the production forest, protection forest and wildlife reserves land. This is much explained by the nature of the ownership types and the large dependence of charcoal and firewood for cooking energy while poles for construction purposes. In contrast, AGC removals that ultimately ends up into carbon emissions are driven by charcoal, natural death, shifting cultivation, poles, timber, fire and firewood collection in all land use types. This may be attributed by population growth that demand more products from the woodlands and climate change impacts that naturally kills trees through eruption of diseases and drought. Moreover, economic growth based on the export of primary commodities and an increasing demand for timber and agricultural products in a globalizing economy are critical reasons behind carbon emissions.

Conclusion

AGC removals in miombo woodlands of Mainland Tanzania are caused by a range of drivers that lead to varying levels of carbon emissions. The results revealed that charcoal, timber, shifting cultivation, fire, firewood collections, poles and natural death are the prominent main drivers of AGC removals in mainland Tanzania. Interestingly, results also revealed that although charcoal, shifting cultivation and fuelwood drive more tree removals and hence jeopardizes future carbon sink its share to carbon removals is minimal as compared to timber and natural death that account for higher AGC removals. For the purpose of reducing emissions emanating from AGC removals and by considering national circumstances, all drivers should be managed although the management intensity and priorities should consider the significance contribution of AGC emissions by timber, fire, charcoal, shifting cultivation, and natural death in the entire miombo woodlands and its subsequently categories. This would contribute to creation of considerable carbon sink as well as ensure persistent potential for the miombo woodlands to store carbon thus contributing to the REDD + process in Tanzania. Moreover, this kind of study need to be conducted in other vegetation types like Montane and Mangrove forest in Tanzania. On the other hand, since NAFORMA provide national picture on drivers and their variation on AGC removals, we recommend site specific studies be conducted to bring information that would be used to devise appropriate strategies to deal with drivers in their order of contribution to AGC removals in the local settings. Additionally tree planting for timber and energy should be encouraged as mitigating measure.

Methods

Study Area Description

The study involved the entire miombo woodlands of mainland Tanzania that covers about 44.7 million ha (Table 1). Vast areas of miombo woodlands falls under the village lands ownership, which lack proper management institution [40]. Depending on altitude and latitude, mainland Tanzania is characterised by both tropical and subtropical climates. The mean annual rainfall varies from below 500 to over 2000 mm per annum. The rainfall for the large part of the country is bimodal with short rains from October to December and long rains from March to May. The weather conditions of the country may be divided into a hot dry season from mid-August to the end of October, a hot wet season from November to the beginning of April and a relatively cool dry season from April to mid-August.

Data Collection

Sampling design

The data used for the assessment of drivers and their influence on variation of AGC removals presented in this paper were collected by NAFORMA [22]. Systematic double sampling for stratification with optimal allocation of individual plots in cluster was sampling design of the NAFORMA(Fig. 2).The design was chosen after sampling simulations to reduce uncertainty of estimates under given budget constraints. The detail of the planning of this design and other uncertainties are given in [42, 22, 2, 3]

Data acquisition

All stumps with diameter $\geq$ 5 cm within the circular plot radius of 15 m were measured for diameter and height using calliper or measuring tape. In addition, age, name and end uses to which the removed trees were put into were identified. The details on how age of the stumps and end uses of the removed trees were decided are given in [43, 3]. For the purpose of the present study, all plots that were surveyed for stumps measurement were extracted from NAFORMA database. A total 7 323 stumps from 16 803 plots were extracted.

Data analysis

Analysis of drivers of aboveground carbon removals

To obtain the drivers of AGC removals, the identified trees with their corresponding drivers for their removals were listed. The drivers were sorted alphabetically in order to identify total number of drivers responsible for removals in miombo woodlands. Those drivers that were similar like removals due to firewood collection for domestic and industrial use were regarded as firewood collection.

Drivers and their influence on aboveground carbon removals

We included multiple drivers identified (11 drivers) in the analysis, so that the interrelationships between the drivers and AGB removed could be accounted. To define the influence of each driver on AGC removals, AGB removed per tree was estimated using allometric equation that estimates tree biomass from the remaining stump [7]. The estimated individual tree AGB removal in its corresponding driver was divided by age of the stump to get the rate of AGB removals per year. AGB removals per year per tree was summed up and expressed on per plot basis. Since each stratum had unique sampling intensity, it was necessary to calculate expansion factors (*EF*) for each respective stratum since simple mean of AGB would ignore the nature of the sampling design upon which the data were collected. The *EF* describes the area in which a sample plot represents in each stratum. The details on how the *EF* factor was calculated are shown in [2, 3]. Consequently, AGB plot level values were multiplied by respective *EF* value corresponding to each stratum. The AGB plot level values were expressed on per hectare (ha). To obtain the influence of each driver on AGC removals, AGB removals per ha values were multiplied by 0.49 as the conversion factor of AGB to AGC [44]. Finally, the AGC and their corresponding drivers were summarized in terms of Zones, miombo vegetation subtypes, Land use and Ownership types.

Abbreviations

AGC: Aboveground carbon; NAFORMA: National Forest Resources Assessment and Monitoring; GHG: Greenhouse Gas Emissions; AGB: Aboveground biomass; NFI: National Forest Inventory; REDD+: Reduced Emissions from deforestation and forest degradation "plus," the role of conservation, sustainable management of forests, and enhanced carbon stock; TFS: Tanzania Forest Services Agency; IPCC: Intergovernmental Panel for Climate Change.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Funding

No financial support was provided regarding the preparation of this manuscript

Availability of data and materials

All authors declare that the datasets used in this study are available upon request from the Tanzania Forest Service, Ministry of Natural Resources and Tourism Tanzania.

Authors' contributions

BJM has been involved in designing the study, drafting the manuscript, data analysis and write up: WAM performed analysis and revised the manuscript: EFN and REM made substantial contributions to conception and revising the manuscript. REM, EFN, WAM have given final approval of the version to be published. All authors read and approved the final manuscript.

Acknowledgments

The authors would like to thank the Tanzania forest services (TFS) of the Ministry of Natural Resources and Tourism (MNRT) in Tanzania for giving us a permit to use NAFORMA data.

Competing interests

The authors declare that they have no competing interests

References

1. United Republic of Tanzania. Tanzania's Forest Reference Emission Level passed by the United Nations Framework Convention on Climate Change (FREL). Ministry of natural resources and tourism. Tanzania: Dar es Salaam; 2018. 42 pp.
2. Mauya EW, Mugasha WA, Njana MA, Zahabu E, Malimbwi RE. Carbon stocks for different land cover types in Mainland Tanzania. Carbon Balance Management. 2019;14:4.
3. Manyanda BJ, Nzunda EF, Mugasha WA, Malimbwi RE Estimates of volume and carbon stock removals in Miombo woodlands of mainland Tanzania. Inter J For Res. 2020; 2020: 10 pp.
4. United Republic of Tanzania

   National Bureau of statistics population and housing census 2002

   Accessed on 24 December 2019.

   United Republic of Tanzania. National Bureau of statistics population and housing census 2002. http://Tanzania.go.tz/census/region. Accessed on 24 December 2019.
5. FAO. Global Forest Resources Assessment, Main Report. Forestry Paper no. 163, Rome, Italy 2010.
6. WWF. Importance of Forests. 2016. http://wwf.panda.org/about_our_earth/deforestation/importance_forests/ Accessed on 16 October 2019.
7. Manyanda BJ, Mugasha WA, Nzunda EF, Malimbwi RE Biomass and volumes models

based on stump diameter for assessing forest degradation in Miombo woodlands in Tanzania. Inter J For Res. 2019; 2019: 15 pp.

8. IPCC. Climate change Impacts, Adaptation and Vulnerability. Summary for policy makers. IPCC AR4, 2007.

9. Asner GP, Knapp DE, Broadbent EN, Oliveira PJC, Keller M, Silva JN. Selective logging in the Brazilian Amazon. Science. 2005;310:480–2.

10. Marklund LG, Schoene D. Global assessment of growing stock, biomass and carbon stock. Global forest resources assessment. Food and Agriculture Organization of the United Nations; Rome Italy.2006.

11. Geist H, Lambin E. Proximate causes and underlying driving forces of tropical deforestation. Bio Science. 2002;52:143–50.

12. Gallardo AR. The influence of markets and culture on the use of native forests in the south of Chile. A thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy in the faculty of graduate and postdoctoral studies (forestry), the University of British Columbia. 2017; 106p.

13. Schoene D, Killmann H, Von Lu PKE, Loychewilkie M Definitional issues related to Reducing Emissions from Deforestation in Developing Countries. Forests and Climate Change Working Paper no.5. Rome Italy. 2007.

14. Hosonuma N, Herold M, DeSy V, De Fries RS, Brockhaus M, Verchot L, Angelsen A, Romijn E. An Assessment of Deforestation and Forest Degradation Drivers in Developing Countries. Environmental Research Letters. 2012;7:4009.

15. Agriculture IPCC, Forestry and other Land use. In: Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, eds. IPCC guidelines for national greenhouse gas inventories. Prepared by the national greenhouse gas inventories programme, institute for global environmental strategies (iges), Hayama, Japan. 2006.

16. FAO. Towards Defining Degradation. Forest Resources Assessment Working Paper no.154, Rome, Italy. 2009; 11p.

17. Lambin EF, Geist HJ, Lepers E. Dynamics of land-use and land-cover change in tropical regions. Annual Rev Environ Resource. 2003;28:205–41 pp.

18. Kissinger G, Herold M, De Sy V Drivers of Deforestation and Forest Degradation: A synthesis Report for REDD + Policymakers. Lexeme Consulting, Vancouver Canada. 2012; 45 pp.

19. Chave J, Condit R, Lao S, Caspersen JP, Foster RB, Hubbell SP. Spatial and temporal variation of biomass in a tropical forest: results from a large census plot in Panama. J Ecol. 2003;91:240–52.

20. Baker T, Phillips O, Malhi Y. Variations in wood density determines spatial patterns in Amazonian forest biomass. Glob Change Biol. 2004;10:545–62.

21. Houghton R. Aboveground Forest Biomass and the Global Carbon Balance. Glob Change Biol. 2005;11:945–58.

22. MNRT. National Forest Resources Monitoring and Assessment of Tanzania mainland (NAFORMA). Main results. 2015, 106p.

23. Kessy JF, Nsokko E, Kaswamila E, kimaro F. Analysis of drivers and agents of deforestation and forest degradation in Masito forests, kigoma, Tanzania. International Journal of Asian Social Science. 2016;6(2):93–107 pp.

24. Makunga EJ, Misana BS. The Extent and Drivers of Deforestation and Forest Degradation in Masito-Ugalla Ecosystem, Kigoma Region, Tanzania. Open Journal of Forestry. 2017;7:285–305 pp.

25. Miya M, Ball SMJ, Nelson FD Drivers of Deforestation and Forest Degradation in Kilwa District. Mpingo Conservation and Development Initiative. 2012, 34p.

26. the Forestry Development Center, University of the Philippines Los Banos - College of

Forestry and Natural Resources

Carandang AP, Bugayong LA, Dolom PC, Garcia LN, Villanueva MB, Espirit NO. and the Forestry Development Center, University of the Philippines Los Banos - College of Forestry and Natural Resources. Analysis of Key Drivers of deforestation and Forest Degradation in the Philippines. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Manila, Philippines. 2013; 128p.

27. FAO. Emerging approaches to Forest Reference Emission Levels and/ or Forest Reference Levels for REDD+. The UNREDD Programme 2014. [http://www.unred d.net/index.phpop tion = com_docma n&task = doc_downl oad&gid = 13469 &Itemi d = 53] Accessed 20 December 2019.

28. Sawe E. An overview of charcoal industry in Tanzania-issues and challenges; prepared for the national R&D committee on industry and energy. Tanzania Traditional Energy Development and Environment Organization (TaTEDO), Dar es Salaam.2004.

29. Mwampamba TH. (2007). Has the Wood Fuel Crisis Returned? Urban Charcoal Consumption in Tanzania and Its Implications to Present and Future Forest Availability 2019. [http://www.charcoalproject.org/wp-content/uploads/2011/01/Mwampamba-2007-Charcoal-Tanzania] Accessed on 24 May 2019.

30. Angonese GJ, Grau G. Assessment of swaps and persistence in land cover changes in a subtropical periurban region, NM Argentina. Landscape urban Planning. 2014;127:83–93.

31. Ouedraogo I, Mbow C, Balinga M, Neufeldt H. .Transitions in Land Use Architecture under multiple Human Driving Forces in a Semi – Arid Zone. Land. 2015;4:560–77.

32. United Republic of Tanzania. National Forest Policy. Ministry of Natural Resources

and Tourism, Dar es Salaam, Tanzania.1998, 59p.

33. Brown S, Schroeder P, Birdsey R. Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development. For Ecol Manage. 1997;96(1–2):37–47.

34. Dewees PA, Bruce M, Campbell YK, Almeida S, Angelsen ABC. A. and Wunder S. Managing the Miombo Woodlands of Southern Africa: Policies, Incentives and Options for the Rural Poor. Journal of Natural Resources Policy Research. 2010;2(1):57–73.

35. Ahrends A, Burgess ND, Milledge SAH, Bulling MT, Fisher B, Smart JCR, Clarke GP, Mhoro B,E, Lewis SL. Predictable waves of sequential forest degradation and biodiversity loss spreading from an African city. PNAS. 2010;107(33):14556–61.

36. Milledge SAH, Elibariki R The status of logging in Southern Tanzania. A technical report submitted to the WWF East Africa Coastal Forests Ecoregion Programme. Project number: IP0002/2005. TRAFFIC East/Southern Africa. 2005.

37. Ryan CM, Williams M. How does fire intensity and frequency affect miombo woodland tree populations and biomass? Ecol Appl. 2011;21:48–60.

38. Furley PA, Rees RM, Ryan CM. (2008). Savanna burning and the assessment of long-term fire experiments with particular reference to Zimbabwe. Progress In Physical Geography. 2008; 32, 611–634.

39. Mwakalobo ABS, Kajembe GC, Silayo DS, Nzunda EF, Zahabu E, Maliondo S, Kimaro, D.N. REDD + and sustainable development- perspective from Tanzania. REDD working papers IIED, London. 2011.

40. Malimbwi R, Eid T, Chamshama S. Allometric tree biomass and volume models in Tanzania. Morogoro: E & D publishing on behalf of Department of Forest Resources Assessment and Management, Sokoine University of Agriculture; 2018. 129p.

41. Mauya EW, Mugasha WA, Zahabu E, Ole M, Bollandså S, Eid T. (2014). Models for

estimation of tree volume in the miombo woodlands of Tanzania. Southern Forests: Journal of Forest Science. 2014; 10: 1–11.

42. Tomppo E, Malimbwi R, Katila M, Mäkisara K, Henttonen HM, Chamuya N, Zahabu E, Otieno J. A sampling design for a large area forest inventory: A case of Tanzania. Journal of Forest Research. 2014;44:931–48.

43. United Republic of Tanzania. NAFORMA field manual Biophysical survey. Forestry and Beekeeping Division, Ministry of Natural Resources and Tourism. Dar es Salaam Tanzania. 2010, 96p.

44. MacDicken KG. (1997). A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects. Report No. 1611. International Institute for Agricultural Development, Arlington, USA. 1997, 87 pp.

Figures

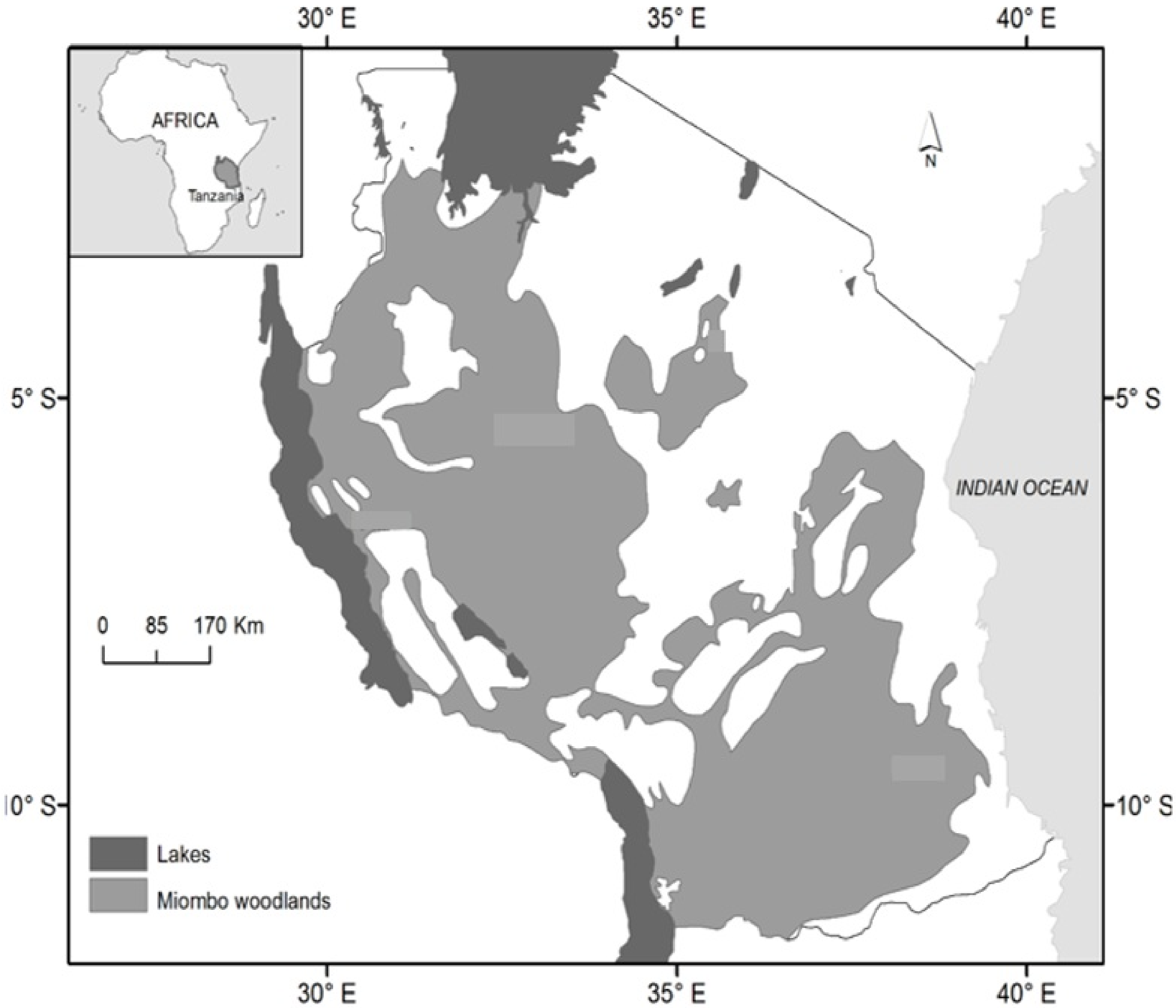

Figure 1

A map of Mainland Tanzania showing Miombo woodlands (modified from [41])

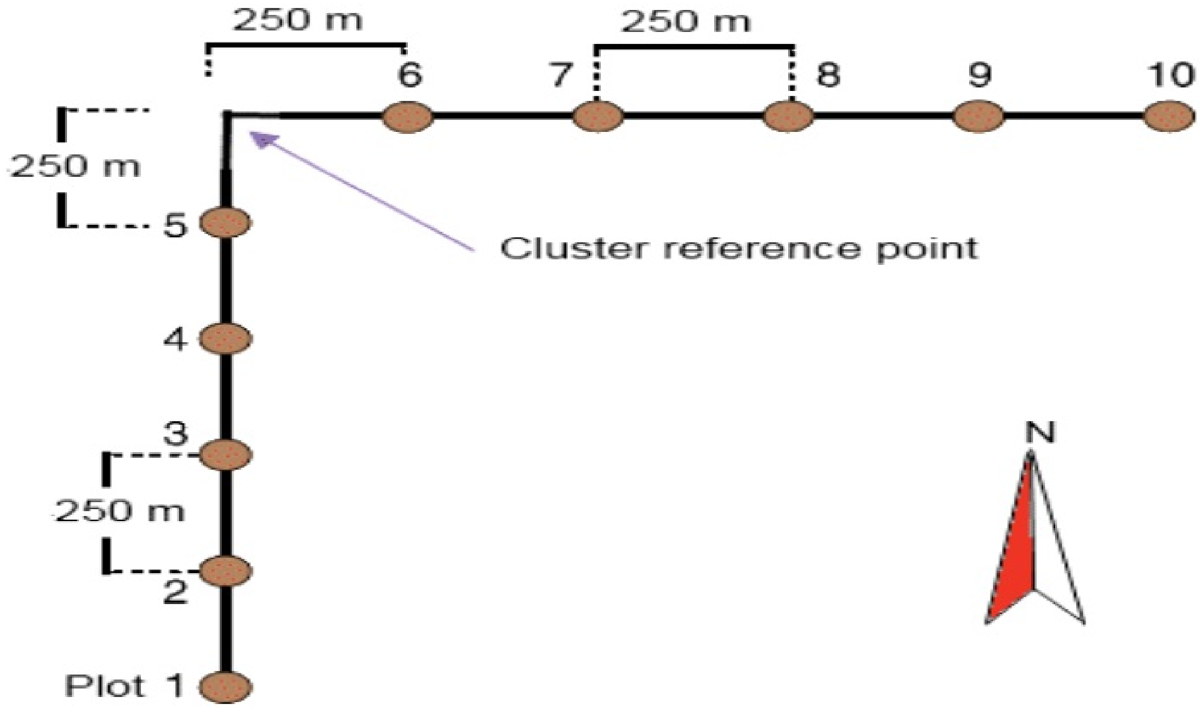

Figure 2

Cluster design (source: [22])